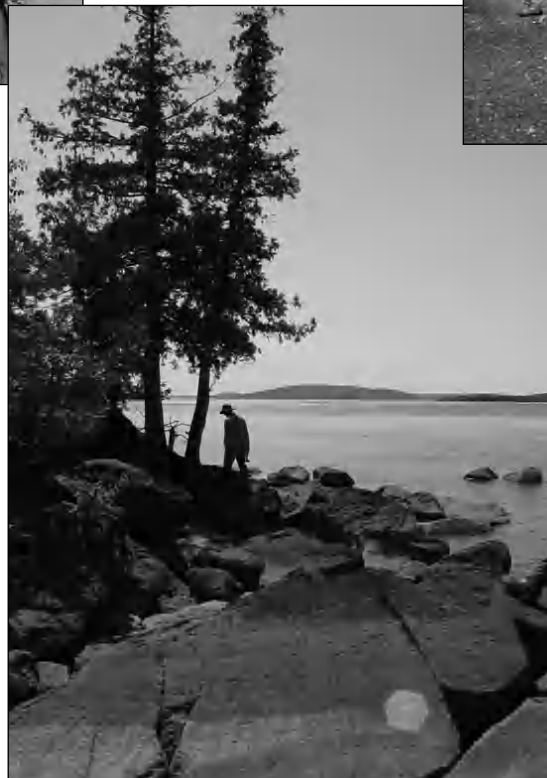


51st ANNUAL MEETING

Nipigon, Ontario - May 24-28, 2005

INSTITUTE ON LAKE SUPERIOR GEOLOGY

Part 1 – Proceedings and Abstracts





51st ANNUAL MEETING

INSTITUTE ON LAKE SUPERIOR GEOLOGY



May 24-28, 2005

Nipigon, Ontario

HOSTED BY:

Mark Smyk and Pete Hollings

Co-Chairs

Ontario Geological Survey and Lakehead University

Proceedings - Volume 51

Part 1 – Proceedings and Abstracts

Edited by Mike Easton (Ontario Geological Survey) & Pete Hollings (Lakehead University)

Cover Photos: Left - pahoehoe texture in basalts of the Osler volcanic group, Wilson Island, Middle - diabase sills on the shores of Lake Nipigon, Right - No. 1 Shaft headframe, MacLeod-Cockshutt Mine, Geraldton.

51ST INSTITUTE ON LAKE SUPERIOR GEOLOGY

VOLUME 51 CONSISTS OF:

PART 1: PROGRAM AND ABSTRACTS

PART 2: FIELD TRIP GUIDEBOOK

TRIP 1: GEOLOGY AND FOLD MINERALISATION OF THE BEARDMORE-GERALDTON GREENSTONE BELT

TRIP 2: QUATERNARY GEOLOGY OF THE BEARDMORE – NIPIGON AREA

TRIPS 3 & 6: A STRATIGRAPHIC TRANSECT ACROSS THE NORTHERN FLANK OF THE MIDCONTINENT RIFT NEAR ROSSPORT

TRIP 4: GEOLOGY AND RARE ELEMENT PEGMATITES OF THE QUETICO SUBPROVINCE NEAR NIPIGON

TRIP 5: GEOLOGY OF THE BLACK STURGEON AREA

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

Albers, P.B., and Miller, J.D., 2005. The Geology and Petrology of the Leveaux Porphyritic Diorite, Cook County, MN: Investigating Possible Magmatic Relationships to the Anorthositic Series of the Duluth Complex. In; Easton, M. and Hollings, P. (Eds.), Institute on Lake Superior Geology Proceedings, 51st Annual Meeting, Nipigon, Ontario, Part 1 - Proceedings and Abstracts, v.51, part 1, 3-4.

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ILSG website: www.lakesuperiorgeology.org

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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
32	1986	Wisconsin Rapids, Wisconsin	J.K. Greenberg
33	1987	Wawa, Ontario	E.D. Frey & R.P. Sage

#	Date	Place	Chairs
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

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)

I. Duties of the Officers and Directors

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

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

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

1. Keep accurate attendance records of all annual meetings.
2. Keep accurate records of all meetings of, and correspondence between, the Board of Directors.
3. Maintain an up-to-date mailing list
4. Act as the first point of contact for all enquires about the Institute
5. Respond to requests for back issues of the Proceedings of the Institute

C. It shall be the duty of the Treasurer to:

1. Hold all funds that may accrue as profits from annual meetings or field trips and to make these funds available for the organization and operation of future meetings as required.
2. Store the Goldich medals and each year ensure one is engraved with the name of that years winner

D. It shall be the duty of the Board of Directors to plan locations of annual meetings and to advise on the organization and financing of all meetings.

II. Duties and Expenses

A. Regular membership dues of \$5.00 or less on an annual basis shall be assessed each member as determined by the Board of Directors..

B. Registration fees for the annual meetings shall be determined by the Chair in consultation with the Board of Directors. The registration fees can include expenses to cover operations outside of the annual meeting as determined by the Board of Directors. It is strongly recommended that registration fees be kept at a minimum to encourage attendance of students.

III. Rules of Order

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

IV. Amendments

These by-laws may be amended by a majority vote (majority of those voting) of the membership of the organization; provided that such modifications shall not conflict with the constitution as presently adopted or subsequently amended.

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. The out-going, senior member of the Board of Directors shall act as liaison between the Board and the Committee for a period of one year.

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 Medalists

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

2005 Goldich Medal Recipient

Mark Smyk

Ontario Geological Survey, Thunder Bay, Ontario

Goldich Medal Committee

Serving through the meeting year shown in parentheses

David Meineke (2005) Meriden Engineering, Hibbing, Minnesota

George Hudak (2006) University of Wisconsin, Oshkosh

Tom Hart (2007) Ontario Geological Survey

David Meineke, as out-going senior member of Institute Board of Directors, is liaison between Goldich Medal Committee and the Board through the 2005 meeting.

Citation for Goldich Medal Recipient

Mark Smyk

It is a pleasure to acknowledge the many contributions of Mark C. Smyk to the understanding of the geology of the Lake Superior region at the 51st annual meeting of the Lake Superior Institute on Lake Superior Geology. This is the 26th Goldich medal awarded by the Institute to individuals that have made significant contributions to Lake Superior geology.

Mark was born in Dryden, Ontario, in 1961 and received his Honors Bachelor of Science degree in Geology from Lakehead University in 1984 upon completion of a thesis titled “A comparative study of silver occurrences, Island Belt Silver Region, Thunder Bay District, Ontario”. From Lakehead University Mark entered Carleton University where he received his Masters of Science degree in geology upon completion of a thesis on silver veins in the Cobalt silver area in 1987. The thesis was titled “Geology of Archean Interflow Sedimentary Rocks and their relationship to Ag-Bi-Co-Ni-As Veins, Cobalt Silver Area, Ontario”.

Mark completed contract geological mapping in the Schreiber-Hemlo and Swayze greenstone belts in 1984. He has also completed contracts with David Bell Geological Services Inc. and Saarberg-Interplan Ltd.

From 1998 to the present Mark has served as guest lecturer at Lakehead University, Thunder Bay. He has also lectured and prepared course curriculum in geology for the Qikiqtaaluk Corporation, Iqalut, Northern Territory.

Mark has long been active in the Institute on Lake Superior Geology and co-hosted the 41st and 51st annual meetings. He is a Registered Professional Geologist in the Province of Ontario, fellow in the Geological Association of Canada, member of the Northwest Prospectors Association and guest editor for “Exploration and Mining Geology”, Canadian Institute of Mining and Metallurgy.

Since 1987 Mark has worked with the Ontario Geological Survey. During this period he has authored or co-authored 7 reports, 14 abstracts and 7 guidebooks. The Ontario Geological Survey library lists 62 items as authored or co-authored by Mark.

Since working with the Ontario Geological Survey Mark has advanced to become Regional Resident Geologist, Thunder Bay North. His work entails geology related publications, land use planning and interaction with the public, prospectors and industry.

Submitted by Ron Sage

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.



www.lakesuperiorgeology.org

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 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 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 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 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 will be noted on the Program.

Student Paper Awards Committee

Penelope Morton, University of Minnesota Duluth

Greg Stott - Ontario Geological Survey, Sudbury, Ontario

Wally Rayner - Toronto, Ontario

Session Chairs

Charlie Blackburn, Blackburn Geological Services

Terry Boerboom, Minnesota Geological Survey

William Cannon, United States Geological Survey

Mike Easton, Ontario Geological Survey

Mary Louise Hill, Lakehead University

Peter Hinz, Ontario Geological Survey

Tom Lane, CAMIRO

Mark Severson, Natural Resources Research Institute

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.

Board of Directors

Board appointment continues through the close of the meeting year shown in parentheses, or until a successor is selected

Mark Smyk/Pete Hollings - General Chair 2005 meeting (2008) - Ontario Geological Survey/Lakehead University

Steve Hauck (2007) - University of Minnesota, Duluth

Laurel Woodruff (2006) - U.S. Geological Survey

Peter Hinz (2005) - Ontario Geological Survey

Peter Hollings - Secretary (2006) - Lakehead University, Thunder Bay, Ontario

Mark A. Jirsa - Treasurer (2007) - Minnesota Geological Survey

Local Committee

Co-Chairs

Mark Smyk - Ontario Geological Survey, Thunder Bay, Ontario

Pete Hollings - Lakehead University, Thunder Bay, Ontario

Program and Abstracts Editors

Mike Easton - Ontario Geological Survey, Sudbury, Ontario

Pete Hollings - Lakehead University, Thunder Bay, Ontario

Field Trip Guidebook Editor

Pete Hollings - Lakehead University, Thunder Bay, Ontario

Organising Committee

Mary Louise Hill - Lakehead University, Thunder Bay, Ontario

Phil Fralick - Lakehead University, Thunder Bay, Ontario

Bill Addison - Thunder Bay, Ontario

Ryan Tuomi - Ontario Geological Survey, Thunder Bay, Ontario

Levina Collins - Township of Nipigon

Banquet Speaker

Jim Franklin, Franklin Geosciences Ltd.

Mineral Resources for the Future: The Resource Potential of Northern Lake Superior

(See abstract on page 19)

Report of the Chair of the 50th Annual Meeting

Duluth, Minnesota

The Natural Resources Research Institute (NRRI) of the University of Minnesota Duluth hosted the 50th Annual Institute on Lake Superior Geology on May 4 – 9, 2004 at the Radisson Hotel Duluth-Harborview in Duluth, Minnesota. The meeting consisted of two days of technical sessions with four pre- and four post-technical session field trips. Julie Ann Heinz, Barbara Hauck, and Jeanne Lukkarila provided excellent on-site assistance. John Heine was responsible for: the 50th ILSG website and online registration; AV expertise that kept the sessions flowing on time; and worked with Mark Severson on logistics for the field trips. Julie Oreskovich was the poster session czar. Richard Patelke was invaluable as the data base manager and the designer of the 50th ILSG T-shirt. Bill Cannon and Gene LaBerge compiled a CD of photographs of past ILSG members and field trips. Other members of the local committee included: Charlie Matsch, Jim Miller, Penny Morton, Dean Peterson, and Larry Zanko – all of whom provided much need expertise. Pre-meeting registration was 275 students and professionals, with an additional 24 on-site registrations, for a total of 299 registrants. This was the first time that on-line registration was offered, and 222 individuals registered on-line.

Proceedings Volume 50 was published in two parts: Part 1 – Program and Abstracts, edited by Steven Hauck, with 69 published abstracts, for 39 oral and 30 poster presentations; and Part 2 – Field Trip Guidebook, edited by Mark Severson.

The 50th meeting marked the sixth time (1958, 1963, 1971, 1979, 1989, 2004) the ILSG annual meeting was held in Duluth, Minnesota. The nine field trips (one trip with two sections) were well attended with 315 total participants attending one or two field trips. On Tuesday, May 4th, marked the beginning of two two-day field trips: George Hudak and co-leaders lead a field trip to examine the volcanic stratigraphy, hydrothermal alteration, and VMS potential of the Lower Ely Greenstone; and Terry Boerboom and co-leaders lead a trip to visit newly mapped outcrops in the Southwestern Sequence of the North Shore Volcanic Group and in the Beaver Bay Complex. On Wednesday, May 5th, there were two one-day field trips: Howard Hobbs led a trip to look at the Late Wisconsinan Superior-lobe deposits northeast of Duluth; and Richard Ojakangas, Mark Severson, and co-leaders examined the geology of the eastern Mesabi Range. On Saturday, May 10th, there were four field trips: Mark Jirsa, Terry Boerboom, and co-leaders led two sections on a two-day investigation of the classic outcrops of northeastern Minnesota; Lisa Marlow and co-leaders examined the glacial and post-glacial landscape evolution in the Glacial Lake Aitkin and Upham basin; Dean Peterson and Richard Patelke led a field trip to the Vermilion District, northeast of Soudan, MN, to look at the economic geology of Archean gold occurrences; and Mark Severson and Jim Miller visited outcrops along the western contact of the Duluth Complex to illustrate the geology and Cu-Ni mineralization.

One hundred and sixty-three participants attended the annual banquet on Thursday night. This year's banquet speaker was Bob Dott of the University of Wisconsin, Madison. Dr. Dott is professor emeritus from the Department of Geology and Geophysics. Dr. Dott's post-banquet presentation was: The Van Hise army and other pioneers of Lake Superior geology. The other highlight of the evening was the presentation of the 2004 Goldich medal to Paul Weiblen of the Department of Geology and Geophysics at the University of Minnesota, Minneapolis, which recognized his efforts in many areas in the Lake Superior region, especially in the Duluth Complex.

The technical sessions began with a special session on "The History of Geologic Investigations in the Lake Superior Region". The "Old Prospector" (Richard Ojakangas) gave a brief historical overview of geology between 1848 and 1900 that was followed by four other presentations on the geology, mineralization, and geochronology of the Lake Superior region.

As always, the student paper committee had a difficult time of picking a winner. There were six oral presentations and four poster presentations. The winners were:

- 1) Andy Breckenridge – Large Lakes Observatory (\$250, Winner, best oral presentation)

- 2) Heidi Drexler – University of Wisconsin Oshkosh (\$125, Winner, best poster presentation)
- 3) Justin Johnson, Lakehead University (\$125, Honourable mention)
- 4) Adam Hoffman - University of Minnesota (\$125, Honourable mention, best poster presentation)

In addition five Eisenbrey Student Travel awards were presented in 2004, they winners were: Paula Shafer, Indiana University (\$250); Justin Johnson - Lakehead, Thunder Bay (\$125); Geoff Heggie - Lakehead, Thunder Bay (\$125); Adam Richardson - Lakehead, Thunder Bay (\$125); and Riku Metsaranta - - Lakehead, Thunder Bay (\$125)

The Institute's Board of Directors met on May 6, 2004, and brief summary of the meeting follows:

1. Accepted the Report of the Chair for the 49th ILSG from Laurel Woodruff, and the minutes of the last Board meeting, May 8, 2003 from Pete Hollings.
2. Accepted the 2003-2004 ILSG Financial Summary from Mark Jirsa.
3. Approved Steven Hauck to continue on as a Board member.
4. Approved Nipigon, Ontario as the 51st annual meeting location with Mark Smyk and Pete Hollings as co-chairs.
5. Replaced Ron Sage, who was on the Goldich Committee with Tom Hart, who had agreed to serve.
6. Discussed splitting the Secretary-Treasurer position. Pete Hollings was nominated and elected secretary by the ILSG members, and Mark Jirsa was nominated and elected treasurer.

The 50th ILSG meeting was a great success, and we wish to thank all of the individuals who contributed to this success. The staffs of the Radisson Hotel Duluth-Harborview, UMD Food Service, and the Fortune Bay Casino (field trips) were always professional and responsive to our evolving needs to handle a very large group. The following organizations provided generous monetary contributions: Department of Geosciences, University of Minnesota Duluth, MN; Franconia Minerals Corporation, Spokane, WA; Idea Drilling Incorporated, Virginia, MN; Iron Mining Association, Duluth, MN; Lehmann Exploration Management, Minneapolis, MN; Meriden Engineering, LLC, Hibbing, MN; Minerals Processing Corporation, Duluth, MN; Minnesota Exploration Association (MEXA), Minneapolis, MN; Minnesota Minerals Coordinating Committee, St. Paul, MN; Teck Cominco American Incorporated, Spokane, WA; and Wallbridge Mining Company, Lively, ONT. The field trips were very well attended, and our appreciation is due to the field trip leaders, van drivers, and everyone else who contributed to the success of the 50th ILSG meeting. Because of the large attendance for the meeting and field trips, the 50th ILSG meeting generated several thousand dollars to the ILSG general fund. The 50th ILSG meeting also coincided with the 50th anniversary of the Department of Geosciences at the University of Minnesota Duluth (UMD). A special session on Friday afternoon featured papers by UMD faculty, students, and alumni. A banquet celebrating this occasion was held at the Duluth Depot on Friday evening after the ILSG meeting, which was attended by many UMD alumni, faculty, and students, and ILSG members.

Both of us are very happy with the results of 50th meeting, and we hope that future ILSG meetings can be as well attended as this meeting. We also hope that the attendees were as happy with the meeting as the local committee was. This meeting, like every ILSG meeting requires a lot of work and time on behalf of the co-chairs and the local committee. The additional assistance of ILSG members at-large helped make the meeting a success.

Respectively Submitted,

Steven Hauck and Mark Severson

Co-Chairs, 50th ILSG meeting

Acknowledgements

The following organizations made generous contributions to the 51st Annual Meeting. We thank them for their commitment to the Institute on Lake Superior Geology. For the past 50 years this organization has thrived as a result of the interest of individuals, corporations, universities and government agencies. The dedication to an exchange of scientific ideas and a passion for field trips has enabled the institute to provide one of its primary objectives – to promote better understanding of the geology of the Lake Superior Region.

North Western Ontario Prospectors Association

Lake Nipigon Region Geoscience Initiative

Ontario Prospectors Association

Ministry of Northern Development and Mines – Ontario Geological Survey

Township of Nipigon

Municipality of Greenstone

Canadian Institute of Mining and Metallurgy, Thunder Bay Branch

Department of Geology, Lakehead University

David Malouf, Roxmark Mines Limited

Chaltrek Geological Supplies Inc.

Program

Tuesday May 24

8:00 a.m. **Field Trip 1:** Geology and gold mineralization of the Beardmore-Geraldton greenstone belt

Leaders: Mark Smyk & Tom Hart (OGS) and Phil Fralick (Lakehead University)

6:00 p.m. Overnight in Beardmore

Wednesday May 25

8:00 a.m. **Field Trip 1:** Geology and gold mineralization of the Beardmore-Geraldton greenstone belt

Leaders: Mark Smyk & Tom Hart (OGS) and Phil Fralick (Lakehead University)

8:00 a.m. **Field Trip 2:** Quaternary Geology of the Beardmore – Nipigon area

Leader: Peter Barnett (OGS)

8:00 a.m. **Field Trip 3:** A Stratigraphic transect across the Northern flank of the Midcontinent Rift near Rosspoint (I)

Leaders: Peter Hollings and Phil Fralick (Lakehead University)

6:00 p.m. **Return of Trips 1,2 and 3**

4:00 p.m. - 8:00 p.m. **Registration** (Nipigon Community Centre)

7:00 p.m. - 9:00 p.m. **Ice Breaker Social** (Nipigon Curl-a-Drome) **and Poster Setup** (Nipigon Community Centre)

Thursday May 26

8:00 a.m. - 4:00 p.m. **Registration** (Nipigon Community Centre)

9:00 a.m. - 9:05 a.m. **Introductory Remarks - Mark Smyk and Peter Hollings, Co-Chairs**

Technical Session I

Session Chairs: T. Boerboom (Minnesota Geological Survey), W. Cannon (US Geological Survey)

9:05 a.m. **Addison, W., Brumpton, G., Vallini, D., McNaughton, N., Davis, D., Kissin, S., Fralick, P. and Hammond, A.**

Discovery of distal ejecta from the 1850 Ma Sudbury impact

9:25 a.m. **Schnieders, B. and Scott, J.**

Mining and exploration activity in the Thunder Bay South District

9:45 a.m. **Hill, M.L. and Smyk, M.**

Penokean fold-and-thrust deformation of the Paleoproterozoic Gunflint Formation near Thunder Bay, Ontario

10:05 a.m. **Middleton, R. and Heggie, G.**

Seagull Intrusion; A unique PGE-Ni-Cu Setting.

10:25 a.m. - 11:00 a.m. **Coffee Break and Poster Session**

11:00 a.m. **Maric, M.*, and Fralick, P.**

Sedimentology of the Rove and Virginia Formations and their tectonic significance

11:20 a.m. **Easton, R.M.**

The Grenvillian Tomiko quartzites of Ontario: correlatives of the Baraboo quartzites of Wisconsin, the Mazatzal orogen of New Mexico, or unique? Implications for the tectonic architecture of Laurentia in the Great Lakes region.

11:40 a.m. **Medaris, G. and Dott, B.**

Riddle of the sands (Proterozoic) solved by quartzites at Hamilton Mounds Wisconsin

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

Technical Session II

Special Session - Lake Nipigon Regional Geoscience Initiative

Session Chairs: Tom Lane (CAMIRO), Mark Severson (Natural Resources Research Institute)

1:30 p.m. **Heaman, L. and Easton, R.M.**

Proterozoic history of the Lake Nipigon area, Ontario: Constraints from U-Pb zircon and baddeleyite dating

1:50 p.m. **Smyk, M.**

Mineral deposits and metallogeny of the Midcontinent Rift in Ontario

2:10 p.m. **Fralick, P., Metsaranta, R., and Rogala, B.**

Stratigraphy of the Mesoproterozoic Sibley Group and Nipigon Sills

2:30 p.m. **Hart, T. and MacDonald, C.**

Mesoproterozoic diabase sills of the Nipigon Embayment, northwest Ontario

2:30 p.m. - 3:00 p.m. **Coffee Break and Poster Session**

3:00 p.m. **Richardson, A.* and Hollings, P.**

Geochemical variation within the Mesoproterozoic Nipigon diabase sills

3:20 p.m. **Metsaranta, R.* and Fralick, P.**

Depositional setting of the Pass Lake and Rossport Formations (Sibley Group) inferred from a combined sedimentologic/geochemical approach

3:40 p.m. **Laarman, J.* and Hollings, P.**

Petrogenesis and PGE mineralization of the Eva Kitto Intrusion, Northern Ontario

4:00 p.m. **Magee, A.*, Hollings, P. and Fralick, P.**

Preliminary stratigraphy and geochemistry of the Mesoproterozoic Pillar Lake volcanics, Wabigoon subprovince, Superior Province, Armstrong, Ontario, Canada

6:00 p.m. **Annual Banquet and Award Presentation (Royal Canadian Legion)**

Announcement of 52nd Annual Meeting Location

2005 Goldich Award Presentation to Mark Smyk

2005 Banquet Address - Dr. J. Franklin

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

Friday May 27

9:00 a.m. - 12:00 p.m. **Registration**

Technical Session III

Session Chairs: Mary Louise Hill (*Lakehead University*), Mike Easton (*Ontario Geological Survey*)

- 9:00 a.m. **Holm, D., Cannon, W., Chandler, V., Schneider, D., Schulz, K., & Van Schmus, W.**
The incredible shrinking Penokean orogen: a new look at the accretionary history of the southern Lake Superior region.
- 9:20 a.m. **Vallini, D.*, Cannon, W. and Schulz, K.**
New age data for the Chocolay Group, Marquette Range Supergroup: implications for the Paleoproterozoic evolution of the Lake Superior and Lake Huron regions
- 9:40 a.m. **Knudson, D.*, Saini-Eidukat, B., Miller, J., and Daniels, P.**
Structural state of plagioclase phenocrysts in porphyritic rocks of the Midcontinent rift, northeastern Minnesota
- 10:00 a.m. **Albers, P.* and Miller, J.**
The geology and petrology of the Leveaux porphyritic diorite, Cook County, MN: Investigating possible magmatic relationships to the Anorthositic Series of the Duluth Complex
- 10:20 a.m. - 11:00 a.m. **Coffee Break and Poster Session**
- 11:00 a.m. **Conly, A. and MacDonald, J.**
Origin of high-sulphate waters of the Hogarth Pit Lake, Steep Rock iron mine, Atikokan, Ontario.
- 11:20 a.m. **Breckenridge, A. and Johnson, T.**
Lake Superior's oxygen isotope record suggests overflow to Lake Ojibway between 10,000 and 9,400 CAL BP (~8.9-8.4 ¹⁴C KA)
- 11:40 a.m. **Blackburn, C. and Kor, P.**
Control of Quaternary erosional and depositional landforms at the Eastern outlet of glacial Lake Agassiz by Precambrian bedrock and structure, Ottertooth-Pantagrel Lakes area, northwestern Ontario
- 12:00 p.m. - 1:30 p.m. **Lunch Break**

Technical Session IV

Session Chairs: Peter Hinz (*Ontario Geological Survey*), Charlie Blackburn (*Blackburn Geological Services*)

- 1:30 p.m. **Weiblen, P., Peterson, D., Vislova, T.**
Implications of Midcontinent Rift and oceanic ridges analogies and 3D interpretations of the subsurface structure of the Bald Eagle Intrusion in the Duluth Complex and the East Pacific Rise
- 1:50 p.m. **Halls, H.**
Dyke swarms around the Lake Superior Region define Proterozoic (~2 Ga) deformation of the Archean Superior Province associated with evolution of the Kapuskasing Zone
- 2:10 p.m. **Dahl, D.**
Gold grains, pathfinder elements, and till clast composition in a portion of the Vermilion Greenstone Belt, Northeastern Minnesota
- 2:30 p.m. **Miller, J. and Jirsa, M.**

Geology, geochemistry and PGE potential of mafic and ultramafic intrusions in Minnesota, excluding the Duluth Complex

2:50 p.m **Presentation of Best Student Paper Award and Eisenbrey Awards**

3:00 p.m. - 3:30 p.m. **Coffee Break and Poster Session** (Posters removed after the break)

7:00 p.m **Mixer - Cash Bar** (Nipigon Curl-a-Drome)

Poster Presentations

Bucholz, T., Falster, A., and Simmons, W.

Mineralogy of pegmatites and spatially associated metasomatized zones, Michels Materials Quarry, Waterloo, WI

Cannon, W., Schulz, K., Daniels, D., Anderson, R., Chandler, V., Holm, D., Schneider, D., Van Schmus, R.

Geology of Precambrian basement rocks in Iowa and the southern parts of Wisconsin and Minnesota

Jirsa, M. and Miller, J.

Geologic implications of bedrock mapping in the Ely and Basswood Lake quadrangles, Northeast Minnesota

Lane, C.* and Hollings P.

Geochemistry and petrography of the Rabbit Islands Breccia, North Central Lake Nipigon

MacTavish, A.

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

Magee, A.

Mining and exploration activity in northwestern Ontario

Planavsky, N.* and Murphy, J.*

New thoughts on old circles: A reexamination of spheroidal Gunflint taxa

Rossell, D. and Coombes, S.

The geology of the Eagle Lake Nickel-Copper deposit: Marquette County, Michigan

Severson, M.

PGE and gold potential of the Archean Deer Lake Complex, Minnesota, USA

Shareef, S. and Craven, J.

A view into the Nipigon Embayment: preliminary results of the largest magnetotelluric study ever in Ontario.

Stott, G. and Rayner, N.

Discrimination of Archean terranes in the Sachigo subprovince and relevance to volcanogenic massive sulphide exploration

Trow, J. and Young, C.

Correlation between self-potential and dowsing (IESG) at the Quincy Mine and at the Calumet and Hecla Mine, Michigan

Weiblen, P., Peterson, D., and Vislova, T.

Implications of Midcontinent Rift and oceanic ridges analogies and 3D interpretations of the subsurface structure of the Bald Eagle Intrusion in the Duluth Complex and the East Pacific Rise

Zieg, M., Forsha, C., and Habarka, J.

Textural examination of Kama Point diabase sill, Nipigon, Ontario

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

Saturday May 28

8:00 a.m. **Field Trip 4:** Geology and Rare Element-bearing pegmatites of the Quetico Subprovince

Leaders: Mark Smyk (OGS) and Steve Kissin (Lakehead University)

8:00 a.m. **Field Trip 5:** Geology of the Black Sturgeon Area

Leader: Tom Hart (OGS)

8:00 a.m. **Field Trip 6:** A Stratigraphic Transect Across the Northern Flank of the Midcontinent Rift near Rossport (II)

Leaders: Peter Hollings and Phil Fralick (Lakehead University)

6.00 p.m. **Return of Trips 4, 5 and 6**

Discovery of Distal Ejecta from the 1850 Ma Sudbury Impact

ADDISON, W.D., R.R. 2, Kakabeka Falls, Ontario, P0T 1W0, Canada; **BRUMPTON, Gregory, R.**, 211 Henry Street, Thunder Bay, Ontario, P7E 4Y7, Canada; **VALLINI, Daniela A, McNAUGHTON, Neal, J.**, Centre for Global Metallogeny, School of Earth and Geographic Sciences, University of Western Australia, Nedlands, Western Australia, 6009, Australia; **DAVIS, Don W.**, Department of Geology, Earth Sciences Centre, University of Toronto, 22 Russell Street, Toronto, Ontario, M5S 3B1, Canada; **KISSIN, Stephen A., FRALICK, Philip W., HAMMOND, Anne L.**, Department of Geology, Lakehead University, Thunder Bay, Ontario, P7B 5E1, Canada

A 25–70-cm-thick, laterally correlative layer near the contact between the Paleoproterozoic sedimentary Gunflint Iron Formation and overlying Rove Formation and between the Biwabik Iron Formation and overlying Virginia Formation, western Lake Superior region, contains shocked quartz and feldspar grains found within accretionary lapilli, accreted-grain clusters, and spherule masses, demonstrating that the layer contains hypervelocity impact ejecta. Smectite replaced microtektites, spherules and crushed spherules, and sphere-in-sphere features make up the bulk of the ejecta. Accretionary lapilli appear near the middle of the ejecta column in the Ontario Gunflint Formation cores but they are not present in the Minnesota Virginia Formation cores. Zircon geochronologic data from tuffaceous horizons bracketing the layer reveal that it formed between circa 1878 Ma (Fralick et al., 2002) and 1836 Ma. The Sudbury impact event, which occurred 650–875 km to the east at 1850±1 Ma (Krogh et al., 1984), is therefore the likely ejecta source, making these the oldest ejecta linked to a specific impact. Shock features, particularly planar deformation features (French, 1998) are remarkably well preserved in localized zones within the ejecta, whereas in other zones, mineral replacement, primarily carbonate, has significantly altered or destroyed ejecta features.

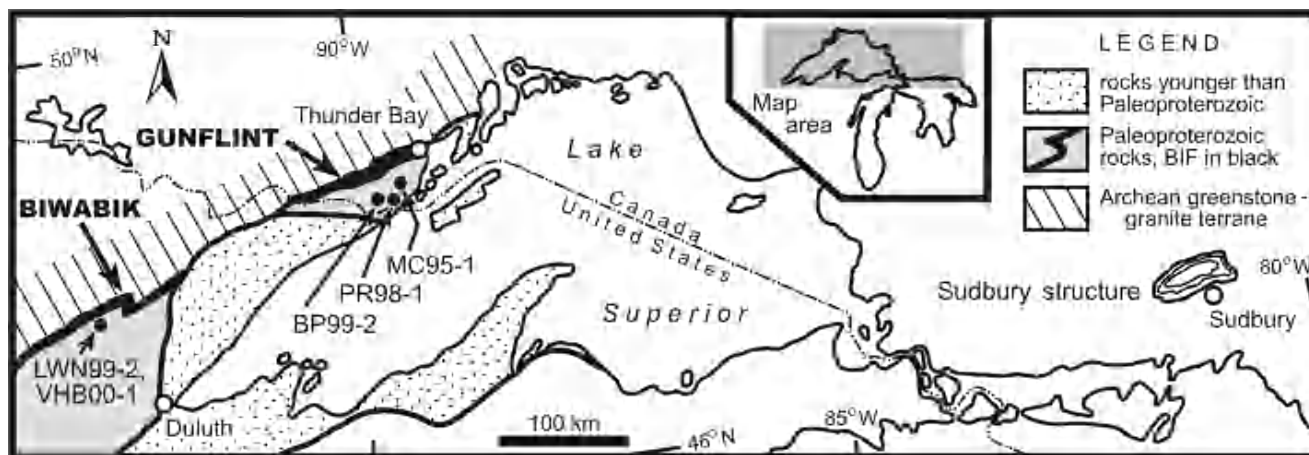


Figure 1. Location of drill holes in relation to the Sudbury structure.

The Sudbury impact is the only known impact location close enough to have produced a craton-sourced (quartz and feldspar grains), westward-thinning ejecta layer (70 cm thinning to 25 cm) this thick, in these locations, given the time constraints established by zircon dating.

References

- Addison, W.D., Brumpton, G.R., Vallini, D.A., McNaughton, N.J., Davis, D.W., Kissin, S.A., Fralick, P.W. and Hammond, A.L. 2005. Discovery of distal ejecta from the 1850 Ma Sudbury impact: *Geology*, 33, 193–196.
- Fralick, P., Davis, D.W. and Kissin, S.A. 2002. The age of the Gunflint Formation, Ontario, Canada: Single zircon U-Pb age determinations from reworked volcanic ash: *Canadian Journal of Earth Sciences*, 39, 1085–1091.
- French, B.M. 1998. Traces of catastrophe: *Lunar and Planetary Institute Contribution* 954, 120p.
- Krogh, T.E., Davis, D.W. and Corfu, F. 1984. Precise U-Pb zircon and baddeleyite ages for the Sudbury area, in Pye, E.G., Naldrett, A.J., and Giblin, P.E., eds., *The geology and ore deposits of the Sudbury structure*: Ontario Geological Survey Special Volume 1, 431–446.

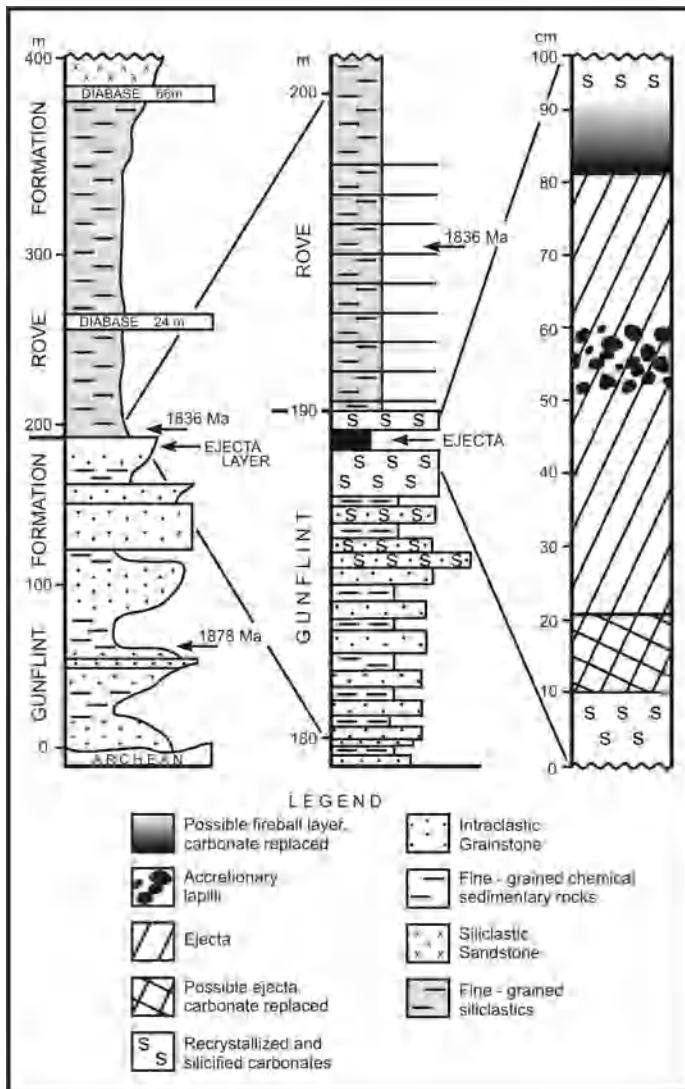


Figure 2. Overview of the Gunflint and Rove Formations based on drill core 89MC-1s. The 1878 Ma tuff age is from Fralick et al (2002). Detail from column 1 showing the Gunflint-Rove boundary zone and the relationship of the ejecta to the dated Rove tuff. The Minnesota cores and other Ontario cores show similar features in this zone. Detail of the ejecta layer in drill core BP99-2, the most complete and least altered ejecta section in all the cores. The possible carbonate-replaced fireball layer fades into the overlying carbonate. Minnesota ejecta layers are thinner and lack accretionary lapilli.

The Geology and Petrology of the Leveaux Porphyritic Diorite, Cook County, MN: Investigating Possible Magmatic Relationships to the Anorthositic Series of the Duluth Complex

ALBERS, Paul B., Department of Geological Sciences, University of Minnesota-Duluth, Duluth, MN 55812, albe0167@d.umn.edu and **MILLER, James D., Jr.**, Minnesota Geological Survey, c/o NRRI, 5013 Miller Trunk Hwy, Duluth, MN 55811, mille066@umn.edu

The Leveaux porphyritic diorite (LPD) is a 72-m thick, discontinuous, hypabyssal, sheet-like intrusion located within the Mesoproterozoic (1.1 Ga) Midcontinent Rift-related Beaver Bay Complex of northeastern Minnesota (Miller and Chandler, 1997). The LPD makes up five prominent, cuesta-like ridges (Figure 1) that trend parallel to Lake Superior over a 20 km distance. In the Caribou Lake region, the LPD makes up smaller knob-like outcrops that dip in multiple directions and are segmented by the younger Beaver River diabase. The LPD is composed of an upper porphyritic zone, which contains 40-50% of 1-4 cm labradorite megacrysts in a fine-grained ferrodiorite matrix (Figure 2), and a lower aphyric zone composed of fine-grained ferrodiorite with rare megacrysts. The aphyric and porphyritic zones are separated by a 20-30 cm thick gradational transition. The orientation of this planar transition and sheet joints from the aphyric section indicate a gentle (10-20 degrees) southeast dip. The upper contact of the LPD is fault bounded. In two localities, the lower contact is observed to be chilled against a thin arkosic sandstone unit, which in turn is underlain by an ophitic basalt. Few outcrops of a sparsely porphyritic (5-20% plagioclase megacrysts) ferrodiorite off the trend of the main sheet are found and may represent feeder zones to the LPD.



Figure 1. Cuesta-like ridge of LPD at Moose Mountain dipping gently toward Lake Superior (looking southeast). The ridge to the right is the Beaver River diabase.



Figure 2. Nonfoliated, lath-shaped labradorite megacrysts (1-4 cm) in a dark, fine-grained ferrodiorite matrix at Oberg Mountain.

Geochemical and petrographic characteristics of the aphyric zone and the matrix material of the porphyritic zone are nearly identical vertically and laterally throughout the sheet. Mineralogically, the ferrodiorite is composed of plagioclase, augite, K-feldspar, Fe-Ti oxides, and minor accessory minerals of quartz, inverted pigeonite, calcite, and apatite, which collectively display an intergranular, nonfoliated texture. Modally, the ferrodiorite varies between diorite and quartz monzonite. XRF analyses indicate a normative An (An/(An+Ab+Or)) matrix composition of 39, while microprobe analyses range from 19-64. Matrix augite contains a constant composition (mg # 55-61) throughout the intrusion. Microprobe traverses and Nomarski DIC microscopy of plagioclase megacrysts indicate subtle zoned cores (~An 65) and strongly zoned rims with An compositions comparable to matrix plagioclase. XRD analyses indicate that the plagioclase megacrysts have an intermediate ordered structural state (see Knudsen and others, this volume).

Based on these observations, we conclude that the LPD formed by the shallow emplacement of a single plagioclase-phyric ferrodiorite magma. Density calculations indicate that the upper porphyritic section may have

formed by plagioclase megacryst flotation in the host ferrodiorite magma. The average composition, zonation patterns, and structural state of LPD plagioclase megacrysts are similar to cumulus plagioclase of the anorthositic series of the Duluth Complex. Also, the evolved compositions of the LPD ferrodiorite are similar to the estimated anorthositic series trapped liquid compositions (Miller and Wieblen, 1990). With these petrogenetic links, we conclude the LPD is a hypabyssal equivalent to the anorthositic series, which is thought to have formed from plagioclase crystal mushes derived from deep crustal magma chambers.

References

- Miller, J. D., Jr., and Chandler, V. W. 1997. Geology, petrology, and tectonic significance of the Beaver Bay Complex, northeastern Minnesota, in Ojakangas, R.W., Dickas, A.B., Green, J.C., eds., *Middle Proterozoic to Cambrian Rifting, Central North America: Geological Society of America Special Paper 312*, 73-96.
- Miller, J. D., Jr., and Wieblen, P. W. 1990. Anorthositic rocks of the Duluth Complex, Minnesota: Examples of rocks formed from plagioclase crystal mush: *Journal of Petrology*, 31, 295-339.

Control of Quaternary Erosional and Depositional Landforms at the eastern outlet of Glacial Lake Agassiz by Precambrian Bedrock and Structure, Ottertooth-Pantagreu Lakes area, Northwestern Ontario

BLACKBURN, C.E., Blackburn Geological Services, Victoria, B.C. and KOR, P.S.G., Ontario Parks, Peterborough, Ontario

During late Wisconsinan/early Holocene time, glacial Lake Agassiz debouched into the Nipigon basin in catastrophic bursts at the continental divide through a number of spillway channels. Two protected areas managed by MNR Ontario Parks, Ottertooth Conservation Reserve and Pantagreu Creek Provincial Nature Reserve, encompass the eastern portion of the 15-km-wide Kaiashk Spillway corridor, the southern-most of five major channel complexes (Figure 1). The power of the bursts can be appreciated by the fact that water flowing through the outlet would have fallen from the 457 m elevation of the divide to about the 320 m level of Lake Nipigon - a drop of 137 m over a distance of 20 km.



Figure 1. Location of the Kaiashk Spillway system, and its relation to four other systems that linked Lake Agassiz with Lake Nipigon during the Nipigon Phase (from Teller and Thorleifson, GAC Special Paper 26, 1983, Fig. 7).

During late Wisconsinan/early Holocene time, glacial Lake Agassiz debouched into the Nipigon basin in catastrophic bursts at the continental divide through a number of spillway channels. Two protected areas managed by MNR Ontario Parks, Ottertooth Conservation Reserve and Pantagreu Creek Provincial Nature Reserve, encompass the eastern portion of the 15-km-wide Kaiashk Spillway corridor, the southern-most of five major channel complexes (Figure 1). The power of the bursts can be appreciated by the fact that water flowing through the outlet would have fallen from the 457 m elevation of the divide to about the 320 m level of Lake Nipigon - a drop of 137 m over a distance of 20 km.

Erosional features resulting from this outflow include plunge basins that formed at the break in slope from the Archean gneissic basement into the Nipigon lowlands. Two plunge basins are present. The more spectacular of the two, Devils Crater, has walls on the order of 100 m high down which today two water falls cascade. The second un-named plunge basin lies some 1.5 km to the southwest. Streams drain to the southeast from both plunge basins, the one from Devil's Canyon being through a deeply incised, narrow gorge. Similar though less prominent features suggesting plunge of water over a pre-existing bedrock "lip" can be seen: a) at the north end of Rabelais Lake; b) about 3 km to the northeast of Devils Crater, and c) near the west shore of Pantagreu Creek. Notably, all of these features lie along a NE-trending line over a distance of ~20 km. Depositional features resulting from the outflow include an alluvial fan at the mouth of the more southerly of the channel-ways exiting from the two plunge basins, which unites with the main spillway channel through which Pantagreu Creek now flows. An "island" of braided eskers forms an erosional remnant in the centre of the channel.

Underlying Archean and Proterozoic bedrock geology had a profound influence on development of the above Quaternary features. To the northwest of the northeasterly-trending line joining points of plunge of Agassiz lake waters, Archean gneissic bedrock was peneplained prior to deposition of Proterozoic Sibley Group sediments, and exhumed during the time of outlet from Lake Agassiz. The result is a broad, level plain. Flat-lying Sibley sedimentary rocks were intruded by Nipigon diabase sills, the erosional remnants of which form numerous scarps and cuestas. Evidence of regional scale faulting post dating intrusion of the sills is seen at Devil's Crater, where Archean gneisses exposed on its northwest face are uplifted relative to Proterozoic diabase that is exposed throughout the rest of Devil's Crater and its gorge. Faulting is probably present at the smaller plunge basin, and at the north end of Rabelais Lake where there is also transition from peneplained Archean gneiss to the incised channel-way of Rabelais Creek. However this latter channel has eroded completely through the diabase "cap" into the gneisses below. Interpretation of

such a regional scale fault is supported by presence of similar NE to NNE-trending regional-scale faults that have been mapped throughout the region.

Projection of the regional-scale NE-trending fault is coincident with the five identified points of plunge of Agassiz lake waters during late Wisconsinan/early Holocene time. Other such fault structures, as yet undetected, may have had considerable influence on development of landform features at the eastern exit from glacial lake Agassiz, possibly along the entire length of the spillway channels northwest of present Lake Nipigon (Figure 1).

References

Teller, J.T. and Thorleifson, L.H. 1983. The Lake Agassiz–Superior connection; in Glacial Lake Agassiz, Geological Association of Canada, Special Paper 26, p.61-290.

Lake Superior's Oxygen Isotope Record Suggests Overflow to Lake Ojibway between 10,000 and 9,400 CAL BP [~8.9-8.4 ¹⁴C ka]

BRECKENRIDGE, Andy and **JOHNSON, Thomas C.**, Large Lakes Observatory and Dept. of Geological Sciences, University of Minnesota Duluth, Duluth, MN 55812

Late glacial ostracode and bivalve records from Lakes Huron and Michigan are characterized by extreme $\delta^{18}\text{O}$ variations, ranging from values that reflect a source that is primarily glacial in origin (~-20 ‰ PDB) to much heavier values characteristic of a regional meteoric source (~-5 ‰ PDB). In contrast, a coeval record from benthic ostracodes (*Candona subtriangulata*) from a varve sequence in Lake Superior is consistently depleted in ^{18}O , ranging from -18 to -22 ‰ PDB.

Between 10,000 and 9,400 cal BP [8.9-8.4 ¹⁴C ka], high $\delta^{18}\text{O}$ values in Huron strongly contrast with much lower values in Superior, which suggests Lake Superior overflow circumvented Lake Huron, and discharged through the Pic-White Otter River Valley en route to Glacial Lake Ojibway. The northern outlet may have opened when lake levels fell from an upper post-Minong water plane at around 10,000 cal BP [~8.9 ¹⁴C ka]. Thereafter, lake levels probably transgressed towards the post-Minong III shoreline. Because deltaic deposits in the Pic River Valley dated around 9,200 cal BP [8.2 ¹⁴C ka] record glacial meltwater flow towards Lake Superior (Bajc et al., 1997), northern drainage of Lake Superior must have been blocked by ice advance at around 9,400 cal BP [8.4 ¹⁴C ka], rather than by differential uplift of a northern outlet.

Negative $\delta^{18}\text{O}$ excursions in Lakes Huron and Michigan between 9,400 and 9,000 cal BP [8.4-8.1 ¹⁴C ka] record the return of Lake Superior overflow to the upper Great Lakes. In Huron the negative $\delta^{18}\text{O}$ excursion was previously ascribed to the Late Stanley lowstand (Rea et al., 1994), and in Michigan the event was attributed to Lake Agassiz overflow and labeled 'A2' (Colman et al., 1994). During this entire period, both Lake Agassiz and glacial meltwater discharged into Lake Superior via the Nipigon inlets. Lake Agassiz and glacial meltwater fluxes into Lake Superior diminished to zero between 9,040 and 8,840 cal BP [~8.1-7.9 ¹⁴C ka].

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Mineralogy of Pegmatites and Spatially Associated Metasomatized Zones, Michels Materials Quarry, Waterloo, WI

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The Michels Materials Waterloo Quarry exposes Baraboo Interval quartzites and metapelites that have been intruded by pegmatites of Wolf River age, approximately 1,440 Ma (Aldrich, 1959; cited in Brown, 1986). A pegmatite outcropping nearby in the Crawfish River has been long known, but pegmatite exposures in the quarry itself were first noted during an ILSG field trip in 2001. Samples of pegmatites and associated rocks were collected at that time and during a number of subsequent visits.

The pegmatites are highly weathered and in hand specimen consist of kaolinite, quartz and muscovite; virtually all feldspars have altered to kaolinite. The dikes are small, discontinuous, apparently randomly oriented and frequently crosscut bedding in the metasediments. Despite the extensive alteration of feldspars, associated muscovite is quite fresh and a number of accessory phases persist. Small miaroles appear to be present, but are obscured by kaolinite. Most pegmatites exposed to date are in the upper level of the quarry, although recent operations (2004) have exposed one pegmatite in the lower level.

Accessory minerals identified in dikes in the upper level of the quarry include dark green gahnite as small aggregates to approximately 2 mm and as well-formed octahedral crystals to approximately 500 μm : MnO content ranges from 0.4 to 1.1 wt. % and FeO content ranges from 1.5 to 2.9 wt. %. Columbite-tantalite group minerals are not uncommon but are inconspicuous due to their small grain size. They form prismatic crystals up to about 900x50 μm . Mn enrichment is pronounced and Ta-enrichment is modest, with compositions falling into the manganocolumbite and manganotantalite fields; there are two distinct composition trends present in these small dikes, one clustering around a Nb-dominant composition and the other clustered around a Ta-dominant composition. TiO_2 contents range from 0.4 to 0.9 wt. %. Sn, Bi, and Sb were not detected; the absence of Bi is interesting in light of recent finds described below. Additional minerals in the upper level dikes include apatite, sprays of acicular goethite crystals, ilmenite as crude hexagonal platelets, small grains of a LREE-Ca phosphate (probably monazite-(Ce) or rhabdophane-(Ce)), zircons giving evidence of minor Hf enrichment and a grayite-like Th-phosphate associated with gahnite. Despite the intense alteration of pegmatitic feldspars, associated muscovite is well preserved and retains a substantial Li_2O content of up to 0.98 wt %.

In September 2004 a somewhat less weathered pegmatite was discovered in the lower level of the quarry. Similar to the upper level dikes, this pegmatite appears to cut across the bedding and terminates before intersecting the upper bench level. Remnants of partially altered feldspars are present in this pegmatite, and the overall mineralogy is somewhat more complex than in the upper level dikes. Some micas in this pegmatite have a pronounced dark pink color and contain substantial Li_2O enrichment up to 2.05 wt %. Some additional minerals found include manganotantalite, goethite replacements of pyrite and chalcopyrite crystals, thin tabular crystals of hematite and sparse apatite. Noteworthy are small grains of bismutomicrolite $\{(\text{Bi,Ca})(\text{Ta,Nb})_2\text{O}_6(\text{OH})\}$ to approximately 0.4 mm embedded in feldspar. EMP analysis indicates $\text{Ta} > \text{Nb}$, and $\text{Bi} > \text{Ca} + \text{Na}$. Pale greenish elongated crystals forming small branching groups in vugs and voids, usually along surfaces of quartz grains, are a mixture of kettnerite $\{(\text{Ca,Bi})(\text{CO}_3)_2\text{O,F}\}$ and other Bi secondary minerals as indicated by x-ray diffraction study. Kettnerite is a typical secondary Bi mineral probably derived from alteration of a primary Bi mineral such as bismuthinite, although the primary Bi mineral has not yet been found.

The Waterloo occurrence represents the first find of gahnite from a pegmatite in the state and the overall composition of these small pegmatites indicates highly peraluminous composition, even though such common peraluminous species such as garnet and tourmaline appear to be absent in them. These are also the first finds of kettnerite and bismutomicrolite for Wisconsin.

Spatially and perhaps genetically related alteration or metasomatic vein-like bodies have been found near the pegmatites. These range from quartz-muscovite±andalusite veins to massive fine-grained lithian muscovite (0.6 wt % Li_2O), the two phases interfingering and grading into each other laterally. Considering the close spatial association of these bodies to pegmatites, it seems likely that the fluids responsible for the alteration may have been derived either from the pegmatites or the source igneous body, although mobilization from the metasediments cannot be excluded based on the present evidence.

Schorl tourmaline is locally common in the quartz-muscovite±andalusite veins in small vugs and adjacent pelitic schists. Colors range from black to olive green, brown and pinkish brown. Microprobe analysis indicates FeO contents of 8-9%, reflecting an overall schorl composition, though site occupancy considerations indicate a significant Li content. Hence, as the Fe-content of these tourmaline crystals is only slightly on the schorl side of the line between elbaite and schorl they might be considered elbaitic or lithian schorl. Apatite is common in small vugs near tourmaline, and ranges from dark red tabular hexagonal crystals to short visually zoned yellow-brown hexagonal prisms. Additional accessory minerals noted in vuggy portions of the veins include Ti-oxides, ilmenite-hematite, pyrite, chalcopyrite (both sulfides usually replaced by goethite), calcite and sparse REE-phosphate grains. Accessory minerals noted in the massive fine-grained muscovite-rich portions include ilmenite-hematite grains, enigmatic muscovite replacements of an undetermined mineral, and sparse zircon. The zircons may be detrital and predate metasomatism.

Hence it is likely that the highly evolved pegmatites formed in conjunction with regionally widespread Wolf River age magmatism (Medaris et al., 2003). Elevated Ta and Mn levels evidenced in the pegmatites, and B and Li in the metasomatic units are anomalous for Wolf River age intrusions in Wisconsin. However, it appears likely that fluids either from these pegmatites or more directly from the parent intrusion may have had a strong, localized metasomatic effect on adjacent rocks, introducing P, B, Li and perhaps other elements to favorable areas in the host rocks. An intriguing question is what influence assimilation of peraluminous metasediments may have had on the source magma, and subsequently on pegmatite composition. Could this have influenced the mineralogy of the pegmatites and other features, or was the source magma already evolved, having originated by partial melting of different source rocks than typical Wolf River intrusions?

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Geology of Precambrian basement rocks in Iowa and the southern parts of Wisconsin and Minnesota

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The well-known Precambrian rocks of the Lake Superior region record geologic events in the evolution of Laurentia from 3.6 Ga to 1.1 Ga. Similar rocks extend southward as the crystalline basement beneath Paleozoic and Cretaceous strata in southern Minnesota and Wisconsin and throughout Iowa. Using aeromagnetic and gravity maps of the region, and several hundred basement-penetrating drill holes, we have produced a geologic map and preliminary tectonic interpretation of the Precambrian subcrop for this region (Figure 1). Our interpretation extends the well known Superior Province (Archean) and Penokean orogenic belt (Paleoproterozoic) of the Lake Superior region southward to a prominent geophysical discontinuity, shown clearly by aeromagnetic patterns, named the Spirit Lake-Trempealeau discontinuity (SLTD). This discontinuity separates fundamentally different terranes; rocks to the south are part of the Yavapai Province and those to the north are part of the Penokean Province. Although rocks of Yavapai age, represented by extensive ultra-mature sediments, such as the Baraboo and Sioux Quartzites, and granitic plutons, extend north of the discontinuity, there are as yet no firmly identified Penokean or older rocks south of the discontinuity, although data are sparse. Thus we suggest the possibility that the discontinuity marks the southern limit of the preserved Penokean orogen and its Archean basement. South of the SLTD, rocks at the subcrop include subaerial potassic rhyolite and epizonal granite, formed at about 1.75 Ga, and ultra-mature quartzite, such as the Baraboo Quartzite, which lies unconformably on them. An orogenic complex of gneisses and mafic volcanic rocks, probably basement rocks on which the rhyolites were deposited and from which they formed by partial melting, are inferred from gravity and magnetic patterns to be at subcrop throughout much of this terrane, but its lithology and age are not well constrained. All of these rocks were strongly deformed at about 1.63 Ga during the Mazatzal orogeny, whose northeastern limit may underlie the extreme southeastern part of the map area. The nature of the SLTD is controversial with possibilities including a north-directed Yavapai subduction zone or a major strike-slip fault zone. Major granitic plutons were emplaced into the Yavapai terrane in the interval 1.50-1.43 Ga and some are stitching plutons of the SLTD providing an upper age limit on deformation within it. The final major Precambrian event in the region was formation of the Midcontinent Rift at 1.1 Ga. The rift transects older terranes at a high angle and consists of more than 10 km of flood basalts accumulated in and near a series of grabens, and slightly younger clastic rocks. Its location in the subsurface is clearly shown by very pronounced geophysical anomalies. A major igneous complex in NE Iowa and SE Minnesota is also interpreted to be part of the Midcontinent Rift.

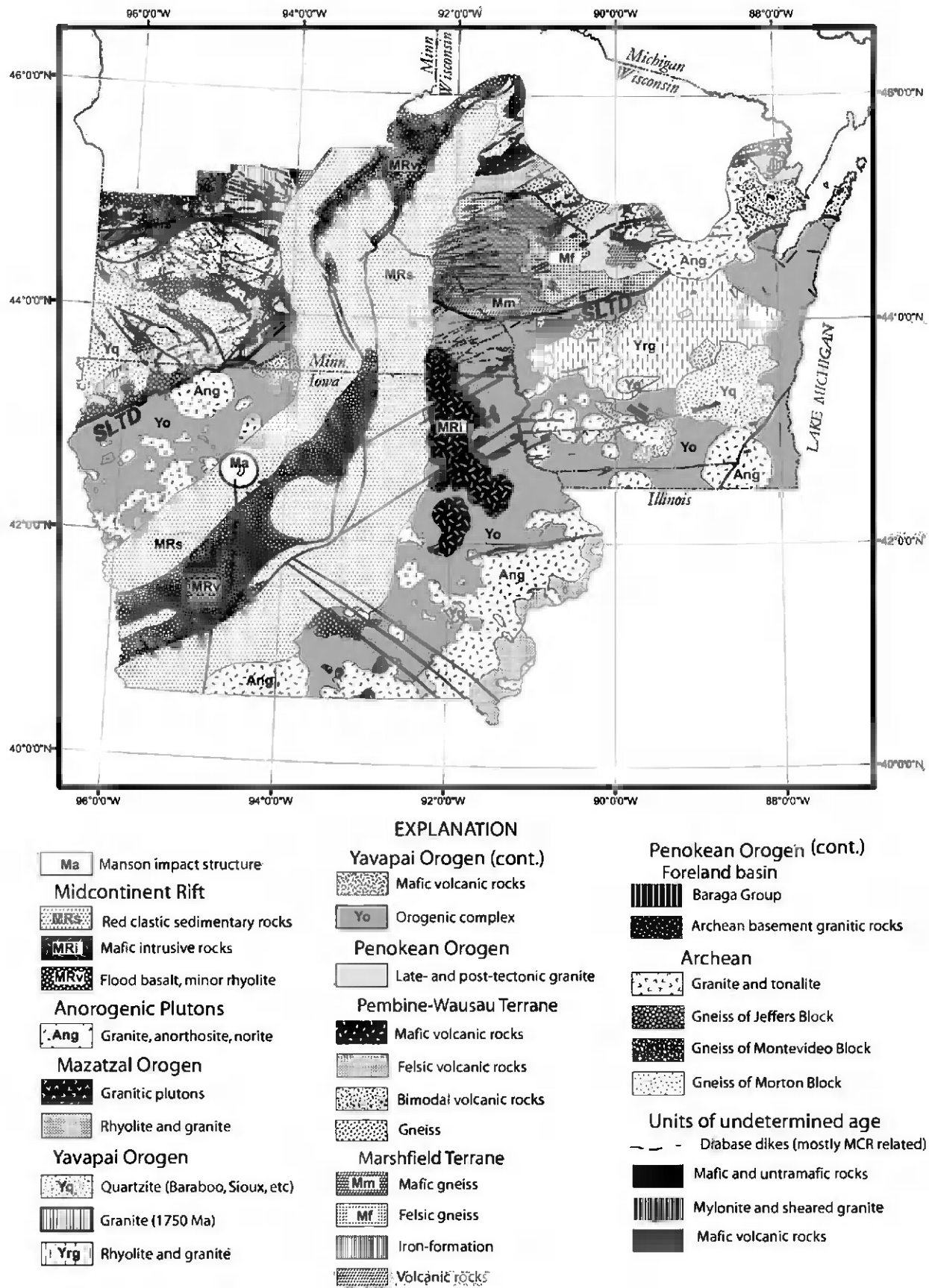


Figure 1. Geological Map of Precambrian basement rocks in Iowa and the southern parts of Minnesota and Wisconsin inferred from aeromagnetic and gravity data and drill holes.

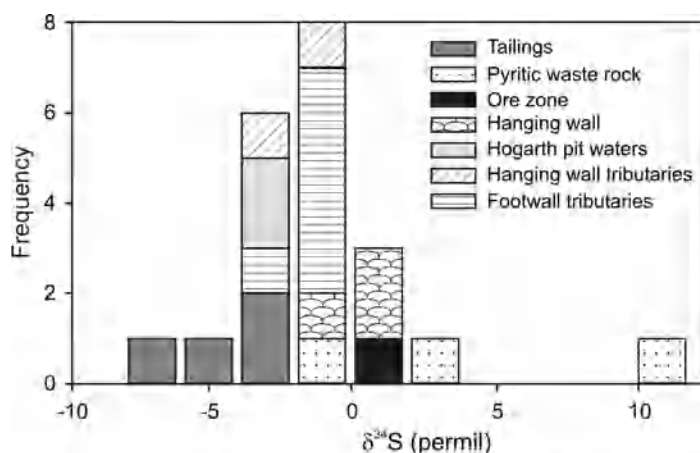
Origin of High-Sulphate Waters of the Hogarth Pit Lake, Steep Rock iron Mine, Atikokan, Ontario

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Hogarth Pit Lake was formed from the continual flooding of the main open pit iron mine at Steep Rock Lake near Atikokan, Ontario. Hogarth Pit Lake is located in the former middle arm of Steep Rock Lake and was mined for its predominantly goethite iron ores from 1954 to 1977. During this time over 25 million tons of ore were mined [1]. Water within the pit lake is characterized by near neutral pH and extraordinarily high SO_4^{2-} concentrations (1000 to 3000 ppm; [2], this study). Consequently, the aim of the research is to determine the source(s) of the high SO_4^{2-} levels. Possible sources of sulphate that are evaluated include: i) oxidation and leaching of finely disseminated sulphides within hanging wall and footwall rock units by groundwater; ii) oxidation and leaching of pyritic portions of the ore zone by groundwater; and, iii) oxidation and leaching of sulphides/sulphates contained in waste rock dumps and tailings piles by surface waters

Hogarth Pit Lake is approximately 160 m deep, with a surface area of approximately 100 hectares and is elongated along a north-south axis. The lake is steep sided, well-sheltered by high rock walls. Footwall rocks, east of the Jolliffe ore zone, consist of (in ascending stratigraphic order) the Marmion Geniss Complex, metasedimentary rocks of the Wagita Formation and the Mosher Carbonate [3]. To the west, hanging wall rocks include ultramafic-mafic volcanic and volcanoclastic rocks of the Dismal Ashrock Formation, which is overlain by mafic to felsic volcanic rocks of the Witch Bay Formation [3]. Since cessation of mining activities the water level within the pit continues to increase (~ 3 m/year) from surface runoff and groundwater seepage. Environmental assessment studies completed shortly after closure of the mine indicate that approximately 85% of the water entering the pit is groundwater (R. Bernachez, personal communication, 2003). The lower contribution of surface water is consistent with the limited number of tributaries that currently flow into the pit lake.

Water from Hogarth Pit Lake sampled for this study has a pH of ~ 7.6 , contains 1340 to 1381 ppm of SO_4^{2-} , only trace levels (0.1-0.2 ppm) of Fe and Mn, and no detectable deleterious metals (As, Cd, Pb). Pit water has $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ values that range from 0.8 to 0.9‰ and -2.7 to -2.9‰, respectively. Surface waters that are following into the pit are characterized by a wide range in pH (2.8 to 8.1) and SO_4^{2-} content (734 and 2580 ppm), with $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ values ranging from -20.3 to 1.5‰ and -3.6 to -0.4‰, respectively. The composition of surface and pit waters is comparable with the data of [2], although there is a trend of decreasing SO_4^{2-} between 1998/99 and 2003. The variation in the chemistry of surface water reflects differences in wall-rock interactions. Surface waters with low pH and $\delta^{13}\text{C}$ values reflect reactions with footwall and hanging wall volcanic and genesis units and organic matter. Water with near neutral pH values and $\delta^{13}\text{C}$ values approaching 0‰ indicate buffering by the Mosher Carbonate. Groundwater was not sample as part of this study. However, regional groundwaters in the Atikokan area are generally enriched in Cl^- with substantially lower SO_4^{2-} contents than observed at Hogarth Pit [4]. However, some regional groundwaters have SO_4^{2-} contents that approach the lower values for surface waters [4].



The sulphur isotope composition of the pit and tributaries waters (Figure 1) is consistent with oxidation and dissolution of pyrite from the ore zone, waste rock dumps and the hangingwall. The data for the pyritic waste rock dumps is also used to better constrain the composition of pyritic

Figure 1. Histogram showing the distribution of sulphur isotope data for Hogarth Pit Lake waters and lithological units

portions of the ore zone, since only one *in situ* ore sample was obtained for the study. The shift to slightly more depleted $\delta^{34}\text{S}$ values for the water samples relative to pyrite-bearing rocks is within the range anticipated for pyrite oxidation [5]. However, sulphur isotopes cannot be used in isolation to discriminate potential sources of SO_4^{2-} . It is necessary to consider both the total sulphur content of the potential source material and water flow pathways. Consequently, the most likely source of SO_4^{2-} is the oxidation and dissolution of pyrite contained with the Jolliffe ore zone by groundwater. The high bulk sulphur content (3.5-43.8 wt% as FeS_2) of pyritic ore and waste rocks indicate that there is an amply supply of pyrite. Conversely, only very minor amounts of SO_4^{2-} could have been derived from the hanging wall units and tailings, since these lithologies are characterized by low sulphur contents (<2 wt% and <0.06 wt%, respectively). Furthermore, the substantially higher proportion of groundwater to surface water filling the pit indicates that water-rock interactions with exposed lithologies contribute a subordinate amount of SO_4^{2-} .

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Gold Grains, Pathfinder Elements, and Till Clast Composition in a Portion of the Vermilion Greenstone Belt, Northeastern Minnesota

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An orientation project to determine variability of glacial till in the Mud Creek area of northeastern Minnesota's Vermilion Greenstone Belt demonstrates that gold grains and pathfinder elements are present in basal till, and that anomalies stand out in contrast to regional background levels. Clastic and chemical variations within the till sample set are sufficient to consider using the basal till as sampling media for gold dispersal mapping.

Of the thirty-two till samples analyzed, four were highly anomalous for gold, with counts of 88-1,282 gold grains per 10 kg of -2mm table sample, and pristine gold grain proportions up to 98%; up to 8,050 ppb gold in HMC (nonmagnetic heavy mineral concentrates); and up to 1,050 ppb gold in the -63 μ m silt/clay fraction of till. A suit of bedrock grab samples collected as reference mineralization returned assays up to 12,247 ppb Au, and silver concentrations up to 42,500 ppb. Analytical results for the till samples support a hypothesis that clastic dispersal trains of mineralized material exist in tills in the area.

Within the project area, particulate gold is more anomalous in basal till samples than in the thin drape of overlying melt-out till. The gold grain counts and gold grain morphology add a transport distance value to chemical measurements of gold in soils and till, and suggest that the gold in the samples is locally derived. Pebble counts and pebble morphology similarly suggest a local derivation for the particulate gold. Analytical results for the present study are comparable to larger, more extensive regional evaluations conducted in neighboring Ontario and further confirm anomalous soil and fine fraction gold values reported in earlier Vermilion Greenstone Belt studies. Analysis of basal till in this portion of the Vermilion Greenstone Belt, particularly for gold grains, offers a capacity to positively detect local, previously unrecognized mineralization both inside and outside of areas of detailed bedrock geologic mapping.

The Grenvillian Tomiko quartzites of Ontario: correlatives of the Baraboo quartzites of Wisconsin, the Mazatzal orogen of New Mexico, or unique? Implications for the tectonic architecture of Laurentia in the Great Lakes region

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The Baraboo and 6 other correlative red quartz arenite sequences in the southern Lake Superior region were deposited between 1710 and 1630 Ma, and locally were affected by regional deformation and metamorphism at about 1630 Ma, as well as by potassium metasomatism at 1465 Ma (Medaris et al., 2003). The Baraboo and related quartz arenites may be correlative with quartz arenites in the Athabasca and Thelon basins (Medaris et al. 2003), indicating widespread sedimentation across much of North America in the late Paleoproterozoic. Key features of the Baraboo and Athabasca basin quartz arenites, include the local presence of well-developed paleosols, a high-degree of supermaturity of the quartz arenites, and chemical index of alteration (CIA) values of 95-99. These three features have been interpreted to indicate that profound chemical weathering occurred across much of North America between 1750 and 1630 Ma (e.g., Medaris et al., 2003).

A thick sequence of paragneiss, including quartz arenite and iron formation (hereafter referred to as the Tomiko supracrustal rocks), occurs within the Tomiko terrane of the northern Central Gneiss Belt of the Grenville Province in Ontario. Holmden and Dickin (1995), based on Nd-Sm model age data and regional tectonics, suggested that the Tomiko quartz arenites were possible correlatives of the Baraboo and related quartz arenite sequences. If valid, then this correlation indicates that sedimentation and weathering between 1710 and 1630 Ma occurred east of Lake Superior, and that rocks of the Penokean orogen may underlie large parts of the northern Central Gneiss Belt in Ontario. Testing this correlation has been problematic, as until recently, only limited mapping and geochronological data were available for Tomiko terrane. Mapping during the 2003 field season (Easton, 2003) provides additional constraints for regional correlation, as follows:

- Discovery of B-rich (>15% tourmaline) and Mn-rich rocks in association with magnetite-chert iron formation in northern Tomiko terrane, as well as epidote-rich (>20%) rocks in association with rusty gneisses near Crocan Lake and chemically unusual (high TiO_2 & P_2O_5) calc-silicate rocks).
- The recognition of possible dacitic metavolcanic rocks and sills interlayered with the Tomiko supracrustal rocks, along with amphibolites that may represent sills or flows.
- The possibility that many of the muscovitic and feldspathic units within the Tomiko supracrustal sequence may represent hydrothermally altered rocks (CIA of 60 to 64).
- The recognition of possible Archean “basement” rocks infolded with the Tomiko supracrustal rocks. This basement is likely structural, not depositional.
- The identification of at least 3 metamorphic events affecting the Tomiko supracrustal rocks, with the intensity of the 2 latest events increasing to the southeast. M_2 forms a migmatite front between northern and southern Tomiko terrane, with lower grade rocks to the north. M_3 is a regional hydrothermal event, and results in the replacement of blue kyanite and granite leucosome formed during M_2 by pale-green kyanite and quartz segregations.
- Stratigraphic correlation with metasedimentary rocks of the Huronian Supergroup, exposed immediately to the north, is unlikely, based on geochemistry and Nd/Sm ages.

On the basis on the new data, correlation of the Tomiko rocks with the Baraboo and related quartz arenites is still compelling. The Tomiko quartz arenites appear to be mature rather than supermature (CIA of 69 to 78 for quartzites), even though they are associated with metamorphosed volcanic and plutonic rocks and minor amounts of iron formation. It can be argued that kyanite-bearing and muscovite-rich gneisses in Tomiko terrane represent a combination of metamorphosed paleosols and potassium metasomatized quartz-rich sedimentary rocks, respectively. U/Pb zircon ages on detrital zircons from quartz arenite at two localities at different metamorphic grades give a maximum depositional age of 1687 Ma (Krogh, 1989; Easton and Kamo, 2004). Minimum

depositional age is 1250 ± 10 Ma, based on the age of grey gneisses interlayered with the quartz arenite; identical within error to the age of several A-type granite plutons that intrude the Tomiko supracrustal rocks (1257^{+4}_{-2} and 1244^{+4}_{-3} Ma; Easton and Kamo, 2004; Lumbers et al., 1991, respectively). If the correlation with the Baraboo is valid, then the Tomiko supracrustal rocks likely have limited mineral potential.

Equally compelling, however, is that the Tomiko supracrustal rocks have many lithologic, stratigraphic and geochronologic similarities to Geon 17 rocks of the Mazatzal orogen exposed in Arizona and New Mexico (Tonto Basin Supergroup and Hondo Group, respectively). For example, the Hondo Group overlies a sequence of older greenstones, and consists of a thin basal unit of quartz pebble conglomerate, over 1 km of quartz arenite, and a capping sequence of muscovite schist and arenite, metarhyolite, phyllite and calc-silicate rocks (Robertson et al., 1993). A manganese-rich horizon, possibly a paleosol, perhaps lateritic, occurs at the top of the greenstones. Furthermore, some of the muscovite schists in the Hondo Group represented hydrothermally altered felsic volcanics. Rocks of the Hondo Group were deposited between 1700 and 1644 Ma (Robertson et al., 1993), and contain detrital zircons ranging in age from 1850 to 1700 Ma. A key difference is that plutons intruded the Hondo Group between 1680 and 1650 Ma, not at circa 1250 Ma. The rock types, stratigraphy, thickness, alteration history and age of the Tonto Basin Supergroup and the Hondo Group is similar to that observed in the Tomiko supracrustal rocks, even though the Mazatzal rocks in New Mexico are now some 3500 km distant. If correlation with the Mazatzal Orogen is valid, then the iron formation in northern Tomiko terrane may be equivalent to the manganese-rich unit at the base of the Tonto Basin Supergroup and the Hondo Group, and may have served as the decollement surface along which northward-directed thrusting occurred. If the Tomiko supracrustal rocks do represent a sliver of the Mazatzal Orogen, which at one time must have stretched from Arizona to Labrador, then the eastern end of the Penokean Orogen has been truncated in Ontario. A third possibility, that the Tomiko quartz arenites were deposited close to 1270 Ma, similar in age to the grey gneiss units interlayered with them, would mean that the sequence is unique in the Lake Superior region, and further begs the question of what happens to the Penokean Orogen east of the Grenville Front?

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Stratigraphy of the Mesoproterozoic Sibley Group and Nipigon Sills

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This paper is designed to complement papers on the geochemistry of the Sibley Group (Metsaranta and Fralick, this volume) and Nipigon Sills (Richardson and Hollings, this volume). It will review the existing nomenclature and highlight recent advances made in deciphering the stratigraphy of the Sibley Basin during field investigations forming a portion of the Lake Nipigon Region Geoscience Initiative.

Rocks correlated with the Sibley Group are present primarily to the south and west of Lake Nipigon. They are divided into five Formations (Franklin et al., 1980; Cheadle, 1986; Fralick et al., 2000; Rogala, 2003) encompassing, at their thickest, approximately nine hundred meters of stratigraphic section. The basal Pass Lake Formation lies on metamorphosed igneous and sedimentary rocks, except for a limited area in the southwest where it overlies Paleoproterozoic strata of the Rove Formation. Evidence for the existence of small hills and valleys on the paleosurface is common. Age of the Pass Lake Formation is constrained by a Rb-Sr isochron on overlying dolomitic mudstones of 1339 ± 33 Ma (Franklin, 1978), probably representing a diagenetic reset, and detrital zircon geochronology on a Pass Lake sandstone giving a concordant youngest zircon age of approximately 1650 Ma (*see* Heaman and Easton, this volume). The conglomerates and sandstones of this unit represent a number of depositional environments ranging from Scott-type and South Saskatchewan-type braided streams to cobble beaches, offshore storm sand sheets and possible aeolian dunes. The subaerial environments, where present, are situated at the base of the section, overlain by a flooding event. As the water depth increased the nearshore, storm deposited, sand sheets were succeeded upwards by laminated and massive silt (Rossport Formation). Delta progradation reversed this trend in areas proximal to sediment entry points. Caliche developed in underlying fluvial, off-channel deposits attests to a semi-arid climate and this caused the water body to become saline. Cyclically banded red and cream coloured dolomitic siltstone accumulated as salinity increased. The millimeter- to decimeter-scale banding probably reflects periodic movement of the redox front from the water mass to beneath the sediment surface, possibly driven by organic loading. The central portions of thicker, light coloured layers contain bladed crystals and small nodules of gypsum attesting to peak aridity during oxygen minima in the bottom sediments. As the water mass contracted sand, possibly derived from the south, formed extensive sheet deposits in most areas. The strandline is marked by the sporadic development of algal flat deposits with carbonate silt storm layers. Though most of this one to seven meter thick calcareous unit is dominated by smooth mat and breccia small panicles and more classic stromatolites are present. Tepees and gypsum filling stromatactis are also encountered, though more rarely. The upper few centimeters of the carbonates is intensely weathered and commonly overlain by either an excellently developed terra rosa or subareal debris-flows. Regional computer modeling of thickness data indicates that this interval may represent initiation of north-south orientated, half graben formation in the area. The succeeding silt-dominated mudflat assemblage contains abundant nodular and vein gypsum, attesting to the continuation of dry conditions, albeit with a high water table.

The transition from the Rossport to Kama Hill Formation is marked by a flooding event and re-establishment of open water conditions, though no evaporite minerals were precipitated from this water mass. Purple shales dominate the lower portion of the succession with thin ripple laminated, fine-grained sandstones, which become more numerous, thicker and coarser grained upward. Trough and hummocky cross-stratified, medium-grained sandstones (Outan Island Formation) appear and then dominate the section, continuing the coarsening upward trend. Slump scars and large areas of chaotic slide-block deposits attest to the periodic failure of, in places, extensive portions of the outbuilding delta complex. The delta top deposits consist of fining and thinning upwards sandstone successions meters to a few tens of meters thick (channels) interbedded with fine-grained sediments (floodplains). The floodplains are mostly composed of friable mudstone with soil horizons representing subareal accumulation but parallel laminated shales deposited in floodplain ponds are also present. The upper deltaic and fluvial deposits of the Outan Island Formation are only present in a core from a hole drilled in Nipigon Bay.

Detrital zircon geochronology performed on this unit gave a maximum age of deposition of approximately 1470 Ma (*see* Heaman and Easton, this volume). The Outan Island Formation is erosively truncated and overlain by the Nipigon Bay Formation. Planar cross-sets up to 17 meters thick indicate that the winds which deposited this sea of aeolian sand had a predominant direction from the northeast. The medium-grained sandstones of the Nipigon Bay Formation comprise the uppermost 400 meters of the Sibley Group with conglomerates of the basal Osler Group unconformably overlying them.

At approximately 1109 Ma, diabase sills were intruded into the Sibley sedimentary rocks as the Midcontinent Rift established itself in the area. The southernmost region underlying Nipigon Bay has the most complete section of Sibley strata, but only one thin sill near the base of the assemblage. Sibley on the adjacent mainland contains a thick sill in the basal Kama Hill Formation, which is traceable across the southern portion of the basin. Thus, the thick sills are confined to north of Nipigon Bay with a fundamental divide running down this topographic feature. Moving from the southern to central basin a second, lower sill appears in the stratigraphy and sill width increases (toward Muskrat Lake) where their composite thickness is approximately 300 meters. Rosspoint Formation strata between the two thick sills in the central basin have been extensively thermally metamorphosed reaching temperatures of 600°C locally and 300-400°C tens of meters from the sills. The sills are commonly locally discordant, up- and down-ramping through the stratigraphy. They also appear to be vertically offset by faults, in places defined by surface lineaments. Toward the northern portion of the basin the erosion level cuts downward through the stratigraphy, with only the lower sill and a thin layer of underlying, Sibley-like sediment preserved. In the northernmost region this sill directly overlies a Mesoproterozoic volcanic-intrusive complex. To the east of the basin marginal Black Sturgeon Fault a sill overlies a thin, sporadically present, baked sedimentary layer lying on basement; a scenario similar to the northern area west of the Fault. Generally sill thickness decreases to the west of the central basin and the sills may bifurcate in this direction as well. An anomalous area exists in the western region, northwest of Muskrat Lake where a drillhole encountered a thick (500 m) sequence of diabase. The significance of this occurrence is unknown. Regional sill stratigraphy implies the feeder area was probably in the vicinity of Muskrat Lake and possibly related to the Black Sturgeon Fault system.

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Mineral Resources for the Future: The Resource Potential of Northern Lake Superior

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The demand per person in the industrialized nations for primary “old - economy” metals has increased ten-fold since 1900. Globalization in recent years has increased competitiveness and access to highly productive regions such as South America, Africa and Oceania, leading to an overall decline in metal prices of 40%. The demand for “new - economy” metals has increased 5 to 100 times since 1985; their prices have increased significantly. In the past five years, industrial expansion in China and India has created an almost unprecedented need for new metal resources. Even with recycling, vast quantities of new resources, particularly for “green” products, must be found, mined and processed in environmentally sustainable ways.

The geological attributes of the Northern Lake Superior region provide an outstanding opportunity for exploration for an exceptional range of commodities and ore deposit types. Archean volcano-sedimentary strata with much additional potential include the historically productive Abitibi – Wawa and Wabigoon belts, with world – class volcanogenic massive sulfide deposits (Manitouwadge district), orogenic gold deposits (Geraldton) and a porphyry/epithermal district (Hemlo). Significant pegmatite bodies (Georgia Lake) and Algoma iron formations (Wawa) are also present. Early Proterozoic strata are comprised of an extensional and miogeoclinal sequence that includes the giant Gunflint Superior-type iron formation. Mid Proterozoic intrusions associated with magmatic plumes (~1500-1600Ma) and the Keweenawan plume-intracratonic rift assemblage (1130-1090Ma) have proven potential for Cu-Ni-PGE deposits, Nb-REE in carbonatite, as well as potential for IOCG (REE-Zr) mineralization. Vein deposits that are contemporaneous with Keweenawan magmatism include Pb-Zn-Ba unconformity-vein deposits, two generations of Ag veins, and unconformity-style uranium occurrences. Epithermal and breccia – pipe copper deposits occur near Batchawana Bay. Redbed copper occurrences are associated with interflow sedimentary strata in the Osler volcanic sequence.

Future discoveries require innovative exploration. Quantitative estimation of key geological attributes (e.g. magma fluid contents, paleo- permeability, and fault dynamics) must be applied vigorously in the search for ore. Geophysical techniques normally used for deep imaging of the earth (seismic, magnetotelluric) are being adapted for exploring shallow crystalline terrains.

Developing quantitative models of ore forming processes that can be applied at all scales will ensure the supply of metals needed for the rapidly developing nations, and for improved quality of life everywhere.

Dyke swarms around the Lake Superior Region define ~2 Ga Proterozoic deformation of the Archean Superior Province associated with evolution of the Kapuskasing Zone

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Proterozoic dyke swarms in the Archean Superior Province straddle a ~2 Ga crustal dislocation, the Kapuskasing Zone (KZ), that extends for more than 500 km from James Bay to Lake Superior and divides the Archean Superior Province into eastern and western halves. About ten swarms are present ranging in age from the Matachewan, (2446-2473 Ma) to the Keweenawan (1108-1094 Ma). Nearly all the swarms include at least one reversal of the earth's magnetic field. During the Matachewan igneous episode only one reversal, from R to N, occurred at 2446 Ma. Within the KZ only N dykes are found, but outside, R dykes outnumber N by more than 4 to 1. N dykes are relatively common in the focal region of the swarm north of Lake Huron, but gradually disappear to the northwest with only R dykes being found in the Lake Nipigon region.

The KZ can be divided up into a number of domains based on Matachewan dyke polarity, the boundaries between R and N domains being major faults that define the crustal uplift along the KZ. N polarity dykes within the KZ represent the roots of R dykes that have been remagnetized at depth before being uplifted. Using the polarity domain concept, major faults have been mapped that define a new segment of the KZ at its southwestern end (the Pineal Lake block), which is offset about 20 km sinistrally from the main Chapleau block to the NE¹. The pattern of polarity domains follows exactly that produced by variations in feldspar clouding intensity within the dykes, whereby the clouding, (caused by exsolution of magnetite and other minerals in groundmass feldspars) occurs only in N polarity domains. The secondary magnetite, thought to be caused by slow cooling of the dykes at large crustal depths, increases in concentration with increasing depth. The growth of this magnetite led to the secondary N magnetization. Only a few dykes within the KZ show vestiges of their formerly R polarity¹.

When Matachewan dyke populations in regions of about 100 km in lateral dimensions were compared, a positive correlation was found ² between mean Matachewan dyke trend and magnetization declination, a correlation that was absent between dykes *within* the areas. This result suggested that the variation in mean dyke trend was a product of differential crustal rotation about vertical axes, and therefore that the broad Z-shaped trend of the dykes across the southwestern end of the KZ was the result of the deformation of an originally more linear dyke swarm².

Further work on Matachewan dykes³, and also on younger swarms that have equivalents on both sides of the KZ (2170 Ma Biscotasing⁴, 2076 Ma Fort Frances/2069 Ma Lac Esprit⁵), confirm that the western half of the Superior Province has rotated counterclockwise about 20° with respect to the eastern half. More recent work on 2101-2121 Ma Marathon dykes⁶ suggests that the western half of the Superior Province has not rotated as a single unit because the KZ as a fault zone extends for more than 100 km to the northwest of the main zone of crustal uplift.

The age of the rotation is thought to be about 2 Ga old and related to the deformation along the KZ. A possible consequence of the rotation is that a rift in the Superior province opened beneath Hudson Bay and remained a region of crustal weakness to be subsequently exploited in later Phanerozoic subsidence that formed the Hudson Bay basin and associated lowlands⁴.

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Mesoproterozoic Diabase Sills of the Nipigon Embayment, northwest Ontario

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The Nipigon Embayment is an approximately 19,000 km² area of Mesoproterozoic igneous and sedimentary rocks centred on Lake Nipigon, north of Lake Superior. The current extent of the Embayment is defined by the sporadic occurrence of diabase sills suggesting that the Embayment was probably more extensive prior to erosion. A series of shallow dipping, 1110 - 1113 Ma, diabase sills of the Nipigon Sill Complex (Heaman et al., 2005) intrude all Archean and Proterozoic rocks in the Embayment.

The Nipigon Sill Complex is composed of at least 3 major, and a series of minor, diabase sills ranging in thickness from a few tens of metres to >200 m. The diabase is commonly sub-ophitic to ophitic, massive, medium- to coarse-grained feldspar and pyroxene with trace olivine and 1 to 2% magnetite. Medium- to coarse-grained diabase forming the majority of the sills should properly be classified as gabbro, but to avoid confusion with other intrusions in the area the diabase classification has been applied to all rocks associated with the sills. The sills are generally shallow dipping occasionally forming broad, up to 6 km wide, saucers with interiors occupied by older rock types (Figure 1).

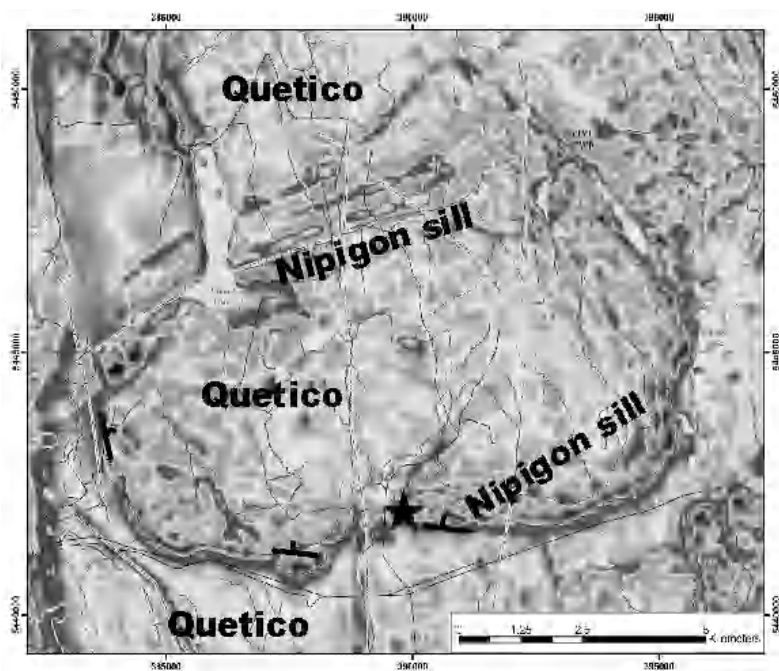


Figure 1. First vertical derivative of the total field magnetic data (Ontario Geological Survey, 2004) showing an inward dipping saucer shaped diabase sill in the southern Black Sturgeon River map area (Hart, 2005).

The geometry of these saucers is in part evident from contact relationships observed during bedrock mapping (e.g. Hart, 2005), and from the magnetic patterns on the first vertical derivative of the total field airborne magnetic data (e.g. Ontario Geological Survey, 2004). Modelling a saucer located in the Garden Lake greenstone belt of the Wabigoon Subprovince, west of Lake Nipigon, produced two possible models (J. Rudd, Ontario Geological Survey, personal communication, 2000). However, the model of a shallow dipping thin sill best agreed with field observations, and is the best fit between field observations and geophysical data for similar structures in the Beardmore area (Hart et al., 2000) and in the southern Black Sturgeon River area (Hart, 2005). Similar sill geometry has been suggested for other mafic sill complexes (e.g., Thomson and Hutton, 2004), although the saucers and nested saucers structures in those areas are generally smaller in diameter. One reason for the large scale of the saucers in the Nipigon Embayment may be the more competent nature of the Archean basement rocks compared to the host rocks of other sill complexes.

The majority of the sills have relatively uniform mineralogy and geochemistry complicating the correlation of the sills within the Embayment. Minor stratigraphic variations within some sills suggest that they may have formed by injection of multiple pulses of magma. However, a thickening of some sills to 250 and 400 m in thickness in the Muskrat and Gieke lakes area, in combination with geochemical trends, suggests that these thicker sills are single cooling units, and may also indicate proximity to the feeders for the sills. The exception to the uniform geochemistry of the Nipigon sills is the >1120 Ma Inspiration Sill (Heaman and Easton, 2005) in the northwest portion of the Nipigon Embayment, which has higher La/Yb and Zr/Y ratios and a positive magnetic polarity in contrast to the negative polarity of the Nipigon sills (MacDonald, Tremblay and Easton, 2005). Another significant geochemical change occurs around Thunder Bay (Hart, 2004) where the majority of the sills located to the south of the city are part of the 1115±1 Ma Logan Sill Complex (Heaman and Easton, 2005). Similar geochemical variations related to geographic position have been observed in some flood basalt provinces (e.g., Mantovani et al., 1985) suggesting that the Logan and Nipigon sills may be part of a single intrusive event.

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Proterozoic history of the Lake Nipigon area, Ontario: Constraints from U-Pb zircon and baddeleyite dating

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The Lake Nipigon Region Geoscience Initiative, a 2-year, science-focused, Industry-Government-University collaborative geological study, collected new geoscience data in the Lake Nipigon region of Ontario between May 2003 and May 2005. As part of this study, over 40 new U-Pb baddeleyite and zircon age determinations were acquired from predominantly mafic rocks of the Lake Nipigon region. Preliminary results of this study are reported herein.

William Logan first described the copper-bearing rocks of the Midcontinent Rift (MCR) in Ontario in 1863. Subsequent studies by many researchers indicate that the MCR in Ontario comprises 3 main tectonic elements: 1) the volcanic and sedimentary rocks in and along the margin of Lake Superior, 2) associated alkalic complexes, 3), the mafic and ultramafic intrusions centred on Lake Nipigon, and whether they represent a “failed arm” of the main rift. Work in Ontario has tended to focus on the Lake Nipigon area, because of accessibility and mineral potential.

The best estimate for a maximum depositional age of a greywacke from the upper Rover Formation is provided by a 1777 Ma concordant detrital zircon grain, as the youngest grain in the sample, at 1731 Ma, is 5% discordant. This interpretation is supported by the abundance of grains ($n=10$) between 1796 to 1777 Ma, and is consistent with U-Pb ash bed ages of 1836 ± 5 and 1832 ± 3 Ma from the basal Rove Formation (Addison et al., 2005).

Detrital zircon ages from sandstones of the lower (Pass Lake Formation) and upper (Nipigon Bay Formation) Sibley Group indicate maximum depositional ages of 1634 and 1670 Ma, respectively, with a predominance of Geon 17 and 18, not Archean, detritus. Data from the middle to upper (Outan Island Formation) Sibley Group indicates a maximum depositional age of 1450 Ma, as well as Geon 15 and 17 detritus, but no Geon 18 grains. The Geon 15 detritus may be locally derived, e.g. from the 1547 ± 4 Ma English Bay complex volcanic rocks, the 1590 ± 1 Ma Pillar Lake felsic intrusion, and the 1599 ± 1 Ma Pillar Lake gabbro. In addition, sediment interbedded with flat-lying mafic volcanic rocks south of Armstrong are younger than 1514 Ma, based on detrital zircons in interbedded sediments, but older than overlying, circa 1159 Ma (minimum age of 1120 ± 1 Ma), Inspiration diabase sills.

The abundance of Geon 15 ages in the western Nipigon Embayment is impressive, as the period between 1600 and 1520 Ma in eastern North America has been recognized for some time as a period of quiescence throughout Laurentia (Gower et al., 1990). Furthermore, there are no dike swarms or reliable paleopoles for the period 1700 to 1500 Ma. The only other reliable Geon 15 age in North America is the 1576 ± 13 Ma upper intercept age from the Priest River metamorphic complex in Idaho, which served as basement to the circa 1450 Ma Belt and Purcell Supergroups (Evans and Fischer, 1986). Gower (1996) suggested that, at least in the eastern Grenville Province, this quiescence might be linked with the development of a passive continental margin, however, such a setting does not explain the felsic magmatism present in the Nipigon area.

The new U-Pb data obtained in this study suggest the presence of an earlier period of magnetically normal, localized alkalic (lamprophyre dikes, Queen et al., 1996) and mafic magmatism (Inspiration sills and the Pigeon River dikes (1141 ± 20 Ma)) between 1150 and 1135 Ma in the MCR in Ontario, including the possibility of localized volcanism and sedimentation in the Pillar Lake area south of Armstrong.

Baddeleyite data from the 4 ultramafic intrusions in the region shows some scatter within individual

intrusions (e.g. from 1113 to 1124 Ma in the Seagull intrusion), which could indicate a protracted (up to 10 m.y.) crystallization history for some of these bodies. In addition, the suite of ultramafic intrusions has a range of ages from circa 1118 to 1107 Ma, however, the aforementioned scatter makes it difficult to ascertain the significance of this range – does it reflect protracted cooling or different emplacement times, or both? A related ultramafic body, the Jackfish Island sill, cuts the English Bay complex and is geochemically similar to the Kitto intrusion, although it appears to be slightly younger in age (1112 ± 3 Ma versus 1118 ± 2 Ma, respectively).

In contrast, baddeleyite ages from 4 different Nipigon diabase sills analyzed so far cluster between 1110 and 1114 Ma. Although geochemically distinct from the Nipigon sills (Hart, 2003), a sample from the Logan sill at Mount McKay in Thunder Bay, is similar in age, at 1115 ± 1 Ma. Thus, most mafic and ultramafic rocks in the Lake Nipigon and Superior areas, including the Nipigon and Logan sills, appear to have been emplaced in a short, magnetically reversed, interval between 1115 and 1100 Ma. Emplacement of alkalic intrusions, such as the Coldwell complex, as well as filling of much of the submerged part of the rift in Lake Superior, also occurred in this period. This was followed by a period of magnetically normal, waning mafic and felsic magmatism, between 1096 and 1085 Ma, that is preserved mainly along the Lake Superior shore by units such as the Crystal Lake (1099 ± 1 Ma), Moss Lake (1095 ± 2 Ma) and Blake Lake (1095 ± 2 Ma) gabbros, and the Arrowhead dike (1093 ± 3 Ma).

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Penokean Fold-and-thrust Deformation of the Paleoproterozoic Gunflint Formation near Thunder Bay, Ontario

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Flat-lying, Paleoproterozoic Gunflint Formation chemical and clastic sedimentary rocks unconformably overlie Archean basement rocks near Thunder Bay. Folds have long been recognized in the Gunflint Formation near Pass Lake, 40 km northeast of Thunder Bay, but no tectonic explanation has previously been demonstrated. The recent recognition of thrust faults in this area appears to link this folding to Penokean compression.

Although Penokean orogenic events (*circa* 1875 to 1835 Ma) and resultant deformation have been well established south and west of Lake Superior, no structures ascribed to Penokean deformation have ever been described north of Lake Superior. Recent geochronologic data show that the Gunflint Formation (*circa* 1878 Ma) predates the earliest Penokean thrusting and thrust-loading caused by the collision of the Pembine-Wausau terrane (*circa* 1860-1850 Ma). This prompted Fralick *et al.* (2002) to contend that the Gunflint formed in a back-arc extensional setting, rather than in a foredeep (foreland basin) and also suggests that Penokean structures should exist in these rocks.

Recent examination of the Gunflint Formation near Pass Lake has led to the recognition of structures typical of fold-and-thrust belt deformation. Discrete bedding-plane faults with locally developed gouge and breccia can be traced laterally into horizontal, hanging-wall ramps with associated fault-bend folding. Fold-and-thrust belt deformation is caused by regional compression. Previous workers had ascribed the folds to syn-sedimentary slumping and Keweenaw diabase sill emplacement and thought that they were attributable to local, rather than regional-scale, deformation.

Displacement in fold-and-thrust belts tends to be localized along discrete bedding planes and not easily recognized. This may account for the perceived lack or absence of structures elsewhere in the Gunflint Formation. Penokean structures on the northern side of Lake Superior represent the northward migration of thrust faults into the foreland (passive margin Archean basement + Gunflint Formation) caused by hinterland collision to the south. Future work will focus on recognizing other deformed locales and quantifying fault displacements based on stratigraphic correlation of sedimentary units.

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The incredible shrinking Penokean orogen: a new look at the accretionary history of the southern Lake Superior region

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The Penokean orogen in the stable continental interior of the upper Great Lakes region records the initiation of rapid late Paleoproterozoic (1.9-1.6 Ga) southward growth of Laurentia. The Penokean orogeny is generally accepted to have been a period of southward subduction from about 1900 to 1850 Ma during which juvenile Paleoproterozoic terranes were accreted to the southern edge of the Superior craton (Archean) and foreland sedimentation and deformation occurred on the craton margin. Historically, juvenile Penokean crust was interpreted to extend southward beneath Paleozoic and Cretaceous strata into southern Iowa, southern Wisconsin, and northern Illinois. However, a growing body of geochronologic data suggests that there may be no rocks older than 1.75 Ga in those areas and that the current Penokean orogen has a much more restricted geographic distribution than heretofore inferred.

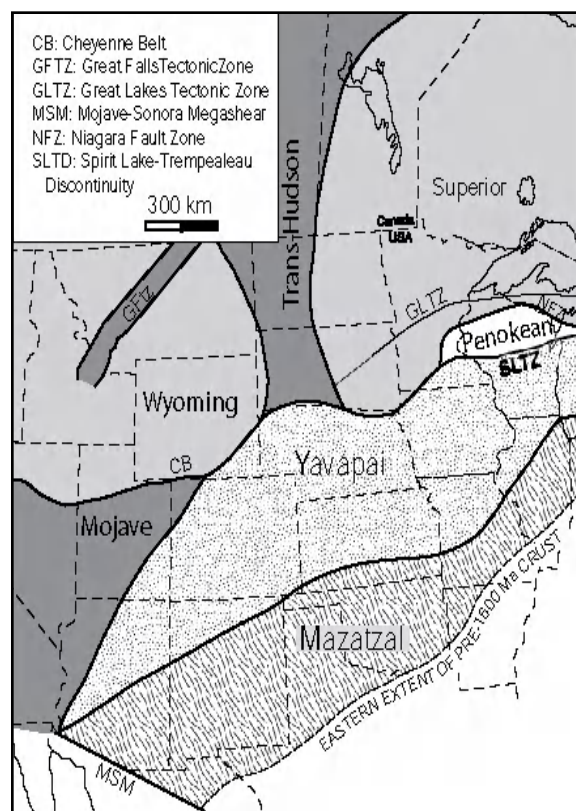


Figure 1. Map showing major Precambrian crustal age provinces and tectonic boundaries in the western and central United States

We have identified a fundamental ENE-trending boundary, the Spirit Lake-Trempealeau discontinuity (SLTD), using a combination of potential field geophysical data and drill hole information (see Figure 1), which marks the southern limit of Archean and known Penokean rocks. South of this boundary rocks at the subcrop are dominated by subaerial potassic rhyolite and epizonal granite, formed at about 1.75 Ga, and ultra-mature quartzite, such as the Baraboo Quartzite, which lies unconformably on them. Gneisses and mafic volcanic rocks, probably basement rocks from which the rhyolites formed by partial melting, are inferred from gravity and magnetic highs to be at subcrop in several areas. Because the SLTD transects geon 18 Penokean structures, it appears to be a post-Penokean feature perhaps marking the northern margin of a Yavapai age accreted terrane. It lies directly above an abrupt offset in Moho depth (deeper to the south) beneath Lake Michigan identified in GLIMPCE deep seismic surveys. The offset was previously interpreted as a north-dipping Penokean subduction zone, but it now seems more likely to be a Yavapai feature. We interpret the SLTD to be a fundamental Yavapai-age Proterozoic boundary, equivalent to the Cheyenne belt paleosubduction zone in southern Wyoming. The Cheyenne belt juxtaposes geon 17 Yavapai orogen crust on the south against the Archean Wyoming craton, and transects geon 18 (Trans-Hudson) structures in southern South Dakota.

The interpretation shown here suggests that the Cheyenne suture extends eastward, joins with the Spirit Lake trend in Iowa, and continues east across the Midcontinent Rift as the Trempealeau discontinuity in Wisconsin. Geon 17 plutonic rocks north of the SLTD, and a north-dipping crustal reflection across it, are consistent with intervals of north-directed subduction during Yavapai accretion. Younger, Mazatzal-age compression deformed quartzites that overlie the Yavapai, Marshfield, and Penokean terrane rocks indicating that geon 16 deformation extended far north of the still imprecisely defined Yavapai-Mazatzal terrane boundary. Barring major strike-slip motion, our revised tectonic map suggests progressive accretion of juvenile arc terranes every 100 million years or so during the late Paleoproterozoic (circa 1.85, 1.75, and 1.65 Ga).

Geologic Implications of Bedrock Mapping in the Ely and Basswood Lake Quadrangles, Northeast Minnesota

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Two regional bedrock geologic compilation maps of northeast Minnesota at scale 1:100,000 have recently been completed by the Minnesota Geological Survey (Figure 1), funded in large part by the STATEMAP program of the U.S. Geological Survey. The most current—described here—covers the Ely and U.S. portion of the Basswood Lake 30' x 60' quadrangles (Jirsa and Miller, 2004). The compilation integrates new mapping, unpublished work contained in 7 theses, and the classic Knife Lake maps of Gruner (1941), into a lithostratigraphically consistent, digital (GIS) format. Much of the map depiction of Paleoproterozoic (Animikie Group) and Mesoproterozoic rocks (Duluth Complex and North Shore Volcanic Group) is not changed substantively from recent works by Miller and others (2001). By contrast, the Archean geology is considerably modified from earlier geologic compilations at 1:250,000 scale (Green, 1982). The area encloses the central part of the Boundary Waters Canoe Area Wilderness (Figure 2), and is the first new publication of mapping of that area in many decades.

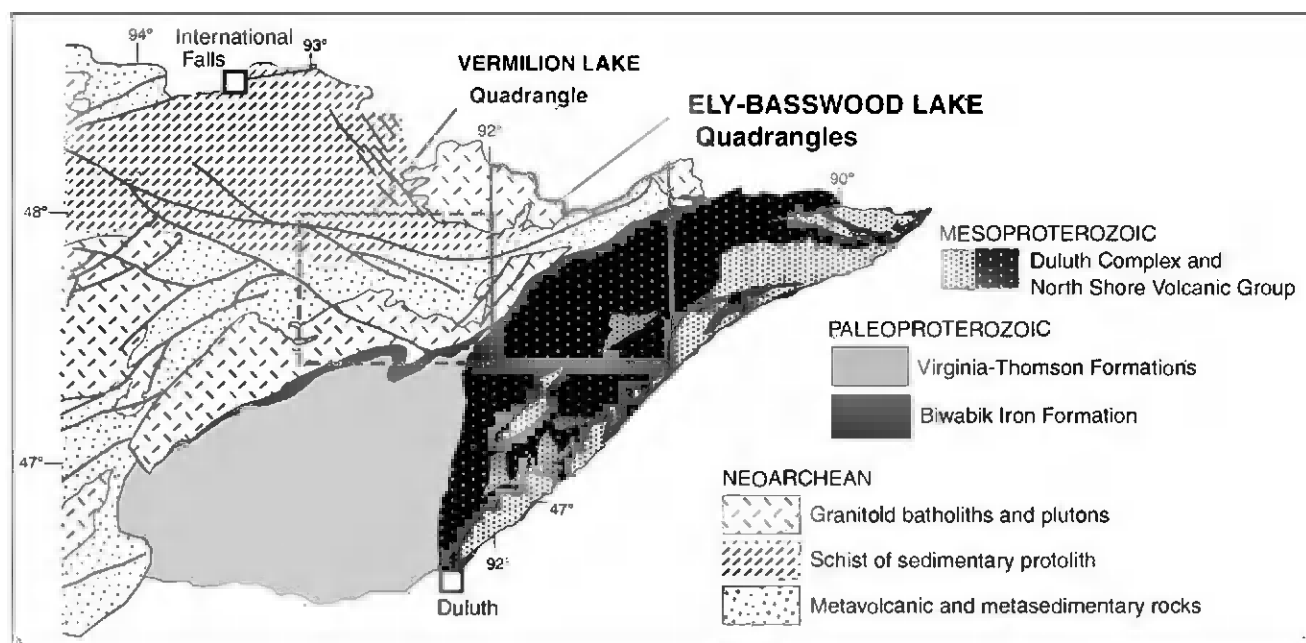


Figure 1. Generalized geologic map of northeastern Minnesota showing the location of recently mapped 30' x 60' quadrangles; Jirsa and Boerboom, 2003, and Jirsa and Miller, 2004.

Exposures provide what is likely the most complete view of Archean geology anywhere in Minnesota. The Neoproterozoic bedrock lies within the Wawa and Quetico subprovinces of the Superior Province (Figure 3). A third, distinctive sequence of rocks—the Knife Lake Group—is interpreted to have been deposited in a complex array of successor basins developed along early-formed faults near the boundary between the two subprovinces. The Knife Lake strata include hornblende-bearing alkaline and calc-alkaline volcanic flows and unusual hornblende-rich tuff, conglomerate derived from multiple sources including the 2,689 Ma Saganaga Tonalite, and feldspathic graywacke and mudstone. Much of the temporal distinction between various geologic elements of the Archean bedrock is based on fabrics that resulted from three major phases of deformation, denoted D_1 , D_2 , and D_3 . All three deformation events are the result of north-south- to northwest-southeast-directed compression. The timing of D_1 deformation is bracketed between deposition of the volcanic and clastic rocks of the Wawa subprovince at about 2,722 Ma (Peterson and others, 2001), and emplacement of the Saganaga Tonalite at about 2,689 Ma (Corfu and Stott, 1998). Folding in volcanic rocks of the Ely Greenstone attributed to D_1 deformation is truncated by Knife Lake strata, indicating that the latter is synchronous with or post-dates deposition and early deformation of the Ely Greenstone. As such, the Knife Lake Group is inferred to be a Timiskaming-type sequence temporally

equivalent to the Shebandowan assemblage exposed in adjacent parts of Ontario (Corfu and Stott, 1998). D_2 deformation affects all of the Archean supracrustal units and is bracketed by U-Pb dates of intrusions in the Giants Range batholith that place the regional deformation and metamorphic event between about 2,674 Ma and 2,685 Ma (Boerboom and Zartman, 1993). D_3 deformation produced faults in the low-grade supracrustal and intrusive rocks of the Wawa subprovince, and folding of granitic and migmatitic rocks in the Quetico subprovince.

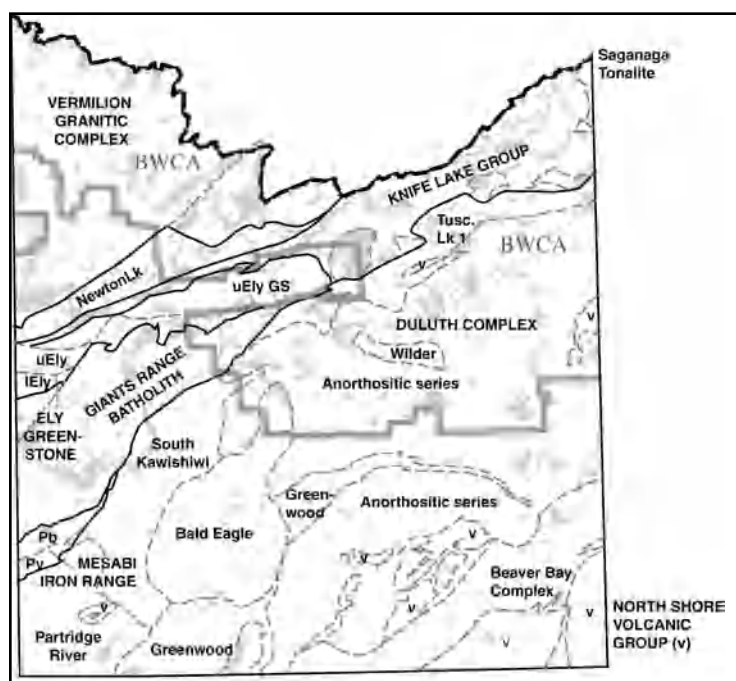


Figure 2. Schematic geologic map of the Ely and Basswood Lake 30' x 60' quadrangles showing major lithologic components, including subdivisions of rock units in the Archean bedrock, Paleoproterozoic rocks of the Mesabi Iron Range, and intrusions of the Mesoproterozoic Duluth Complex.

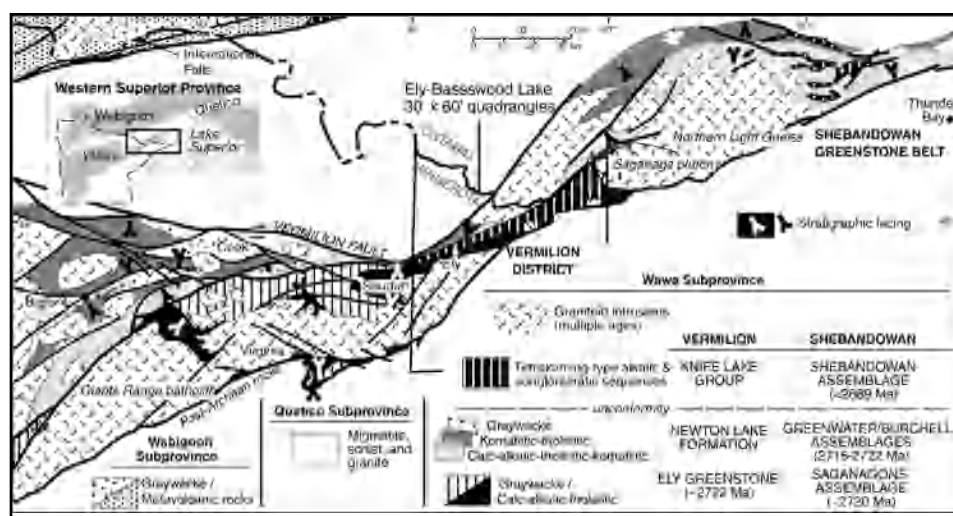


Figure 3. Generalized geologic map showing potential stratigraphic correlation between Archean rocks of the Vermilion district in Minnesota and those of the Shebandowan greenstone belt in Ontario. Shaded areas are lakes.

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Structural State of Plagioclase Phenocrysts in Porphyritic rocks of the Midcontinent Rift, Northeastern Minnesota

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The structural states of plagioclase phenocrysts from porphyritic rocks of the Midcontinent Rift in northeastern Minnesota were analyzed to determine the origin of the plagioclase and to evaluate possible petrogenetic relationships between rock units. As a general rule, higher states of structural disorder in the crystal lattice of plagioclase reflect higher temperatures of equilibration. The units studied include hypabyssal sills of the Beaver Bay Complex (BBC), anorthositic rocks of the Duluth Complex, and porphyritic basalts of the North Shore Volcanic Group (NSVG).

The NSVG is a 7-10 kilometer thick volcanic edifice composed of flood basalts and minor felsic volcanics, intermediate lavas, and interflow sandstones (Green, 1972). The BBC is composed of at least thirteen hypabyssal intrusions, with widely varying compositions, that were emplaced in the medial section of the NSVG (Miller and Chandler, 1997; Miller et al., 2002). The chemistry and texture of plagioclase phenocrysts in some porphyritic NSVG basaltic flows and BBC intrusives suggest they are related to plagioclase-rich magmas (mushes) that are thought to have produced the anorthositic series rocks of the stratigraphically deeper, more plutonic Duluth Complex (Miller and Weiblen, 1990).

Plagioclase phenocrysts were separated for XRD using common magnetic and heavy liquid methods. Patterns were collected in 0.02° step scan mode on a Philips X'pert PW 3040-MPD diffractometer using 2 θ from 18° to 55°, 5 sec/step, and λ = 1.54178 Å. Refined unit-cell parameters were used to approximate plagioclase Al, Si distributions using Kroll and Ribbe's (1980) γ method, and a derivative method using $t_{10} - \langle t_m \rangle$ vs. anorthite content (An). An contents were determined by electron microprobe at the Department of Geology and Geophysics, University of Minnesota-Twin Cities.

The rock types analyzed for this study are: (a) plagioclase porphyritic, ophitic basalts from near Silver Bay and Croftville, (b) plagioclase porphyritic ferrodiorites of the Cabin Creek and the Leveaux Porphyry intrusions (early intrusions of the BBC), (c) porphyritic leucogabbros and gabbroic anorthosites of the Scott Creek and Katydid Lake intrusions that occur near the transition between the BBC and Duluth Complex (both are thought to represent offshoots of the anorthositic series; Boerboom and Miller, 1994); and (d) a porphyritic diabase dike, possibly an offshoot of the main Scott Creek intrusion. The phenocrysts in these rock types are compared with anorthosite xenoliths occurring in the Beaver River diabase (Knudsen et al., 2005) and with anorthositic series rocks of the Duluth Complex (Bandli and Saini-Eidukat, 2000).

XRD results (Figure 1) show the Croftville basalt phenocrysts, along with those of the porphyritic dike, have intermediate to high disorder, plotting near the curve for disordered plagioclase. In contrast, the Silver Bay basalt phenocryst has intermediate to low structure.

The Leveaux Porphyry phenocrysts have intermediate structures and plot near Duluth Complex anorthositic series samples, while the Cabin Creek phenocrysts have distinctly more disordered structures. Plagioclase phenocrysts from the Scott Creek leucogabbro and the Katydid Lake gabbroic anorthosite are intermediate to ordered and plot within the field of Duluth Complex anorthositic series samples. Anorthosite xenoliths in the BBC are intermediate to ordered.

Plagioclase separated from the matrix of selected samples all have lower An contents than the phenocrysts

they host, and show intermediate to high disorder. The relationship of the matrix $t_{10} < t_{1m}$ values to those of the phenocrysts they host reverses in a manner similar to that noted by Hoffer (1968) for the Rock Creek porphyritic basalt flow of Idaho.

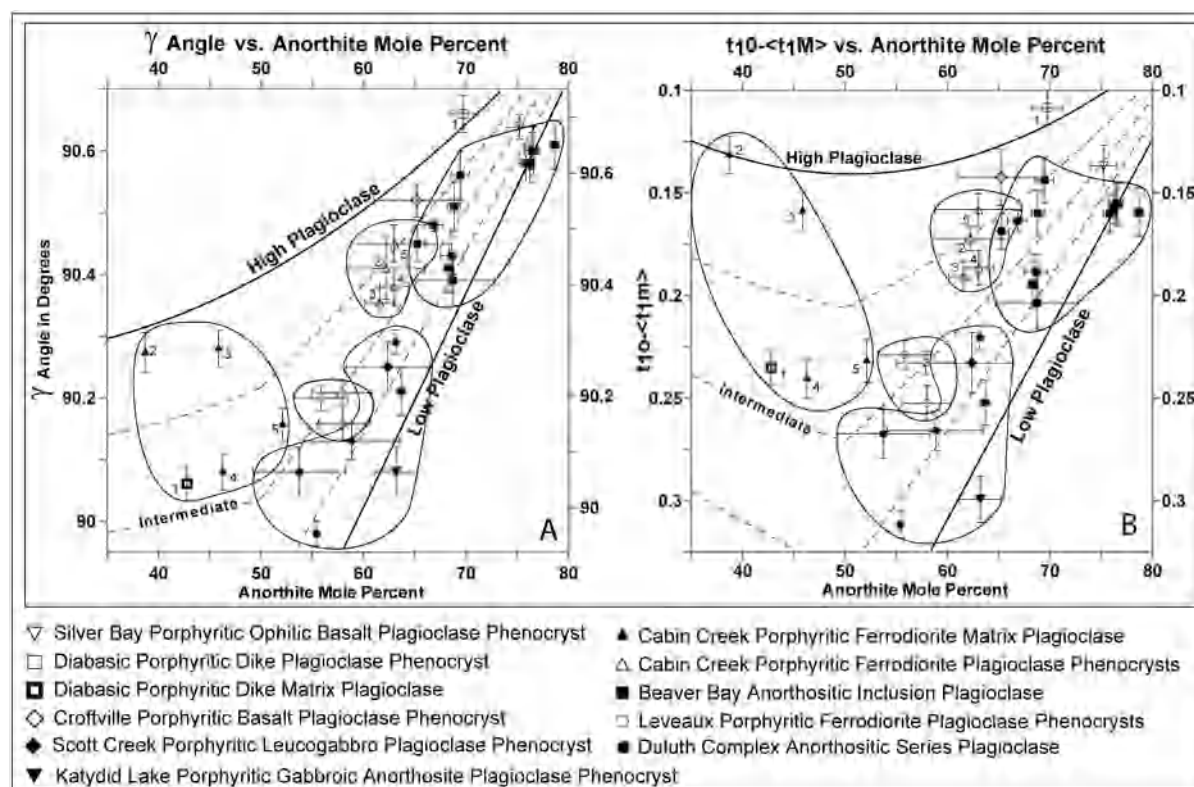


Figure 1. Order distributions of measured plagioclases between the various rock types. A. γ vs. An, after Kroll and Ribbe (1980). B. derivative plot of $t_{10} < t_{1m}$ vs. An.

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Petrogenesis and PGE mineralization of the Eva-Kitto Intrusion, northern Ontario

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The Eva-Kitto Intrusion is a Mesoproterozoic semicircular peridotitic ring complex situated in the Nipigon Embayment on the eastern shore of Lake Nipigon near Beardmore, Ontario. The age of the intrusion is 1117.7 ± 1.8 Ma (L. Heaman, University of Alberta, personal communication, 2005) and has been interpreted to be emplaced as the feeder conduit to a more evolved cone sheet during initial asthenospheric upwelling of a mantle plume in the Midcontinent rift system (MCR) (Sutcliffe, 1986). The intrusion cross-cuts both the Archean Southern Sedimentary Belt (SSB) and the Southern Volcanic Belts (SVB) of the Beardmore-Geraldton Greenstone belt, dated at circa 2696-2691 Ma, of the Wabigoon Subprovince (Lafrance et al., 2004). Within the SVB are sulphidized magnetite-chert iron formations that run parallel to the strike of the main structural trends of the greenstone belt and are intercalated with mafic volcanic units. In drill core, the intrusion cross-cuts calcareous sandstones and mudstones interpreted to be the Sibley metasediments and is cross-cut by Nipigon gabbro sills which are also found to crop out as horizontal circular ridges around the intrusion. The Eva-Kitto peridotite has high TiO_2 , K_2O and P_2O_5 and is LREE-enriched similar to the chemistry of the Fe-Ti Osler Volcanics of the MCR (Hart et al., 2002). The sills, on the other hand, have lower TiO_2 , K_2O and P_2O_5 than the ferropicritic peridotites, and are similar in chemistry to the olivine tholeiitic flood basalts of the MCR. Therefore the Nipigon sills originated from a more fractionated underplated basaltic magma later in the Keewawan event circa 1109 Ma (Sutcliffe, 1987).

The petrography and geochemistry of the lithologies within the Eva-Kitto Intrusion are being studied

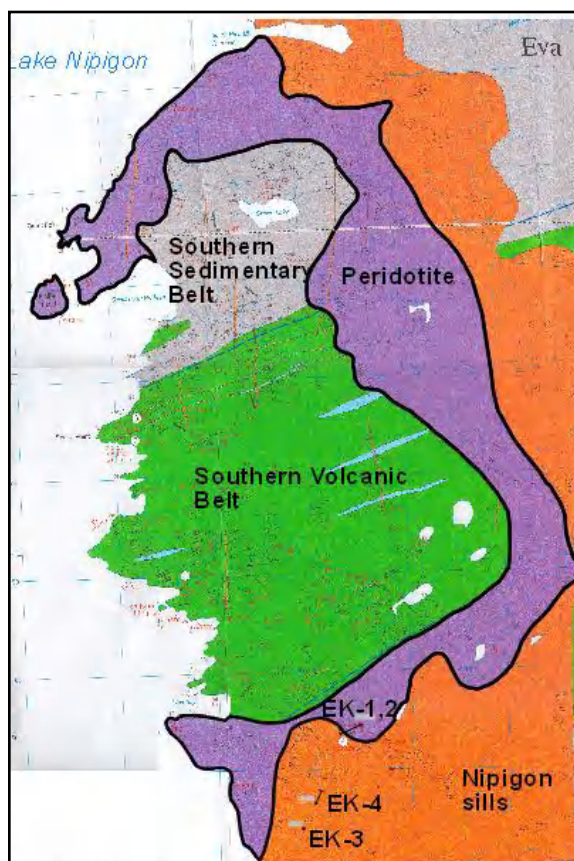


Figure 1. Geological map of the Eva Kitto Ring Complex. The four EK drill holes are located at the southern end of the peridotitic intrusion

from drill core held by East West Resources Inc. Four holes were drilled by Kennecott Canada Exploration Inc. in 2002 based on airborne MegaTEM anomalies surveyed by Fugro Airborne Surveys that same year. Hole EK-2 intersected disseminated po-cpy mineralization and was the only hole to intersect magnetiferous pyritic metasediments of the Archean basement. Assays values up to 0.28%Ni, 0.13%Cu, and 563ppb Pt+Pd in a 1.22m interval have been reported (Rossell, 2003). Lithologies within EK-2 from the top to the end of hole at 345m at depth comprise lherzolite, olivine websterite, sulphidized olivine websterite, vari-textured pyroxenite, spotted pyroxenite, pyroxenite, melanogabbro, magnetiferous pyritic metasediment, and mafic volcanics. EK-2 is the only hole to intersect the more fractionated vari-textured pyroxenite to orthocumulate pyroxenite lithologies that contain PGE mineralization.

Based on preliminary interpretation of the petrography the petrogenesis of the Eva-Kitto Intrusion can be characterized by two magmatic pulses. A first pulse of magma is suggested by the pyroxenite and melanogabbro units of EK-2. The pyroxenite has an orthocumulate texture with cumulate pyroxenes enclosed in a groundmass of lathy plagioclase. The melanogabbro has a poikilitic texture with cumulate pyroxene crystals housed in plagioclase oikocrysts. A second pulse of magma is suggested by the incipient break up of cumulate

pyroxene and growth of clusters of secondary pyroxene in the vari-textured and spotted pyroxenites. The patchy texture within these units can be attributed to the churning up of the pyroxenite by a second influx of magma. Lherzolite is the dominant lithology in all the drill holes and may represent the primary cumulate fractionation of an enriched ferropicritic magma (Sutcliffe, 1986). Lherzolite displays a mesocumulate texture of ovoidal cumulate olivine grains and larger cumulate clinopyroxene within poikilitic orthopyroxene and plagioclase. The olivine websterite is darker due to fractionation of pockety pyroxenes with breakdown of olivine. The olivine websterite possibly formed by flow differentiation of a more fractionated magma from the central lherzolite flow zone. Both the lherzolite and olivine websterite contain large amounts of primary biotite minerals.

PGE minerals are associated with disseminated sulphides in the sulphidized olivine websterite, vari-textured pyroxenite, pyroxenite and melanogabbro units of drill hole EK-2. Within the olivine websterite and pyroxenite, disseminated pyrrhotite-pentlandite-chalcopyrite sulphides are found interstitial to cumulate olivine and pyroxene minerals. Blebby pyrrhotite-chalcopyrite sulphides, possibly a result of liquid immiscibility, are locally found in the sulphidized olivine websterite/melanogabbro units at the contact with the wallrock metasediments.

Ongoing studies are focusing on petrogenesis and mineralization of the intrusion. Scanning electron microscope (SEM) discs made from drill core in Holes EK-1, 3 and 4 are being analysed under the petrographic microscope to compare lithologies in these holes with the fractionated suite of EK-2. The interstitial sulphides will be examined by SEM to identify the PGE minerals. Mineral chemistries within the various lithologies will also be identified using SEM. Bulk rock chemistries, S/Se elemental ratios, trace elements, ϵ_{Nd} and Sr patterns, and Ni abundances of olivine will be analysed to further understand the petrogenesis of source magmas, and crustal contamination involved with mineralization.

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Geochemistry and Petrography of the Rabbit Islands Breccia, North Central Lake Nipigon

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The Rabbit Islands breccia is a dyke-like intrusion, rich in calcite and dolomite, which intrudes the Nipigon diabase on the southern most island of the Rabbit Islands group in north central Lake Nipigon (Figure 1). Geological relationships indicate that the breccia must represent one of the youngest events associated with the Midcontinent rift. In the past this breccia has been referred to as a carbonatite diatreme (Sutcliffe and Greenwood, 1982), and one of the objectives of this study was to evaluate this model and to compare the breccia to the carbonatites of the Coldwell complex. Whole-rock geochemistry, petrography and scanning electron microscope (SEM) data, indicate that the groundmass material of this breccia is not of carbonatite affinity. The low abundance of trace elements such as Sr, Mn and Ba in SEM semi-quantitative scans of the carbonates and feldspars combined with the low abundances of Sr, Ba, V, and rare earth elements (REE's) determined by XRF and ICP-MS, do not satisfy the requirements of Samoilov (1991). Samoilov suggested that in order to be considered a carbonatite the following criteria must be met: enrichment in Sr (>700 ppm), Ba (>250 ppm), V (>20 ppm) and REE (including Y; >500 ppm). The samples analyzed from the Rabbit Islands breccia groundmass contained 191 ppm Sr, 286 ppm V, 115 ppm total REE's and low amounts of barium. Consequently, the breccia does not meet the limits set by Samoilov (1991) and therefore is not considered to be of carbonatitic affinity, but rather a carbonate-rich breccia.

The geochemistry of the clasts and the country rock associated with the breccia has been compared with the different suites of Nipigon diabase: the Inspiration suite, the Jackfish suite, the McIntyre suite and the Main Nipigon suite (MacDonald and Tremblay, 2004; Richardson and Hollings, 2004), showing that the breccia intruded into the Main Nipigon suite (Figure 2). Clasts of diabase found within the breccia have undergone extensive alteration. Many of the clasts display consecutive zones of alteration which can be seen in both hand sample and thin section. Elements which have become mobile within the altered clasts, and show variation between each alteration zone include: potassium, calcium, magnesium, strontium, europium, yttrium, lanthanum, and neodymium. Depletion of calcium, strontium, europium, yttrium, lanthanum and neodymium can be seen from the centre of the clast outwards. Whereas, potassium, magnesium and loss on ignition (due to the presence of chlorite) increase from the centre of the clast outwards.

Evidence for changes in fluid composition has been observed within the groundmass material. For example, in many instances calcite has been shown to brecciate and replace dolomite crystals present in the breccia, however, quartz and feldspar brecciate and replace the dolomite. Other textures, such as calcite replacing feldspar emphasize the fact that there is an overlap of fluid phases, which may be controlled by fluid source or contamination by the

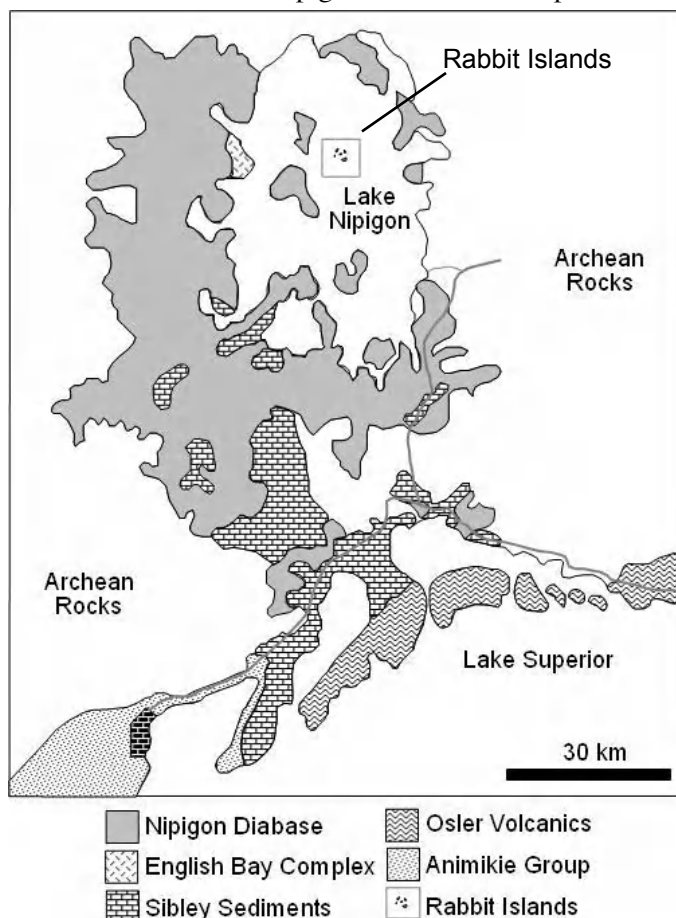


Figure 1. Location of the Rabbit Islands (Modified from Hollings et al. 2004).

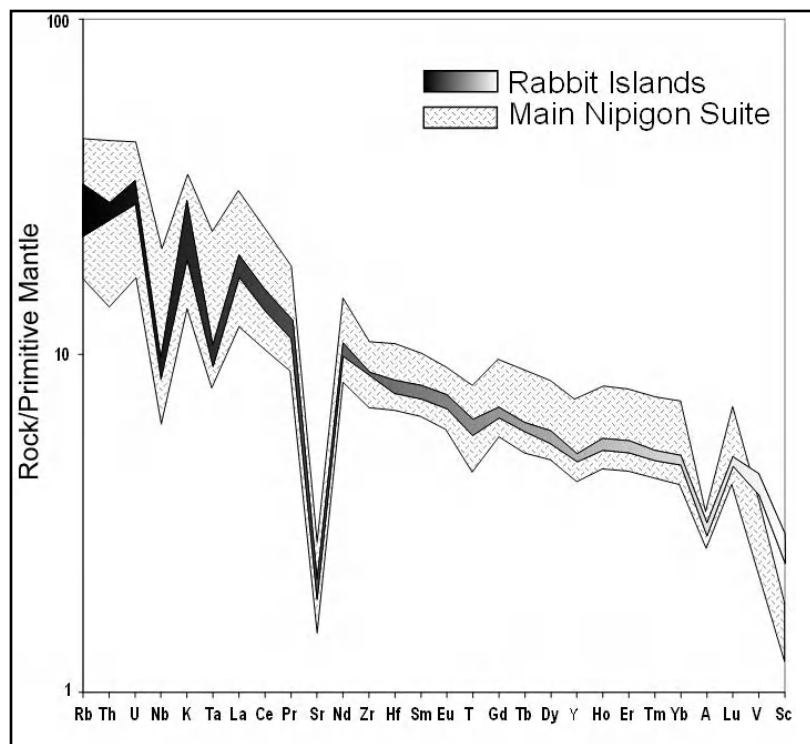


Figure 2. Primitive mantle multi-element plot to show the similarities between the Rabbit Islands Diabase and the Main Nipigon suite.

country rock.

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

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The Big Lake Property of MetalCORP Ltd. of Thunder Bay, Ontario comprises 33 claims (365 units totaling 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 survey, detailed prospecting (677 samples), linecutting, ground pulse-EM surveys, and 2 phases of diamond drilling, totaling 22 diamond holes (5672 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 Zone within strongly altered mafic 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 Cu-Pb-Mo-Ag Prospect which has yet to be 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 Alkaline 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 to ultramafic Gus Creek Intrusion, the Bell's Lake Ultramafic Intrusion, and the Big Lake Ultramafic Complex.

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 sill-like Big Lake Ultramafic Complex. The complex is not layered. The two host intrusive cycles dip approximately 43° north and are very similar in their appearance, progression of rock units, and apparent thickness. The observed mineralization consists of low amounts (trace to ~1%) of very finely disseminated pyrrhotite and chalcopyrite within serpentinitized to locally talcose, fine-grained peridotite. The J4 Reef varies between 0.58 and 2.11 m in thickness, occurs within the basal peridotite unit of the uppermost intrusive cycle of the Big Lake Complex and is usually directly adjacent to the contact with an overlying feldspathic 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 intrusive cycle of the complex near, but not adjacent to, the upper contact of the host unit with an overlying feldspathic pyroxenite. The J4 Reef has been traced for 1.60 km and contains up to 0.70 gpt Pt and 0.79 gpt Pd (1.49 gpt PGE)/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.

The A2 Ni-Cu Zone occurs near the base of the discordant Gus Creek Mafic Intrusion and consists of disseminated, blebby, and stringered, locally semi-massive pyrrhotite, chalcopyrite, and possibly pentlandite hosted within a 2 to 20 m thick host sequence. The host sequence 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-phyrlic melagabbro and feldspathic pyroxenite. The strongest mineralization occurs near the base of the host sequence, 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 between 125 and 150° and dip southwest at between 40 and 60°.

The BL14 Cu-Zn-Ag Zone is located near the east end and stratigraphically below the sill-like Big Lake Ultramafic Complex, approximately 800 metres south of the A2 zone. The zone closely resembles high temperature Cu-rich VMS stringer mineralization and is composed of an intensely biotitized and strongly chloritized 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. The mineralized zone occurs within a strongly to intensely K- and Mg altered, Na₂O-depleted package of mafic metavolcanic rocks, minor associated interflow clastic metasedimentary rocks, and deformed bands of chert. Mineralization intersected to date includes 2.56% Cu, 1.00% Zn, 46.0 gpt Ag, 1.60 gpt Au, and 0.10% Pb/0.93 m; 0.80% Cu, 0.50% Zn, and 21.3 gpt Ag/2.62 m; and 0.74% Cu, 0.23% Zn, and 9.0 gpt Ag/0.75 m.

Mining and Exploration Activity in Northwestern Ontario

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Northwestern Ontario experienced a significant upswing in mining and mineral exploration in 2004. Six mines produced a total of 1.7 million ounces of gold in 2004, approximately 70% of the Ontario 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.);

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

North American Palladium Ltd. produced 308,931 ounces of palladium and 25,128 ounces of platinum at its Lac des Iles Mine and has begun the development of an underground operation below its open pit mine.

There are approximately 300 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-1980s.

Preliminary stratigraphy and geochemistry of the Mesoproterozoic Pillar Lake Volcanics, Wabigoon Subprovince, Superior Province, Armstrong, Ontario, Canada

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The Mesoproterozoic Pillar Lake Volcanics (PLV); an approximately 50 m thick series of flat-lying, greenschist facies undeformed massive and pillowed basalt flows; are located 15 km southeast of Armstrong, Ontario. The Pillar Lake Area was originally mapped as part of a geological compilation series with the dominant lithology in the area comprising Nipigon diabase sills formed during the Keweenawan mid-continent rift system of North America (Breaks, 1980; Davies et al., 1970). Mapping completed at a scale of 1: 50,000 by MacDonald et al. in 2003 resulted in the discovery of previously unmapped lithologies which include the Pillar Lake Volcanics (MacDonald, 2004).

The PLV are part of a suite of Mesoproterozoic rocks that unconformably overlie the Archean basement of the central Wabigoon Subprovince, Superior Province. The PLV have not yet been successfully dated by geochronological methods. Magnetic remanence studies of the PLV places them at 1140 Ma but there is a significant error associated with this date (C. Hercun, pers. comm., 2005). Fifty detrital zircons from an interflow lithic arenite bounded at its base and top by PLV were dated and the youngest detrital zircon was dated at 1514 Ma (Heaman et al., 2005). The dominant populations of zircons from the interflow lithic arenite fall within 1780 to 1880 Ma and 1900 to 1950 Ma (Heaman et al., 2005). The PLV unconformably overlie a 1599 ± 1 Ma layered gabbroic intrusion but no contact has yet been found except in drill core (Heaman et al., 2005; Middleton, 2005). A nearby 1590 ± 1 Ma syenite may also underlie the PLV (Heaman et al., 2005). The PLV are overlain by Inspiration diabase sills dated at 1120 ± 1 Ma (Heaman et al., 2005). The Inspiration diabase sills are geochemically distinct from the Nipigon sills and hence have been given a new designation. The Inspiration diabase sills extend the timing of North American mid-continent rift-related intrusive activity. Based on these age dates, the PLV are Mesoproterozoic in age, and were erupted between 1514 Ma and 1120 Ma.

The PLV have been metamorphosed to greenschist facies and are extensively chloritized with accessory epidote and sericite. The PLV are hematite and actinolite altered with intense alteration found at the top of each flow. The individual massive basalt flows are approximately 0.2 – 1 m thick and each flow is capped with a 5 cm thick flow top breccia with actinolite rims and hematite cores forming the breccia fragments (Figure 1). The pillowed basalt flows tend to be pervasively altered and exhibit autobrecciation throughout the flow layer, perhaps due to higher permeability. Near the base of the volcanic pile, the pillowed basalt flows are rarely unaltered, unbrecciated and preserve primary volcanic features such as pillow selvages, interpillow hyaloclastite, and degassing structures (Figure 2).

Associated with the massive and pillowed basalt flows are numerous breccias including an undeformed volcanoclastic breccia that contains fragments of gabbro, amygdaloidal basalt with clay minerals infilling the amygdules, and possibly

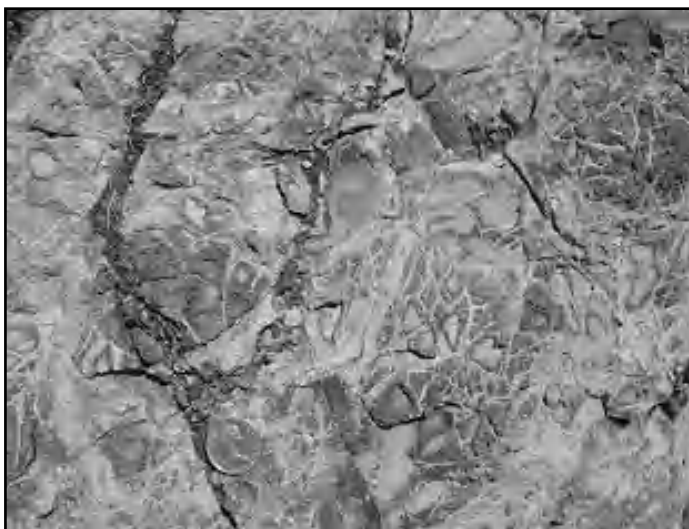


Figure 1. Flow top breccia capping massive basalt flow with actinolite rims and recessively weathered hematite cores

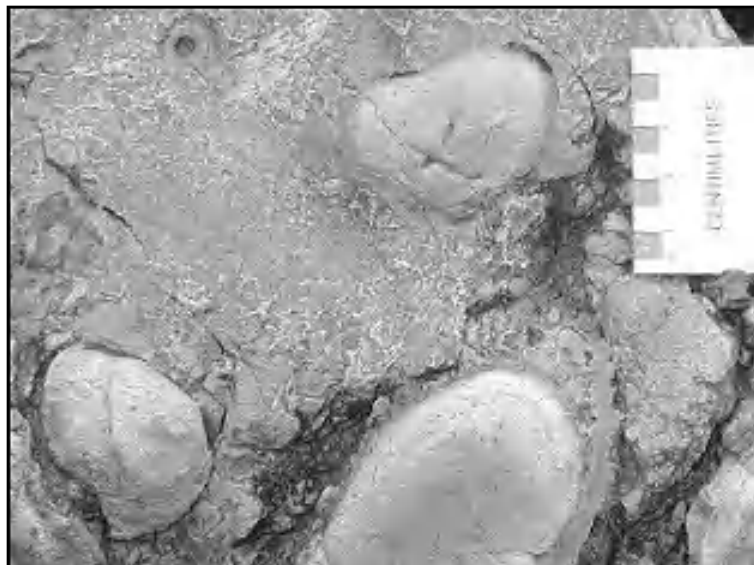


Figure 2. Undeformed chlorite-altered pillowed basalt with preserved selvages and interpillow hyaloclastite.

granitoid. Field relationships between the PLV and the breccias are not always discernible due to poor outcrop control, but in several instances the breccias occur as dikes found within the PLV.

Based on preliminary geochemistry, the PLV may be the result of a mantle plume and possibly predate the main North American mid-continent rift event. It is hoped that detailed mapping of the PLV in conjunction with additional geochemical analyses will determine the source and cause of the volcanism that resulted in this suite of volcanic rocks.

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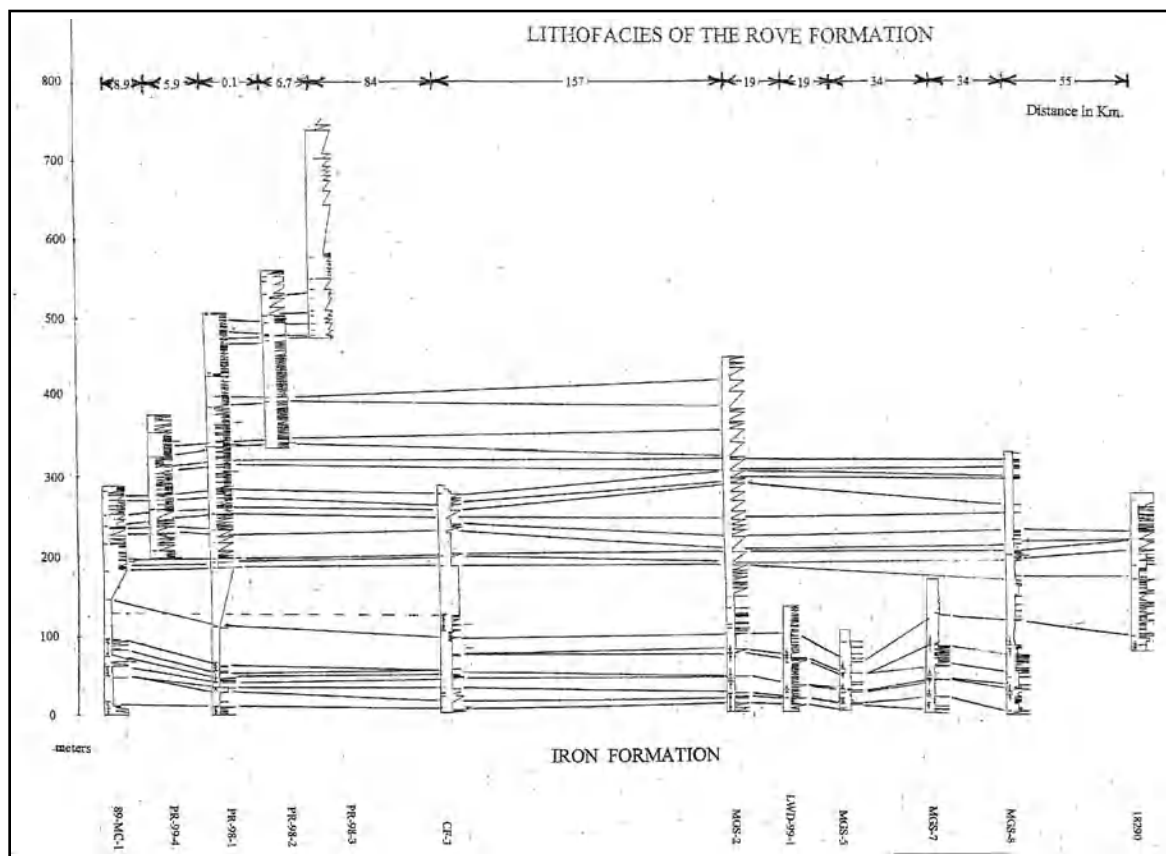
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Sedimentology of the Rove and Virginia Formations and their Tectonic Significance

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The Paleoproterozoic Rove and Virginia Formations form the upper portion of strata in the Animikie Basin. They are lithostratigraphically and chronostratigraphically correlative units overlying iron formation of the Biwabik and Gunflint Formations. Tuffaceous layers very near the base of the Rove and Virginia Formations gave U-Pb zircon ages of approximately 1835 Ma (Addison et al., 2005), whereas a sandstone sample collected by R.M. Easton (O.G.S.), approximately 400 m higher in the stratigraphy, had a U-Pb minimum detrital zircon age of 1780 Ma (*see* Heaman and Easton, this volume). These age constraints place sedimentation commencing during the final stages of Penokean igneous activity and stretching over an extended time span. The Rove and Virginia Formations would have been in the appropriate spatial and temporal setting to represent deposition in a foredeep transitional into a foreland basin. This study investigates the internal stratigraphy and sedimentology within the Rove and Virginia to ascertain what the lithofacies present and their stacking order can reveal about the dynamics of the tectonic setting. The data set consists of detailed logging of twelve continuously cored drill holes extending from south of Duluth to south of Thunder Bay. In total 3200 meters of core were examined. This approach is similar to that of Lucente and Morey (1983), though with advances in depositional models and process sedimentology, since their classic work, more information may be able to be extracted.

The Rove and Virginia Formations overlie an intensely altered zone in the upper Gunflint and Biwabik Formations. Silicification, formation of neomorphic carbonate spar, pyrite growth in strataform bands and pisoliths all occur in the upper few meters of these underlying units. This is sharply overlain by the basal Rove and Virginia consisting of black, carbonaceous shale with thin interbeds of siltstone and very fine-grained sandstone. Green, friable tuffaceous layers are common in this assemblage, especially in the northern drillholes.



Approximately five meters above the base the amount of siltstone and sandstone interlayers gradually begins to decrease upward until they are relatively scarce. The next approximately one hundred to one hundred and fifty meters is almost completely dominated by fissile black shale. Microscopic examination reveals the presence of very thin laminae composed of angular silt grains and other microlayers consisting of carbon. The shale dominated succession is interrupted midway towards its top by a siltstone and very fine-grained sandstone-rich interval traceable across the basin. This coarser unit is thicker near both the northern and southern basin margins. As well, the black shale dominated interval, in general, contains more coarse-grained interbeds in the southern one third of the basin. A gradational contact exists at the top of the shale assemblage with the overlying sandstone-shale unit. The gradation occurs over eighty meters in the north but thins to the south. The overlying sandstone-shale succession is up to 350 meters thick and consists of a stacked assemblage of over one hundred individually coarsening-upwards parasequences. Internally they consist of graded, commonly massive, fine-grained sandstones separated by mm's to cm's of shale. The shales between parasequences are decimeters to one or two meters thick. This sandstone-shale assemblage fines appreciably to the south. The uppermost unit overlying the graded sandstone packages at approximately 500 meters above the base of the section is dominated by black shale with thin rippled sandstones. Both current and wave ripples are present.

The upper Gunflint represents a subareally weathered surface exposed during upbuckling concurrent with the Penokean Orogeny. This is highlighted by the 1878 Ma age of the Upper Gunflint (immediately pre-Penokean, Fralick et al., 2002) and the 1835 Ma age of the Rove (Addison et al., 2005) immediately overlying the weathered surface. Upamped orogenic load probably resulted in resubmergence of the area and a slightly coarser unit was deposited forming the basal Rove and Virginia as the flooding surface migrated across the basin. Eruptions at this time in the core of the Penokean deformed terrain may have supplied the volcanic ash. With increased water depth a sediment starved, condensed sequence developed with anoxia probably caused by high organic loading in the bottom sediments. A slight coarsening of detritus in the southern area probably reflects a source in the Penokean deformation belt, but the general scarcity of sediment influx from this area strongly implies only minor upraising of an orogenic zone during the Penokean. The condensed sequence is further condensed by the lack of biogenic sediments other than carbon resulting in tens of millions of years being represented by only a hundred meters of black shale. Progradation of a turbiditic to shelf system from the north ends the sediment starvation with a flood of detritus from this direction. Detrital zircon geochronology and paleocurrent directions (Morey, 1973) are consistent with derivation of the sediment influx from the TransHudson Orogenic zone to the northwest.

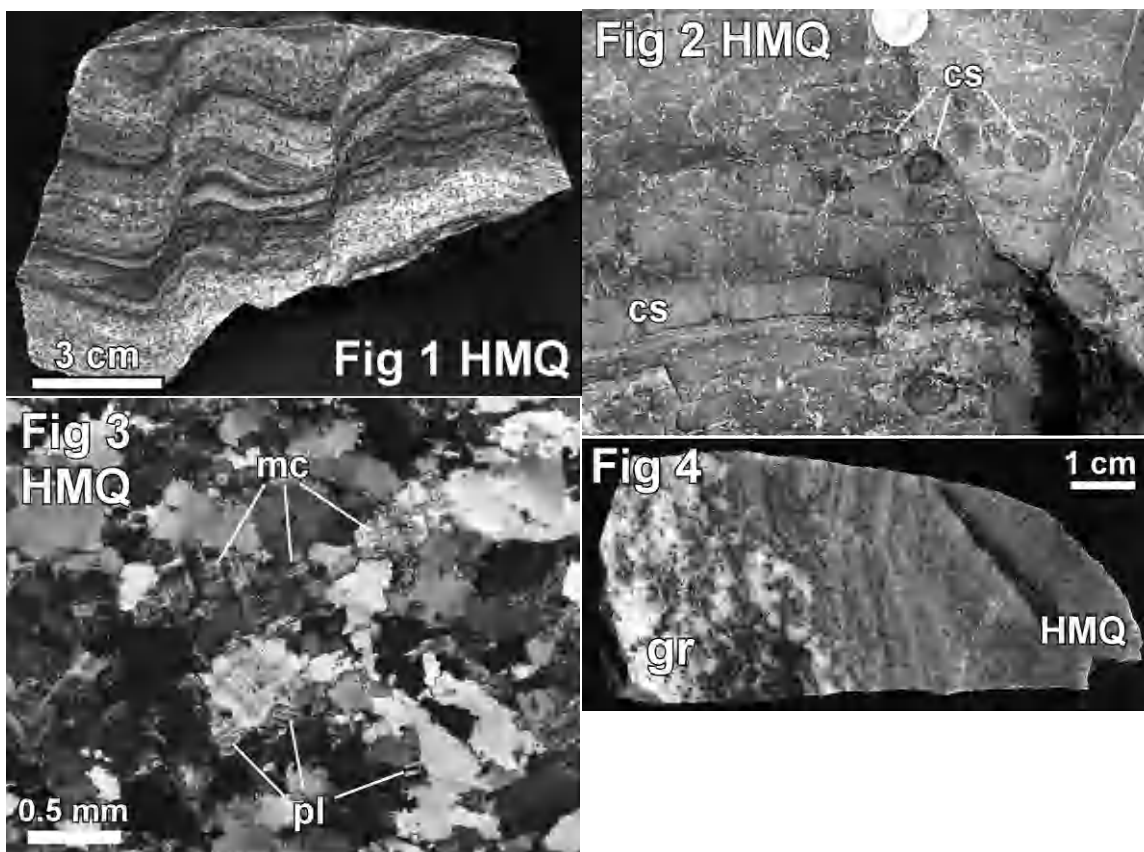
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Riddle of the Sands (Proterozoic) solved by Quartzites at Hamilton Mounds, Central Wisconsin

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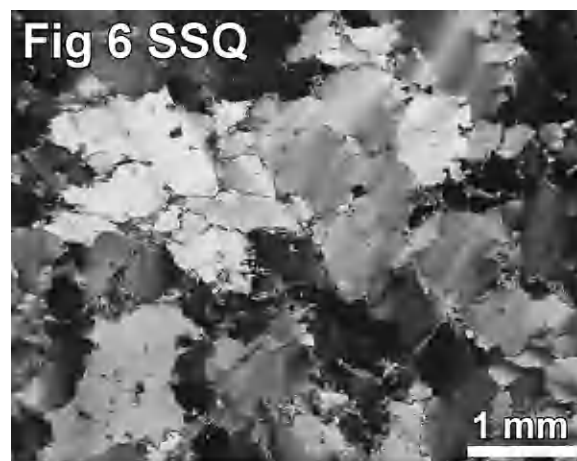
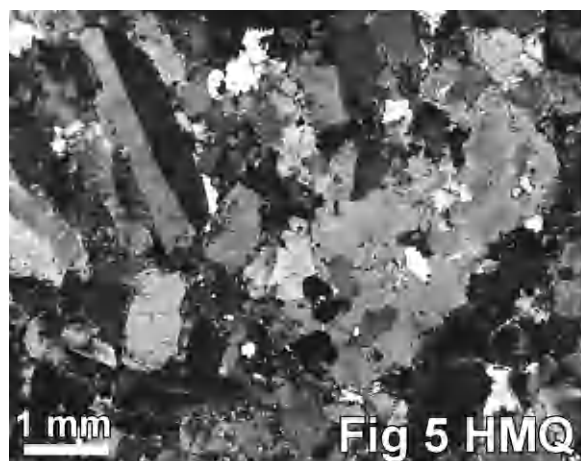
Quartzite inliers in central Wisconsin have long been enigmatic with regard to the Proterozoic evolution of the southern Lake Superior region. At Hamilton Mounds the intrusion of quartzite by 1.76 Ga granite has led some to suggest that Baraboo Interval sedimentation (1.75-1.63 Ga) was spatially and temporally associated with Geon 17 magmatism. Re-examination of the Hamilton Mounds area reveals the presence of two different quartzites, an older one intruded by granite, which we designate the Hamilton Mounds Quartzite (HMQ), and a younger one resembling the Baraboo Quartzite, which we call the Seven Sisters Quartzite (SSQ), from the present name of the quarry.



Quarrying operations have largely removed the HMQ and intrusive granite, although numerous displaced blocks remain for examination. The HMQ consists of gray, laminated quartzite (Fig. 1), which commonly contains calc-silicate (qtz+ep±am) layers and ellipsoidal domains, perhaps former concretions (Fig. 2; cs, calcsilicate). The HMQ is a metamorphosed immature wacke or arenite, which contains biotite, muscovite, and substantial amounts of microcline (mc) and plagioclase (pl) (Fig. 3). The HMQ is intruded by granite (gr) (Fig. 4), which yields a U-Pb zircon age of 1763 ± 7 Ma (Van Schmus, cited in LaBerge *et al.*, 1991). Contact metamorphic effects of the granite on the HMQ include metasomatic growth of alkali feldspar, but the coarse-grained, poikiloblastic texture of such feldspar (Fig. 5) allows easy distinction between it and fine-grained, recrystallized detrital feldspar (Fig. 3).

The SSQ, which crops out in the hills surrounding the quarry, consists of pink, massive to cross-bedded supermature quartzite (Fig. 6), resembling Baraboo Interval quartzites elsewhere, except for a greater degree of recrystallization and the presence of muscovite, rather than pyrophyllite. Such features and extensive brecciation probably reflect the influence of the nearby Wolf River batholith, with which are associated wide-spread Geon

14 hydrothermal alteration and K-metasomatism as documented in the Baraboo and Sioux quartzites (Medaris *et al.*, 2003).



Geon 17 detrital zircons have recently been recognized in a single sample of the “Hamilton Mounds Quartzite” by Van Wyck and Norman (2004). However, the analyzed sample, described as supermature quartzite, was collected several hundred yards from granite and is likely to be from the SSQ, which we correlate with other supermature quartzites of the Baraboo Interval. Thus, it is not surprising that this sample should contain Geon 17 detrital zircons and display a spectrum of detrital zircon ages similar to that from the Baraboo Quartzite.

Although the contact between the HMQ and SSQ is not exposed, we interpret the HMQ and intrusive granite to represent basement upon which the SSQ was deposited unconformably. Thus, like the Baraboo Quartzite, the SSQ appears to be younger than, and rests upon, Geon 17 basement. The results of this investigation are consistent with our view of the Baraboo Interval (1.75-1.63 Ga) as representing an episode of extensive weathering and widespread deposition of supermature quartz arenite on a stabilized craton in the interval following cessation of Geon 17 magmatism and prior to Geon 16 Mazatzal deformation (Medaris *et al.*, 2003).

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Depositional setting of the Pass Lake and Rossport Formations (Sibley Group) inferred from a combined sedimentologic/geochemical approach

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The depositional setting of the lower portions of the Mesoproterozoic Sibley Group have been investigated through detailed lithofacies analysis, stable isotope and trace element geochemistry. The portion of the Sibley Group studied is comprised of a lower clastic assemblage, middle mixed carbonate-clastic assemblage and an upper clastic dominated, evaporite rich assemblage. The thickness of each unit varies but is in general about 20-80m. The lower clastic section was deposited in a variety of depositional environments including: poorly developed, coarse-grained alluvial fans; braided, sand rich fluvial systems; fluvial/wave dominated deltaic settings; and nearshore/beach environments. The middle mixed carbonate clastic succession represents lacustrine or shallow marine deposition in a semi-arid environment. The upper red siltstone, evaporite-rich section has been interpreted to represent a saline mudflat environment or sabhka-like setting. Numerous chemical sediment types are preserved within the three distinct successions. Calcrete soils are developed in coarse-grained alluvial fan conglomerates in the lower clastic dominated package as well as higher in the stratigraphy within the upper package. Dolomitic mudstones are found in a cyclic dolomite-siltstone lithofacies association of the middle assemblage. Stromatolitic carbonates are preserved in the transition from the middle to upper succession along with evidence of subaerial exposure of this strand-proximal lithofacies. Sulfate minerals occur as fine nodules within dolomites of the middle mixed carbonate-clastic assemblage and as coarser nodules in the upper evaporitic succession.

Carbon and oxygen stable isotopic compositions, Sr isotopic compositions and trace element compositions were determined for various chemical sediment types to study facies (process) dependent and stratigraphic variations in isotopic compositions and to evaluate the degree of post depositional diagenetic alteration. Stable isotopic compositions for dolomitic mudstones range from -3‰ (PDB) to about $+1\text{‰}$ (PDB) for $\delta^{13}\text{C}$ and span $\delta^{18}\text{O}$ compositions from -4 to -8‰ (PDB). Stromatolitic carbonates have $\delta^{13}\text{C}$ from 0 to 2‰ and $\delta^{18}\text{O}$ from -3 to -14‰ (PDB). Soil related carbonates vary over $\delta^{13}\text{C}$ compositions from -1.5 to 1.5‰ (PDB) and $\delta^{18}\text{O}$ varies from -2 to -6‰ (PDB). Sampling through a stratigraphic thickness of about 45m of the middle carbonate clastic succession shows a good correlation between increasing stratigraphic height and heavier stable isotopic composition (Figure 1). Petrographic analysis and trace element geochemistry suggests little diagenetic effect on stable isotopic compositions.

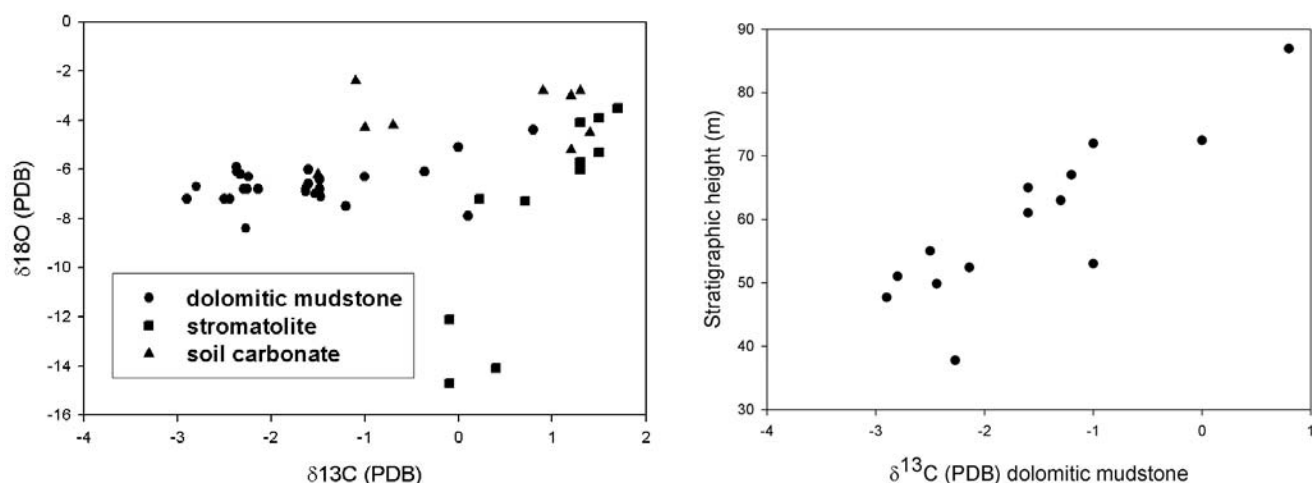


Figure 1. Stable isotopic compositions of various Sibley Group carbonates (left), and stratigraphic variation in $\delta^{13}\text{C}$ for the middle dolomite/siltstone lithofacies association (right)

Sr isotopic compositions were also determined for a variety of carbonate and sulfate samples. Dolomitic mudstones (n=4) display $^{87}\text{Sr}/^{86}\text{Sr}$ ratios varying from 0.70846 to 0.71249 ± 1 . Soil carbonates appear to have variable compositions from a calcrete low in the stratigraphy at 0.70478 ± 1 (n=1) to weathered stromatolitic material higher in the stratigraphy at a value of 0.70737 ± 1 (n=1). One unaltered stromatolite sample has a value of 0.71234 ± 1 . Sulfates (n=8) from the upper evaporitic package vary through a fairly narrow range of compositions between 0.70647 ± 3 to 0.708836 ± 1 . A single sample of sulfate from the middle succession in a dolomitic layer yielded a fairly high value of 0.71090 ± 1 . Further analyses have been undertaken to strengthen the validity of the apparent facies related variation.

Rare earth element geochemistry of carbonate samples was also undertaken using an acetic acid dissolution method to avoid clastic contamination of primary carbonate geochemical signatures. Figure 2 shows Post Archean Australian Shale normalized REE diagram for Sibley Group carbonates. Stromatolites and soil carbonates generally show a distinct negative Ce anomaly, and overall relatively flat slope with a slightly negative HREE slope. Dolomitic mudstones exhibit an enrichment in MREE, with little or no negative Ce anomaly. Positive Gd anomalies are present in most samples of all carbonate types.

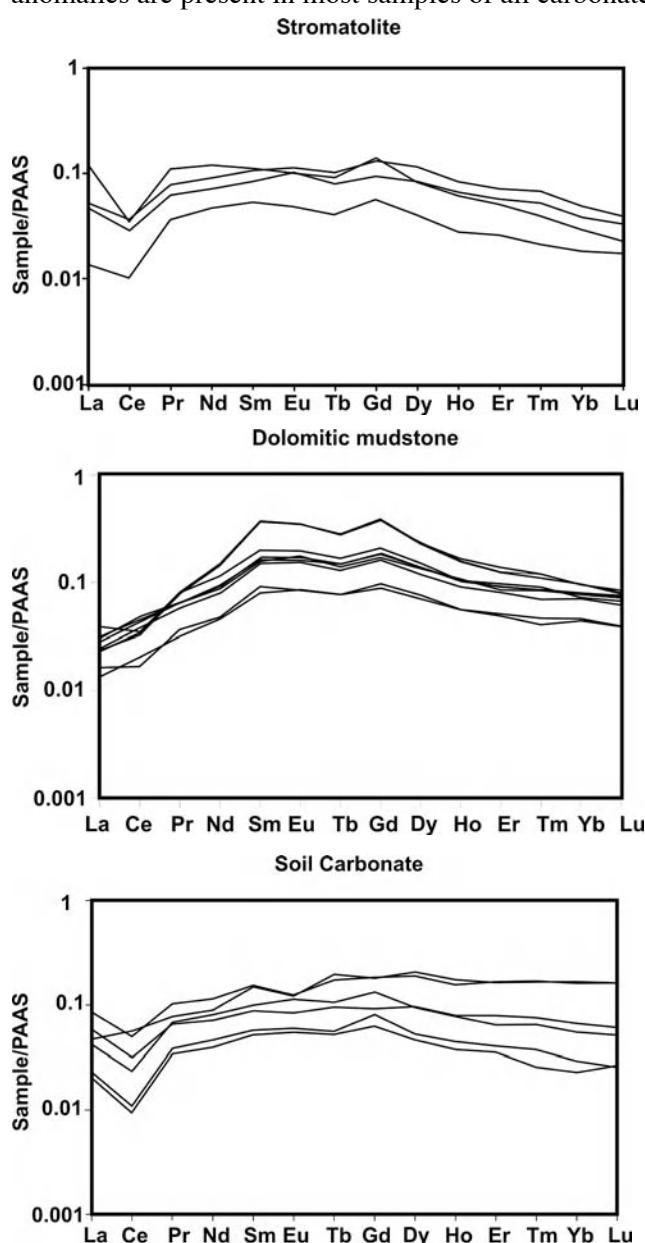


Figure 2. Post Archean average shale normalized rare earth element diagrams for various Sibley Group carbonate types.

Together lithofacies analysis and geochemical data provide insight into the depositional environments of the Sibley Group. C and O isotopic compositions fall within the realm of values determined for other Mesoproterozoic carbonate rocks deposited in marine systems. Upward stratigraphic changes in carbon and oxygen isotopic compositions may have been brought about through global scale changes, with a positive shift in C values attributable to increased rates of light (organic carbon) burial. Alternatively the carbon isotopic shift maybe have resulted from processes occurring within a restricted lacustrine basin with the upward shift corresponding to increasingly restricted depositional conditions near the top of the sampled succession. $^{87}\text{Sr}/^{86}\text{Sr}$ values also lie within the realm of possible seawater Sr values for the Proterozoic. The lowest values in calcrete from near the bottom of the lower succession suggests that the Sr source for these carbonates may have been marine. Relatively high Sr values in the middle succession may imply a lacustrine system. Diagenetic sulfate in the upper succession also falls within “marine” values for the Proterozoic and is generally lower than carbonates in the middle succession. REE element patterns have a signature consistent with oxygenated seawater; however, little comparative data is available for modern or ancient carbonates deposited in lacustrine or evaporitic environments.

Seagull Intrusion, Ontario: A Unique PGE-Ni-Cu Setting

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The Seagull ultramafic (Proterozoic) intrusion is an unique setting when compared to other mafic intrusion in the Lake Superior region and for that matter the rest of the world. A dunite layer exceeding 400 metres in thickness with pristine olivine (unaltered) having a magnesium oxide content exceeding 33% average olivine composition of Fo₈₆ occurs with a 50-100 metre thick gabbro-pyroxenite (lherzolite) basal unit. Overlying is a peridotite 200-250 metres thick and an upper granophyric gabbro-gabbro pyroxenite-gabbro norite (50-100 metres thick). The intrusion has been age dated as 1112 Ma although older dates of 1124 Ma are appearing in other phases (*see* Heaman and Easton, this volume).

The intrusion is adjacent to a failed arm of the Midcontinent Rift that extends north into the Nipigon Embayment and is cut by Nipigon olivine gabbro (1108 Ma) that forms extensive sills in the region. Other olivine-picrite bodies occur in the area such as Eva-Kitto and Hele, but are not known to contain the extensive ultramafic observed at Seagull.

Sulphides occur in the basal lherzolite with zoned blebs containing cubanite tops and pyrrhotite-pentlandite bottoms. Assays up to 3.58g Pt +Pd have been obtained with % S and a 1 to 1.1 ratio of Pt and Pd. Nickel values up to 0.25% and Cu up to 0.35% have been observed. Horizons of fine disseminated sulphide occur in the dunite up to 5 metres in thickness containing up to 5.5g PGE, 0.68% Cu and 0.36% Ni in the 470 to 500 metre depth area. Two distinct layers have been identified so far, with highly anomalous zones in between the layers. The horizons are hosted in a medium to coarse dunite above a very coarse dunite. Fine-grained chalcopyrite with minor pyrrhotite-pentlandite occur in these layers. There is no development of feldspar or oxide mineral (magnetite or chromite) layering, however there appears to be a change in the pyroxene composition from both orthopyroxene and clinopyroxene below the mineralized horizons to just clinopyroxene above the mineralized horizon, which occurs in conjunction with a shift to slightly more primitive olivine compositions.

Magnetic inversion modeling has been the most useful tool for mapping the shape of the intrusion. Down hole EM has identified conductors within the basal lherzolite which will be followed up for stringer-massive sulphide accumulations. Gravity surveying has helped identify a trough extending east and a scarn zone in the Sibley Group Metasediments. Most of the basement rocks beneath the areas containing values are Archean Quetico Metasediments. Sulphur isotope work suggests the Quetico sulphides acted as a sulphur source.

Minerals identified in the basal zone are merenskyite, michnerite, sperrylite, a palladium-copper alloy, native copper, native iron-bismuth, chalcopyrite, cubanite, pyrrhotite and pentlandite. Where the horizons are dominated by bravolite, polarite, sperrylite, telluropalladinite and copper.

Geology, Geochemistry and PGE Potential of Mafic and Ultramafic Intrusions in Minnesota, excluding the Duluth Complex

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Exploration for polymetallic deposits, including platinum group elements (PGE), has traditionally focused on mafic intrusions of the Mesoproterozoic Duluth Complex for obvious reasons—the complex is relatively well exposed and contains occurrences of PGE associated with basal Cu-Ni deposits that were discovered decades ago. By contrast, mafic intrusions in the Archean and Paleoproterozoic terranes of the remaining four-fifths of the state have received only cursory investigations by exploration companies and the state. This stems in large part from thick glacial cover over all but the northeast and southeast parts of the state; there is Paleozoic cover in the southeast.

The completion of a high-resolution aeromagnetic survey of the state between 1982 and 1990 and the increased demand for PGE has spurred more exploration activity targeting ultramafic and mafic intrusions over the past two decades. Because of the requirement that drill core and related geochemical and geophysical data be turned over to the state after mineral leases expire, a sizeable public database of geologic, geochemical, and geophysical information exists on mafic intrusions in the state. However, this database has not been consistently evaluated for what it implies about the potential for these intrusions to host PGE deposits. Beginning in 2001, a four-year, two-phase study was funded by the state for the Minnesota Geological Survey (MGS) and the Natural Resources Research Institute (NRRI) to inventory the public database and acquire new data for the purpose of evaluating the potential for PGE deposits in mafic intrusions outside the Duluth Complex.

Phase 1 of this study, which was completed in July of 2003 and published by the MGS as an interim open-file report, took inventory and digitally compiled basic geologic, lithologic, and geochemical attributes of over 150 individual mafic intrusions studied from field exposures or from drill core. Information was also collected on some of the thousands of diabasic dikes and other geophysical anomalies inferred to be mafic intrusions. The project work conducted on each intrusion varied with the level of detail that existed, but included some combination of geophysical (aeromagnetic and gravity) delineation, outcrop mapping, drill core examination, petrography, and geochemical analysis. This compilation of pre-existing data was augmented with geophysical modeling, relogging of drill core, outcrop mapping and sampling in well exposed areas of north-central Minnesota, petrographic studies of over 100 thin sections from 53 intrusions, and geochemical analyses and assays of 83 samples from 58 intrusions. Also, eight new $^{40}\text{Ar}/^{39}\text{Ar}$ analyses of magmatic hornblende and biotite separates were acquired to better constrain the general temporal framework of some intrusions.

Phase 2 of this study, which is currently underway, sets out to conduct a more detailed evaluation of the geologic setting, igneous stratigraphy, and geochemistry of 15 specific intrusions for which there is sufficient sampling by drill core. The petrographic and geochemical results of this study phase were not ready at the time of this writing, but will be presented at the meeting. Another component of this study, which is being conducted by the NRRI, is a detailed mapping and chemostratigraphic analysis of the well-exposed Deer Lake layered mafic complex of north-central Minnesota.

Based on an evaluation of this database, mafic intrusions can be grouped into several major types according to age and type of host rock, timing of emplacement relative to tectonism and metamorphism, and general lithologic attributes. The attributes of these intrusion types and some examples are summarized in Table 1.

Phase 1 of this study acquired 75 new lithogeochemical and assay analyses from more than 50 intrusions. In addition, over 400 publicly available geochemical analyses have been compiled from exploration company files and data previously acquired by various state and federal agencies. For Phase 2, an additional 85 analyses are

Table 1. Classification of mafic intrusions outside the Duluth Complex in Minnesota.

Intrusion type	Age	Host rock	Tecto-metamorphism	ithologic attributes	Examples (Fig. 1)
Subvolcanic mafic-ultramafic sills	Ar	Archean greenstone belts	Pre- to syn-tectonic; low to moderate metamorphic grade	Tholeiitic-komatiitic; peridotite, pyroxenite, gabbro, & diorite	Deer Lake Complex, Winterfire intr, KIB intrusions, Warroad intrusion
Amphibolite sills & dikes	Ar	Archean high-grade gneiss terrains	Pre-tectonic; high metamorphic grade	Schistose amphibolite (metagabbro)	Small amphibolite bodies in Quetico Subprovince
Lamproid dikes & plugs	Ar	Archean greenstone belts	Syn- to post tectonic; low metamorphic grade	Hbld-, oxide-, & bio-bearing ultramafic rocks	Lamprophyre plugs in Wawa Subprovince
Gabbroic to intermediate intrusions	Ar	Archean granite-greenstone terrains	Post-tectonic; low metamorphic grade	Gabbro/diorite, tonalite, monzonite w/mafic enclaves	Linden pluton, Oaks intrusion, Grygla pluton
Gabbroic anorthosite massifs	p<	Archean granite-greenstone terrains	Syn- to post-tectonic; moderate metamorphic grade	Coarse gabbroic anorthosite	Mentor intrusive complex
Layered gabbro-norite intrusions	p<	Penokean orogen & MN River Valley Subprovince	Syn- to post-tectonic; low to moderate metamorphic grade	Modally & texturally layered gabbro-norite, gabbro, & pyroxenite	Lake Washington, LL, BKV & Providence intrs.
Pyroxenite & peridotite plugs	p<	Penokean orogen	Post-tectonic; low metamorphic grade	Alkaline ultramafic rocks	Small plugs in central Minnesota
Hornblende mafic-intermediate complex	p<	Penokean orogen	Syn- to post-tectonic; low to moderate metamorphic grade	Hornblende, diorite, granodiorite	Tibbets Brook intrusion
Olivine gabbro intrusions	m<	Unknown	Syn-continental rifting	Layered oxide olivine gabbro	Fillmore County intrusions

currently being acquired from 15 intrusions to more completely characterize the chemostratigraphy of these select intrusions. Currently, the highest PGE values have been found in sulfidic basal contact zones of the Winterfire subvolcanic sills in north-central Minnesota with Pd, Pt, and Au values in 1-3 meter intervals in the range of 500-1,000, 100-400, and 50-200 parts per billion, respectively.

The discovery of anomalous PGE values is not the primary objective of this study, however. Rather, the goal is to assess the overall potential of particular intrusion types to host either contact-type or reef-type PGE deposits. Working toward this goal, geochemical data will be used to interpret the composition and PGE tenor of the parent magmas, determine the degree to which the intrusions display internal differentiation, and evaluate conditions of sulfide saturation through the intrusions.

A draft report on this study will be completed in the summer of 2005 with a final report to follow. In addition to digitally compiling pertinent geologic, geophysical, petrographic, and geochemical data, this report will evaluate the data to assess the PGE potential of the various intrusion types and make recommendations as to what intrusion types merit further study and exploration.

New thoughts on old circles: A reexamination of spheroidal Gunflint taxa

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The first systematic description of the Gunflint biota (Barghoorn and Tyler, 1965) is a seminal work in Precambrian paleontology. The Gunflint biota are represented by an assemblage of incredibly well-preserved microfossils contained within the approximately two billion year old Gunflint Iron Range of the Animikie Basin. Because the Gunflint microfossils were the first definitive and widely publicized evidence of Precambrian life, they have become one of the most famous fossil assemblages in the world. The high level of preservation and diversity of the biota has led to the microfossils becoming a benchmark against which early records of life are compared. The Gunflint and other Animikie basin microfossils are also significant because they provide the most complete record of the biosphere during a dramatic change in Earth's history—the initial oxygenation of the atmosphere and shallow seas and the sequestration of the iron from the oceans. The importance of the Animikie microfossils is based upon a clear understanding of the diversity and structure of the Gunflint community.

Most Gunflint genera are determined based on obvious morphological characteristics such as having a filamentous or spheroid morphology. However, species boundaries within broad morphological groups such as the spheroids are more difficult to define. Diameter distribution (i.e. unimodal or polymodal) is one factor that has previously been used to determine species composition of a spheroidal population (Strother and Tobin, 1987; Knoll et al., 1978; Knoll and Simonson, 1981). Although the range of species distributions has always been noted, it has been afforded little attention in the evaluation of specific taxon (Knoll et al., 1978). We conducted a study to determine the diameter distribution within a population of the coccoid cyanobacteria *Microcystis aeruginosa* and a survey of previously recorded diameter ranges for 100 extant coccoid cyanobacteria taxa. Our goal is to determine the validity of Gunflint and other Animikie basin species classifications.

Previous studies that have noted a polymodal diameter distribution in a microfossil population have asserted that this indicates the presence of multiple taxa. This was most notably assumed for the genus *Huroniospora*, one of the most abundant biota of Gunflint. Strother and Tobin (1987) recorded a skewed bimodal size-frequency distribution (modes at 4 and 7 μm) for *Huroniospora* microfossils found within the Schreiber Beach assemblage. *Huroniospora* specimens from the Sokoman Iron Formation have a size-frequency distribution with modes at 3, 5, and 10 μm (Knoll and Simonson, 1981), in accordance with previous findings from the Schreiber locality.

We obtained a diameter distribution for a cultured population (from Lake Winnebago, Appleton, WI) of *Microcystis aeruginosa* through measurements with an optical micrometer. We made wet mount preparations and recorded the diameter of all specimens within a single optical plane. The diameters were placed into .5 μm groups, which is the level of accuracy of the optical micrometer used. In all, 425 individuals were measured. The population showed a distinct bimodal pattern with modes at 6 and 8.5 μm . Although previous algae populations have been shown to have a broadly unimodal diameter distribution, our results show that a monospecific cyanobacteria population can contain a bimodal diameter distribution. Polymodal distributions of cyanobacteria have also been recorded (Prescott, 1951). These results strongly suggest that polymodal diameter distributions with closely spaced modes in a microfossil population, specifically those described by Strother and Tobin (1989) and Knoll and Simonson (1981), in the definitively cyanobacteria taxon of *Huroniospora* are very unlikely to indicate multiple taxa. At minimum the observations show that a polymodal diameter distribution within a microfossil population cannot be used as a diagnostic indication of multiple taxa.

We also conducted an evaluation of the range of diameter distributions in extant cyanobacterial species. Our goal was to see if the reported diameter ranges for fossil taxon are consistent with the ranges seen for extant species. We surveyed 100 marine and freshwater coccoid cyanobacteria species from previous reports. The average diameter distribution was 3.0, with a standard deviation of 3.1. We found a range of 0.2 to 24 μm , with only two species with a reported range greater than 10 μm . This observation is relevant because many of the Gunflint taxon have very large ranges that are skewed left. A notable example is *Leptoteichos golubicii*. The

taxon is broadly unimodal with a mean cell diameter of 13.5µm. However, the reported range for the species is 26µm (5-31µm), larger than any of the species we encountered and far above the mean for diameter range. Less than the five percent of *Leptoteichos golubicci* have a diameter above 24 µm (Knoll et al., 1978). The diameter distribution of and range reported for *Leptoteichos golubicci* is inconsistent with monospecific classification of the population. We believe that the cells above 24 microns in the *Leptoteichos golubicci* population are most likely akinetes, which are large reproductive structures (analogous in many ways to spores) produced by filamentous cyanobacteria. Although akinetes have previously been shown to be present to present in the Gunflint (Licira and Cloud, 1968), no estimate of their abundance was made. Our reinterpretation of the *Leptoteichos golubicci* population could be used to determine an estimate of akinete abundance.

Although the spheroidal Gunflint microfossils are exceptionally well preserved, we need to remember that we are still looking at a collection of circles, from which little morphological variation can be gathered. Therefore information on population structure from modern analogues needs to be used to help ascertain the basic ecology of the Gunflint community.

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Geochemical Variation within the Mesoproterozoic Nipigon Diabase Sills

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The Nipigon sills are related to the Mesoproterozoic Keweenawan mid-continent (MCR) rift event. Centered on what is now the Lake Superior basin, the igneous activity is interpreted to be the result of a mantle plume interacting with the continent as far to the southwest as Kansas, USA, and to the southeast as far as the Grenville front in southern Ontario, Canada (Davis and Green, 1997). The system operated for approximately 20 Ma producing a volume of intrusive and extrusive igneous rock estimated to be in excess of 1.5 million km³ (Klewin and Shirey, 1992). The Nipigon sills are thick, relatively flat lying hypabyssal, medium-grained subophitic to ophitic olivine gabbro-norite with U-Pb ages ranging from 1107 Ma to 1112 Ma (Heaman and Easton, this volume).

The goals of this project are to evaluate geochemical variations within the Nipigon sills, compare them to other MCR rocks and generate an emplacement model which identifies and explains any identified intrasill relationships, magma sources. The project area (Figure 1) covers approximately 15,000 km² of the Nipigon embayment. As part of this project a detailed sampling program was undertaken in the summer of 2003 and 2004 resulting in 250 shoreline samples being collected from Lake Nipigon (Figure 1) and 530 samples from diamond drill core in the southern Lake Nipigon basin near Black Sturgeon and Shillabeer lakes.

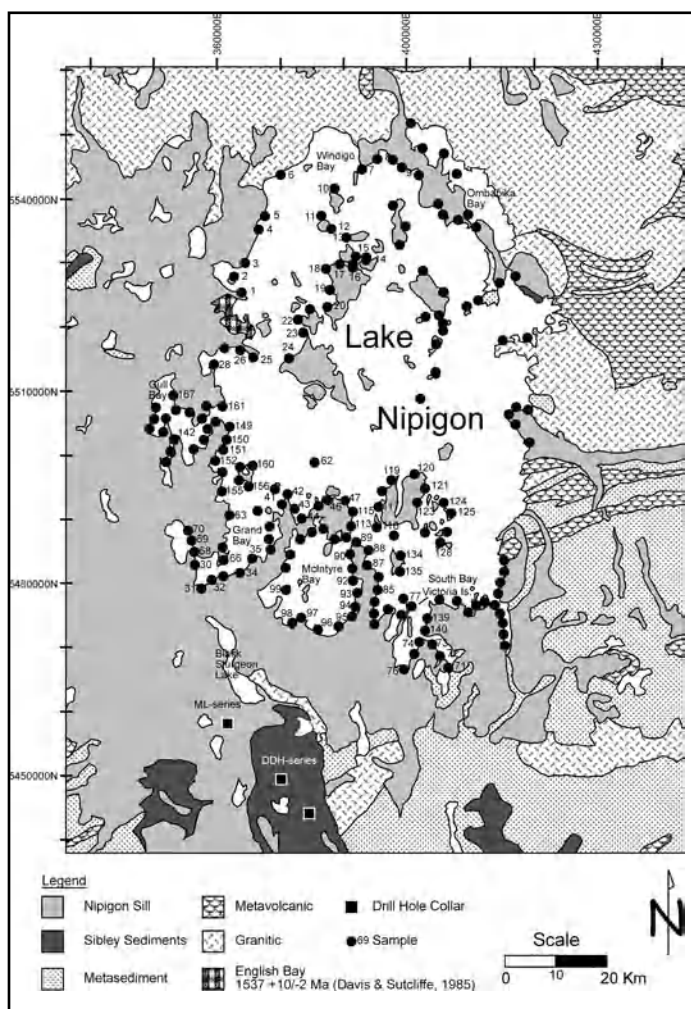


Figure 1. Map showing sample locations, drill holes, geology and project area.

Selected samples were analysed for major, trace and rare earth elements with a representative subset analysed for Rb-Sr, Sm-Nd and Pb-Pb isotopes. Three distinct sill suites were identified within the basin. Two additional suites have been identified by T. Hart and C.A. MacDonald (Ontario Geological Survey) as part of their mapping projects in the Nipigon Embayment (MacDonald, 2004; Hart and Magyarosi, 2004).

The various suites were defined, in part, using rare earth element data (Figure 2). The most spatially abundant suite has been termed the Main Nipigon suite. This suite outcrops over much of the Nipigon embayment having La/Sm_{cn} and Gd/Yb_{cn} ratios of 1.4-1.8 and 1.3-1.5 respectively (Figure 2).

The Main Nipigon and Inspiration suites share similar Gd/Yb_{cn} (Figure 2), TiO₂ and MgO values. The Inspiration suite has a higher La/Sm_{cn} ratio, but these data lie on a possible trend from the Main Nipigon suite and the whole rock data suggest that the Inspiration and the Main Nipigon suites may be related.

Other suites in the Nipigon Embayment include the McIntyre and Jackfish suites. These two suites share similar Gd/Yb_{cn} and La/Sm_{cn} ratios and lie on a fractionation trend (Figure 2) with the Jackfish

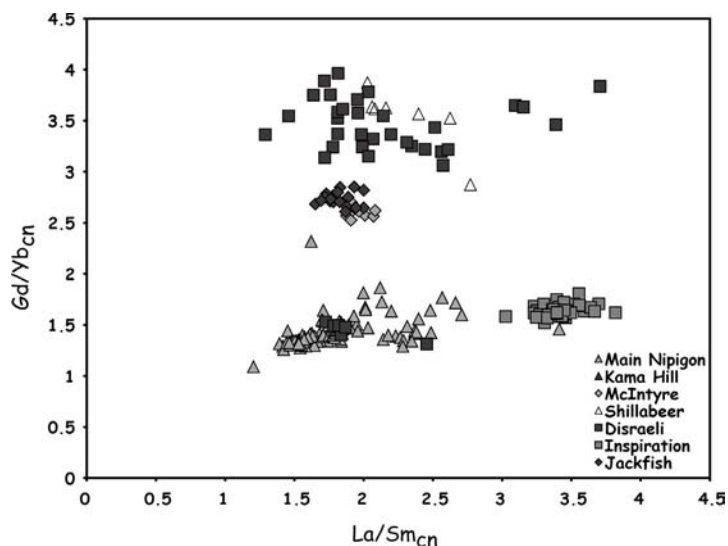


Figure 2. Chondrite normalized rare earth data defining sill suites in the Nipigon embayment.

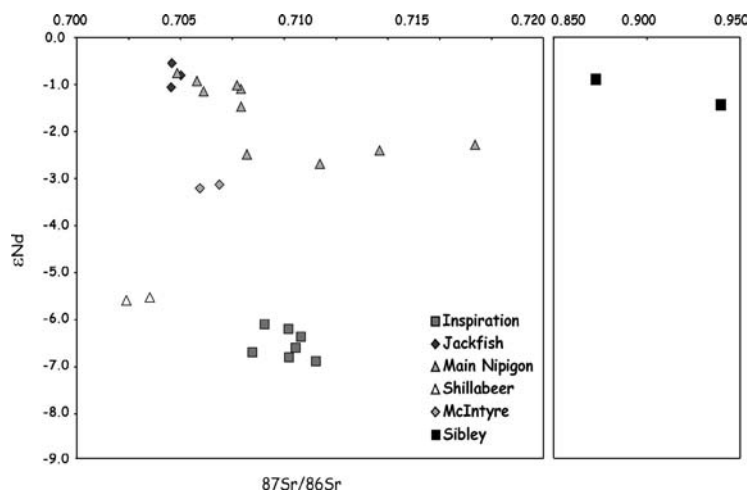


Figure 3. Nd and Sm isotope data for the Nipigon sill suites compared with data from the Sibley sediments and Quetico basement rocks.

possibly being the source of the McIntyre. The Shillabeer suite is geochemically similar to the Disraeli ultramafic intrusion using Gd/Yb_{cn} , La/Sm_{cn} and whole rock geochemistry suggesting the possibility that this suite is not part of the Nipigon sills but is related to the ultramafic intrusions of the southern Lake Nipigon embayment.

Isotope data (Figure 3) reveals differences in the degree of crustal contamination of the sill suites. The Main Nipigon and McIntyre suites are the least contaminated ($\epsilon_{Nd} \sim 0$) with the Main Nipigon data trending toward Sibley group sediments suggesting that these sediments may be the dominant contaminant. Shillabeer and Inspiration sill suites are the most contaminated ($\epsilon_{Nd} -5.5$ to -7) but do not trend towards Sibley data implying a distinct contaminant.

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The Geology of the Eagle Nickel-Copper Deposit: Marquette County, Michigan

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Kennecott's discovery of the Eagle nickel-copper deposit in 2002 marked the culmination of more than a decade of exploration work by Kennecott in the Paleoproterozoic in age Baraga sedimentary basin. The discovery hole, YD02-02 completed in July 2002, intersected 84.2m of massive sulfide mineralization averaging 6.3% Ni and 4.0% Cu. The resource estimate for the Eagle deposit at the end of 2003 was 5 million tonnes at 3.68% Ni, 3.06%Cu and 0.1% Co.

The Eagle deposit is hosted in the westernmost of two small peridotite bodies historically referred to as the Yellow Dog Peridotite. The Yellow Dog intrusions, which lack penetrative foliations and truncate Penokean tectonic fabrics in the surrounding meta-sediments, are believed to be Keweenawan in age (Klasner et al., 1979). The intrusions are mainly comprised of coarse-grained, variably serpentinized peridotite and feldspathic peridotite. A fine-grained, olivine poor phase is found along the margins of the intrusions and as xenoliths within the peridotite. Possible amygdules in the olivine poor phase(s) suggest a shallow level of intrusion.

Three principal types of sulfide mineralization are recognized in the Eagle deposit: disseminated (blebby), semi-massive (matrix) and massive. Although the nickel contents of semi-massive and massive sulfides are relatively uniform through out the deposit, copper contents vary significantly. Platinum group metals (PGM) and gold values are significantly higher in the copper rich massive sulfides. Copper rich veins and disseminations, with significant PGM and gold, in the surrounding meta-sediments may constitute a fourth type of ore.

Massive and semi-massive sulfide ore types in the Eagle deposit are irregularly distributed. The contacts between different ore types are sharp and show little evidence of the gradation or layering that might be expected if gravity driven accumulation of sulfides from an overlying, sulfide saturated, silicate magma was the principle mechanism of ore formation. Sequential emplacement of various mixtures of silicate and sulfide magma and cumulus minerals, derived from a lower stratified magma chamber, may provide a better model.

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Mining and Exploration Activity in the Thunder Bay South District

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The Thunder Bay South District covers an area from west of Atikokan, east to White River and north to Armstrong from the United States border. There were four producing precious metal and base metal mines, as well as 15 seasonal amethyst producers in 2004. The three Hemlo gold mines produced 655,000 ounces of gold in 2004, and more than 18 million ounces of gold has been produced from the Hemlo deposit since mining began in 1985. The Lac des Iles mine produced a record 308,931 ounces of palladium from the open pit, as well as platinum, gold, nickel and copper. Underground development was initiated in 2004 and underground mining is scheduled to begin in 2006.

Exploration for gold, base metals, platinum group metals, uranium, molybdenum, diamonds and industrial minerals were all active in 2004. Highlights include a new base metal discovery by Freewest Resources Canada Inc. in early 2005. The Sungold Occurrence in the Western Shebandowan greenstone belt (Wawa Subprovince) is located 120 km west of Thunder Bay. Grab samples assayed 33.2 % zinc and 12.5 % Cu, discovered after a V-TEM (Dreamcatcher) and winter beep-mat geophysical surveys were conducted. Gold highlights include the Tower Mountain Property of Valgold Resources Ltd. who conducted more than 10,000 m of diamond drilling with results of up to 164.7 g/t gold over 1.5 m. Further drilling is ongoing. In the Hemlo area Navasota Resources Ltd. intersected 18.28 g/t gold and 47.18 g/t silver over 4 m in diamond drilling.

North American Palladium Ltd. continued deep diamond drilling on the High-Grade Offset Zone, including intersecting 5.25 g/t palladium and 0.515 g/t platinum over 3.1 m. Exploration is ongoing on the mine block, and at the Shebandowan project. East West Resource Corporation and Canadian Golden Dragon Resources Ltd. entered into a \$7.5 million joint venture with Platinum Group Metals Ltd. on the Seagull-Disraeli property. Several new reef horizons were discovered, assisted by the Ontario Geological Survey, the Lake Nipigon Region Geoscience Initiative and Lakehead University. Assays of up to 7.90 g/t platinum + palladium + gold over 0.44 m have been intersected with a 1:1 Pt:Pd ratio.

Rampart Ventures Ltd., in joint venture with New Shoshoni Ventures Ltd., have staked more than 2000 claims in the Sibley Basin for uranium. Airborne geophysical surveys have been flown and diamond drilling is planned. Ripple Lake Diamonds Inc. discovered three micro-diamonds in a small 3 by 3 m diatreme associated with a calc-alkalic (minette) dike, located on the Trans-Canada Highway approximately 30 km west of Marathon. More than 2200 claim units have been acquired. Exploration is active for a variety of commodities in the Thunder Bay South District. We invite you to come and explore in Northwestern Ontario!

PGE and gold potential of the Archean Deer Lake Complex, Minnesota, USA

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The precious metal potential of the Deer Lake Complex (DLC) has recently been addressed by detailed geologic mapping (2004) and two detailed sampling campaigns (2002 and 2004). The DLC is Archean in age, is located in northeastern Itasca County, Minnesota, and consists of a series of multiple sills, each of which are variably differentiated and steeply inclined. Sampling results, along several traverses across the DLC, suggest that PGE contents are low with maximums of only 84 ppb Pt and 52 ppb Pd. Gold contents, on the other hand, are more encouraging and values up to 2.4 ppm are associated with a shear zone in one of the basal DLC sills.

The Deer Lake Complex (DLC) consists of a series of steeply-dipping, tholeiitic, mafic-ultramafic sills that are variably differentiated and complexly interfingered. Where differentiation is complete, the sills exhibit a layering sequence consisting of a basal chilled margin grading upwards through peridotite, pyroxenite, melagabbro, melagabbro-porphyrific gabbro, gabbro, quartz gabbro (or diorite), and in some rare localities, an upper chilled margin. The sills were mostly emplaced into calc-alkaline volcanic and sedimentary rocks of the Joy Lake Volcanic Sequence (Jirsa, 1990). The bottom-most portion of the DLC was initially intruded into high-Mg tholeiitic basalt and basaltic komatiite; these volcanic rocks are assumed to be the early extrusive equivalent of the DLC (Jirsa, 1990; Englebert and Hauck, 1991). All of the sills are metamorphosed to greenschist facies.

The DLC was explored for base metal deposits in the 1970s; however, no significant indications of Ni-Cu mineralization were found. Initial geologic mapping of the DLC (Berkley, 1972; Ripley, 1973) suggested that only 2-3 completely differentiated sills were present, and that repetitions of specific rock types were related to tight isoclinal folds. Later review (Severson, 1987; Jirsa, 1990; this study) suggests that the DLC formed from the emplacement of numerous interrupted magmatic pulses with partial to complete fractional crystallization occurring between the pulses. Thus, not all of the sills contain a peridotite base or grade completely upwards into quartz gabbro.

As can be seen on a plot of Pt+Pd versus stratigraphic position (Figure 1), most of the individual DLC sills contain extremely low Pt+Pd contents except for weakly anomalous samples in central portions of several sills. The overall patterns for two of these sills in particular consist of low Pt+Pd values that gradually increase

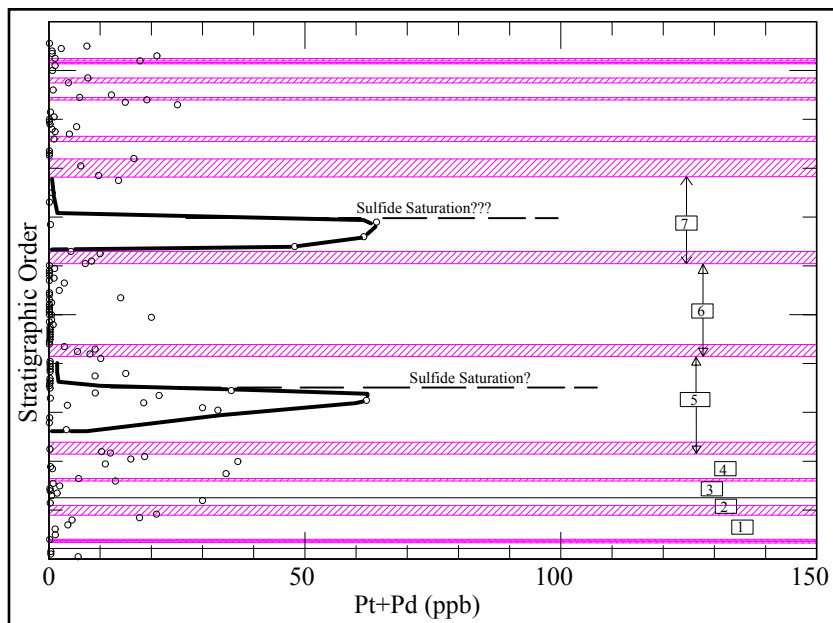


Figure 1. Vertical changes in Pt+Pd (ppb) contents with stratigraphic height in the various sills (numbered in boxes) of the Deer Lake Complex. Shaded areas are peridotite horizons.

with stratigraphic height to noticeable peaks, followed by dramatic drop-offs to virtually no PGE in the upper portions of the sills. It may be possible that this dramatic changeover in the Pt+Pd content may be related to a sulfide saturation event; whereby, PGE was scavenged from the melt. A similar pattern has been reported for the Mesoproterozoic Sonju Lake intrusion, where a PGE-bearing reef with up to 320 ppb Pd and 66 ppb Pt has been identified by Miller (1999). However, detailed follow-up, close-spaced, sampling at one of the “sulfide saturation horizons” during 2004 failed to produce any significant PGE in the DLC.

Several anomalous gold values

(>100 ppb) were obtained in samples collected from a drill hole (26508) near the base of the DLC. These values (up to 2,399 ppm Au) are from a well-foliated/sheared gabbro that contains 1-5% pyrite and pyrrhotite, and contains some of the highest Cu values (up to 0.07% only) in the DLC.

In summary, the PGE potential of the Deer Lake Complex appears to be low but there is an outside possibility that some of the sills may contain PGE reefs that are associated with sulfide saturation events. On the other hand, Au potential appears to be better, especially in the sheared rocks in drill hole 26508.

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A view into the Nipigon Embayment: preliminary results of the largest magnetotelluric study ever in Ontario.

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Over 800 audiomagnetotelluric and combined audiomagnetotelluric and magnetotelluric (A/MT) sites were surveyed along five transects (Figure 1) during the period of late Aug to mid October 2004. The primary goal of the survey was to investigate the deep structures of the region to complement the studies that comprise the Lake Nipigon Regional Geoscience Initiative (LNRGI). The LNRGI was created to provide a comprehensive 4-D geoscience knowledge base in order to facilitate proper land-use decisions and to reduce the risk in mineral exploration of the region. The studies conducted as part of the Initiative are comprised of surface geological and stratigraphic investigation, surface and airborne geophysical surveys and other studies such as geochronological or paleomagnetic studies. Missing from these studies is an investigation of the deep geological structure. The A/MT survey conducted last year was designed to provide subsurface information down to mantle depths and beyond along five major transects.

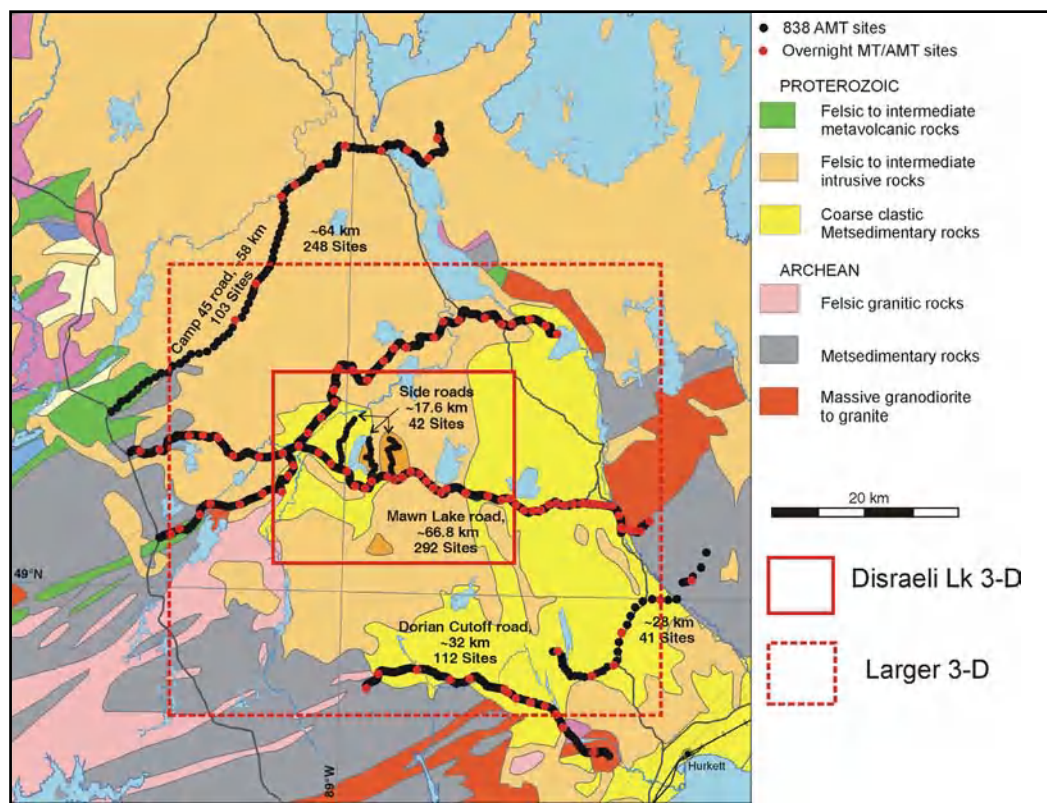


Figure 1. Site Locations for 2004 A/MT Nipigon Survey. Possible plan view locations for future 3-D model studies are also shown by red boxes.

The magnetotelluric technique is a geophysical technique for imaging the deep structure of the Earth. It images conductors in the Earth and as such will be useful to delineate contacts between crystalline and sedimentary units at depth as they have dramatically different electrical characteristics. The novel feature of A/MT is that it uses the Earth's natural magnetic field as a transmitter of energy into the earth. This enables almost an infinite depth of investigation; however in practice the depth of investigation is limited to the asthenosphere. Preliminary results of the Nipigon A/MT survey will be presented with a view to providing a clue to the origin of the enigmatic sedimentary and intrusive units in this area.

Mineral Deposits and Metallogeny of the Midcontinent Rift in Ontario

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A variety of metallic and non-metallic mineral deposits are associated with Mesoproterozoic (Keweenawan) Midcontinent Rift (MCR)-related magmatism and associated hydrothermal activity in Ontario.

Orthomagmatic deposits of copper, nickel and platinum group elements (PGE) are associated with early ultramafic to mafic intrusive rocks. Stratabound, “reef-style” Cu-Ni-PGE mineralization occurs in peridotite in the Seagull layered intrusion; within massive, cumulate Ti-Fe-oxide layers in the border gabbro of the Coldwell Complex; and with Cr-bearing spinel in cyclic anorthosite-gabbro units above the Great Lakes Nickel deposit in the Crystal Lake Gabbro. Varied-textured to pegmatitic gabbro at the base of the Crystal Lake Gabbro hosts the Great Lakes Nickel deposit (~ 41.4 mT @ 0.334% Cu, 0.183% Ni, 0.69 g/t Pd, 0.21 g/t Pt). Similar rocks of the Two Duck Lake gabbro in the Coldwell Complex host the Marathon deposit (24.4 mt @ 1.22 g/t Pd, 0.31 g/t Pt, 0.37% Cu). Late-stage, magmatic deposits of pyrochlore-hosted, U-Nb-mineralization have been investigated in the Prairie Lake Carbonatite Complex and in syenites of the Coldwell Complex (Nb-Zr-Th-U-Ce). Rare metal (Be-Zr-U-Th-) mineralized structures crosscut the Dead Horse Creek carbonatitic diatremes.

Epigenetic deposits associated with MCR structures and hydrothermal activity are hosted in a variety of Neoarchean, Paleoproterozoic and Mesoproterozoic rocks. Native copper and Cu-sulphides occur in Keweenawan basalt and interflow sedimentary rocks at Mamainse Point (*e.g.*, Coppercorp Mine), on Michipicoten Island (*e.g.*, Quebec Mine) and in Osler Group rocks in western Lake Superior. Hydrothermal fluids ascribed to MCR magmatism are believed to have produced Cu-Mo-Ag-Pb-mineralized breccia pipes in Archean country rocks at the Tribag Mine and Cu-Mo-mineralization at the Jogran porphyry deposit. Copper-mineralized carbonate units of the Mesoproterozoic Sibley Group are found near the contacts with Nipigon diabase sills.

Silver-bearing, carbonate-quartz veins near Thunder Bay have been subdivided into two groups: the Mainland Belt (Ag ± Zn-Cu-Pb-bearing veins in Paleoproterozoic Animikie Group sedimentary rocks and Logan diabase); and the Island Belt (Ag-Bi-Co-Ni-As-bearing veins in Keweenawan diabase/gabbro; *e.g.*, Silver Islet Mine). Lead-zinc-barite veins occupy structures near the unconformity between Neoarchean basement and Mesoproterozoic Sibley Group sedimentary rocks. Some of these structures also host amethyst deposits. Silver-bearing, lead-zinc veins occur within and proximal to the Coldwell Complex. All of these veins are likely contemporaneous but were generated by different fluid sources.

Uraniferous, hematite-rich veins and breccias that cut Neoarchean basement and locally contain Proterozoic xenoliths may also be related to MCR hydrothermal activity, which remobilized uranium from granitic pegmatites in the basement.

Discrimination of Archean Terranes in the Sachigo Subprovince and relevance to Volcanogenic Massive Sulphide Exploration

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Geological and geophysical constraints on the mechanisms for tectonic growth of the Superior Province are progressively summarized in Williams et al., 1992; Stott, 1997; and Percival, 2005, the latter based on Lithoprobe and Natmap research activities in northwestern Ontario and Manitoba since 1997. This increased knowledge permits greater confidence in the subdivision of the Superior Province into terranes and superterranes of contrasting tectonostratigraphic history. Prior to this, for many years, the broad region of Archean crust north of Uchi Subprovince in Ontario was more commonly called the Sachigo Subprovince (e.g., Card and Ciesielski, 1986). A reconnaissance geochronological and Hf isotopic study was initiated on a transect of granitoid and felsic volcanic samples just west of the James Bay Lowlands (Figure 1) to complement the Natmap studies previously conducted near the Ontario - Manitoba border (e.g., Stone, 2005). Thus far, results from U-Pb geochronology in eastern Sachigo Subprovince further confirm that this subprovince can be subdivided into several terranes. Most notably, a broad Neoarchean, Oxford-Stull terrane contains crustal magmatic ages ranging from 2690 to 2730 Ma, and separates two major superterranes to the north and south, each of which contains evidence of > 3.0 Ga history. Since virtually all significant Cu-Zn volcanogenic massive sulphide (VMS) deposits in the Superior Province are Neoarchean in age, the presence of Oxford-Stull terrane bears some importance for exploration. A Neoarchean age of 2737 ± 7 Ma has been determined for a felsic volcanic host of recently discovered VMS deposits in the McFaulds Lake area, inside the edge of the James Bay Lowlands (Figure 2). This argues for the potential of a chain of VMS occurrences to be explored along a Neoarchean tectonic assemblage extending from Kasabonika to the McFaulds Lake area, comparable to the VMS-rich assemblage along the discontinuous Shebandowan-Terrace Bay-Manitouwadge greenstone belt (Figure 2).

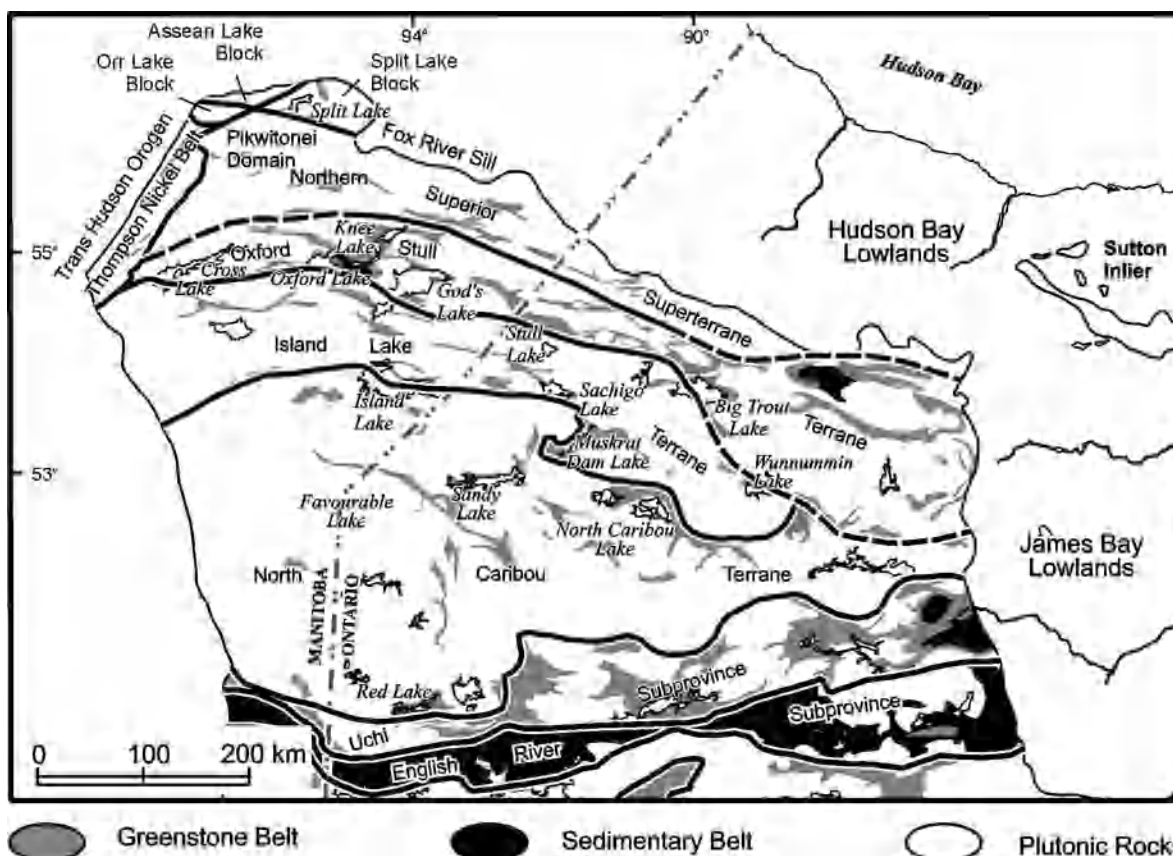


Figure 1. A subdivision of NW Superior Province into terranes (modified from Stone, 2005). Uncertainty of boundaries increases eastwards reflecting current distribution of geochronological and isotopic data.

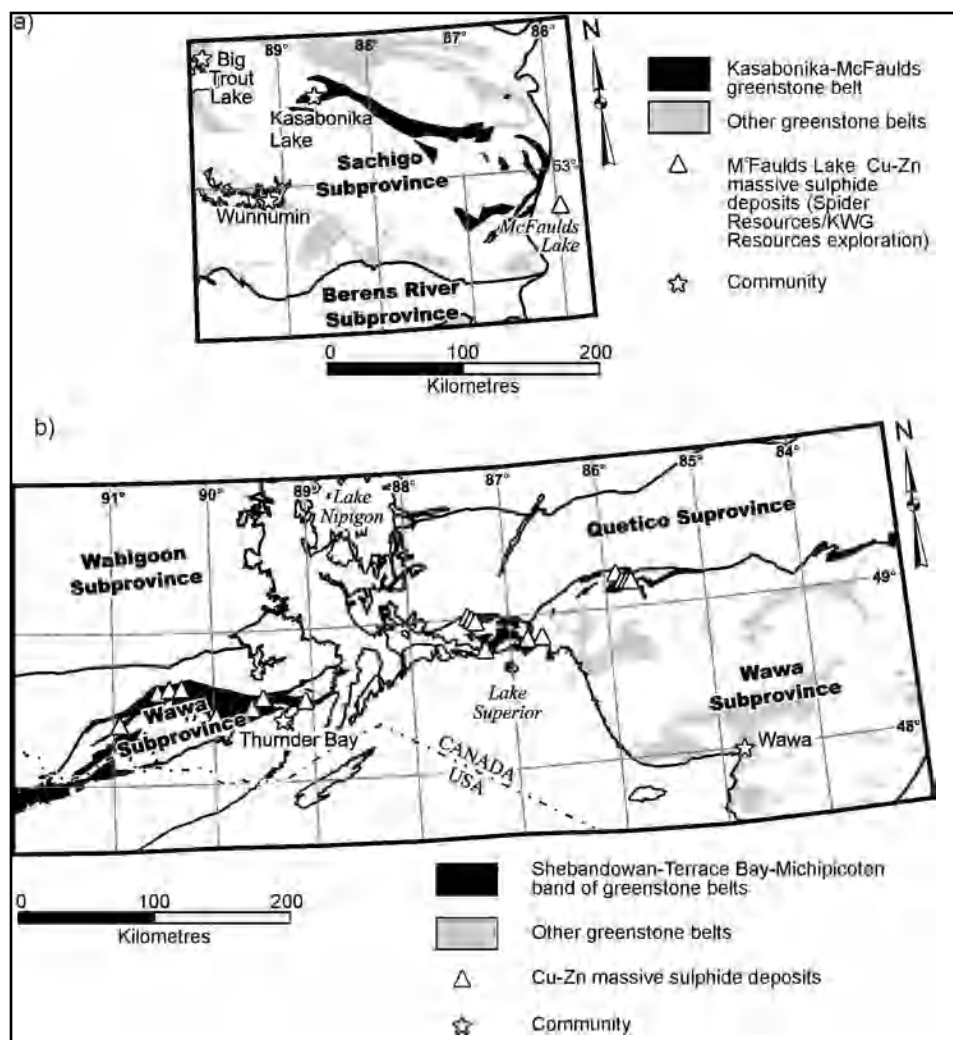


Figure 2. (a). The discontinuous Neoproterozoic Kasabonika-McFaulds greenstone belt is the focus of new Cu-Zn VMS exploration, and may resemble (b) the Shebandowan-Terrace Bay-Manitouwadge belt, a band-like tectonic assemblage, which contains several VMS deposits and mines along its length.

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Correlation Between Self-Potential and Dowsing (IESG) at the Quincy Mine and at the Calumet and Hecla Mine, Michigan

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The focus of this paper is an 11/24/04 joint traverse over and mapwise perpendicular to the strike of the native copper Calumet Conglomerate Lode at the Hecla #1 Mine, Calumet Michigan, with self-potential (Young) and dowsing (Trow) observations plotted in profile on Figure 1. According to Young (Young and Trow, 2005), "The self-potential apparatus consists of hand-made non-polarizing copper copper-sulfate electrodes, a reel containing AWG 20 stranded, tinned copper wire, patch cords and clip leads and a high-input-impedance digital voltmeter. The reference electrode is installed at a convenient sheltered position along the line where the wire can be tied to a sturdy object. The wire is clipped to the reference electrode and is unwound from the reel to the observation points. The electrodes are installed in shallow holes made with a garden trowel, which is used to remove loose and dry surface material so that the electrode is in contact with moist soil. The repeatability of these self-potential measurements is typically about five millivolts." Horizontal distances are measured with fiberglass surveyor's tape.

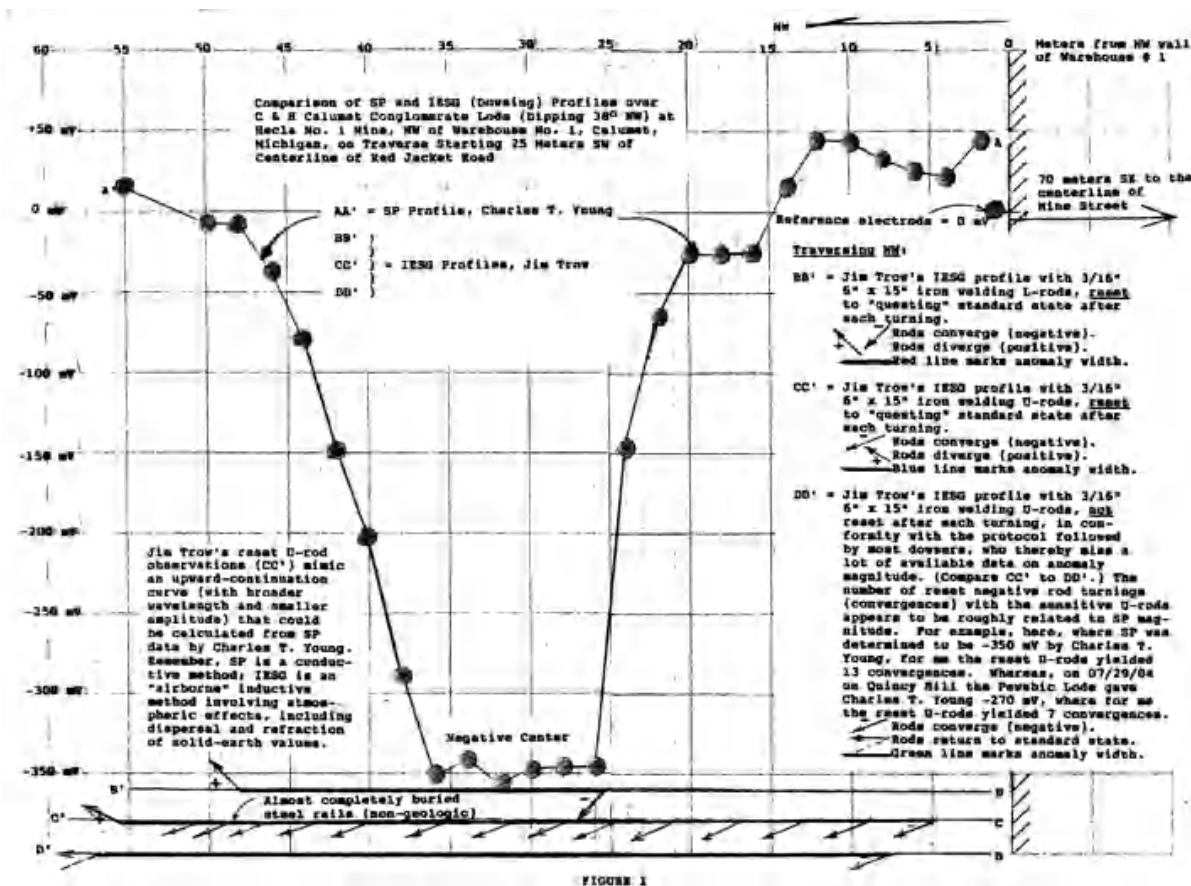


Figure 1 shows dowsing by Trow with sensitive 3/16"-diameter 6" x 15" iron welding rods, bent into a U-shape, and with less sensitive 6" x 15" L-rods of the same diameter and material. Dowsing with U-rods reset to the standard state after each episode of turning (CC') detects a broader and lower anomaly than Young's -350 mV SP anomaly (AA'), but both appear to be distributed symmetrically about the SP negative center, as though dowsing implies an upward-continuation curve for the SP. After all, SP is a conductive method, whereas dowsing is an inductive "airborne" method, involuntarily detected by one's brain (Faraday cage shielding experiments;

Trow, 1992). BB' shows the less sensitive L-rod dowsing results. When favorable weather returns, Trow would like to reverse by traversing SE, to see if the L-rods define the NW edge of the subcrop of the ore body as BB' defines its SE edge when traversing NW. DD' represents Trow's dowsing with the sensitive U-rods, when they are not reset to the standard state after turning, in conformity with most dowsers' procedure, which ignores important data compared to CC'. They have run out of lever arm (physics terminology).

Figure 2 (not shown, please see poster) suggests three hypotheses for a mathematical function to reconcile SP and dowsing: The geologically most plausible is that the square root of the number (x) of U-rod convergences over the total -SP anomaly is proportional to the -SP readings of its negative center. An even better fit than Figure 2 results when one considers the total SP relief on Figure 1, from +15 mV at A' to the -350 mV negative center = -365 mV. Calculating for Quincy $[(\sqrt{7}/\sqrt{13})(-365\text{mV})]$ yields -268mV, 99% of Young's observed -270 mV there. Two points, Quincy and C & H, do not define a curve, but they hint at one.

Figure 3 (not shown, please see poster) symbolically illustrates (some elements displaced to avoid overlap) characteristic dowsers' rod movements, which Trow's (1992) experiments with permanent magnets, low-voltage static electric charges, and Faraday cages demonstrated are related to electrostatics, not magnetostatics.

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New age data for the Chocoday Group, Marquette Range Supergroup: implications for the Paleoproterozoic evolution of the Lake Superior and Lake Huron regions

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A geochronological study of the Chocoday Group at the base of the Paleoproterozoic Marquette Range Supergroup in Michigan, Lake Superior region, is attempted for the first time. Age data from detrital zircon grains and hydrothermal xenotime from the basal glaciogenic formation, the Enchantment Lake Formation, and the overlying Sturgeon Quartzite and its equivalent, the Sunday Quartzite, provide maximum and minimum age constraints for the Chocoday Group. The youngest detrital zircon population in the Enchantment Lake Formation is 2317 ± 6 Ma, in the Sturgeon Quartzite it is 2306 ± 9 Ma and in the Sunday Quartzite it is 2647 ± 5 Ma. The oldest hydrothermal xenotime in the Enchantment Lake Formation is 2133 ± 11 , in the Sturgeon Quartzite it is 2115 ± 5 Ma and in the Sunday Quartzite it is 2207 ± 5 Ma. The depositional age of the Chocoday Group is constrained to 2300-2200 Ma and the radiometric age data proves it is correlative with part of the Huronian Supergroup in the Lake Huron region, Ontario and reveals that the unconformity which separates the Chocoday Group from the overlying Menominee Group is up to 350 m.y. in duration. The detrital zircon suite in the Sunday Quartzite and part of those in the Enchantment Lake Formation and Sturgeon Quartzite were derived from the underlying Archean basement rocks. The source of the ~ 2300 Ma detrital zircon populations in the Enchantment Lake Formation and Sturgeon Quartzite remains an enigma as there is no known terrane of this age in the Michigan area. It is speculated that there was once a widespread volcano-sedimentary cover sequence in Michigan which was removed or concealed prior to Chocoday Group deposition. The hydrothermal xenotime ages are coeval with the 2219 ± 4 Ma Nipissing Diabase in the Lake Huron region and the 2200-2100 Ma Kenora-Kabetogama mafic dyke swarm in Minnesota and adjacent Ontario, Lake Superior region.

Implications of Midcontinent Rift and Oceanic Ridges Analogies and 3D-Interpretations of the Subsurface Structure of the Bald Eagle Intrusion in the Duluth Complex and the East Pacific Rise

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The geometry of the gravity and magnetic anomalies of the Bald Eagle intrusion and the Duluth Complex to the south, as well as the overall Midcontinent Rift, is very similar to the pattern of the seismic reflections profiles of ridge systems (Vislova, 2003). In detail, the geophysical expressions of the Bald Eagle intrusion have the same shape and dimensions as the “bulls eye” pattern of low velocity seismic reflection anomalies along the East Pacific Rise. These anomalies are interpreted to define regions of melt concentrations, i.e., active magma chambers. This suggests that the Bald Eagle intrusion could be a “frozen” dynamic magma chamber. In support of this analogy we note that the magmatic systems of mid-ocean ridges, extensional regimes in back-arc environments, and ophiolites have a common characteristic: the emplacement of magma in extensional environments, and the common products in all four are varieties of layered intrusions, dikes and sills, and overlying volcanic rocks. There is a long history of comparative studies of ophiolites and oceanic magmatic environments (See web sites for ophiolites and the East Pacific Rise). This suggests that it would be profitable to add the studies of the igneous systems of intracontinental rifts to the current interdisciplinary, studies of ophiolites and the oceanic environments. In the accompanying poster session we explore aspects of this approach using 3D modeling of surface mapping, geophysical, and drill hole data of the basal mineralized zone of the Duluth Complex, the Bald Eagle intrusion and seismic reflection data of the East Pacific Rise.

Since its discovery in 1961, the Bald Eagle intrusion has posed unresolved questions concerning its origin and magmatic significance (Weiblen, 1965; Weiblen and Morey, 1980; Miller and others, 2002). A number of its characteristics contrast markedly with those of the other mapped intrusions in the Midcontinent Rift: (1) It has a well-defined intrusive contact in anorthositic gabbros around its perimeter except for its southern extension; (2) There is a subtle, but recognizable metamorphic contact effect on the anorthositic gabbros; (3) A primary magmatic foliation is well defined by mineral orientation and discoid segregation of plagioclase from mafic phases; (4) Over 150 measurements of the foliation define a steeply-dipping asymmetric funnel with the foliation paralleling the contact and grading from steep to horizontal inward; (5) The intrusion consists of two cumulus units, a plagioclase-olivine outer cumulate (troctolite) and an inner plagioclase-olivine-clinopyroxene (olivine gabbro) cumulate; and (6) There is only minor (< a few %) intercumulus material in the cumulates which is found as the expected lower temperature minerals in the crystallization sequence, i.e. clinopyroxene and iron oxides in the plagioclase-olivine.

Recent petrologic studies include over 2000 electron microprobe analyses and interpretations using the computer-based mineral-melt equilibria routines MELTS and COMAGMAT (Vislova, 2003). These studies indicate that the following scenario could account for the characteristics of the Bald Eagle intrusion listed above.

As up-welling magma streams through a dynamic (expanding) funnel-shaped feeder, a constant temperature appropriate to plagioclase-olivine crystallization is maintained by a balance between the heat content of the incoming magma plus the heat of crystallization and the heat loss through the chamber walls. Plagioclase and olivine are left behind and oriented/segregated on the walls of the expanding chamber. At some point conditions change and a temperature appropriate to plagioclase-olivine-clinopyroxene crystallization is established and maintained to form the inner olivine gabbro of the intrusion. This scenario could also produce the plagioclase-olivine-clinopyroxene-iron oxide cumulates found to the south of the mapped expression of the Bald Eagle intrusion. A dynamic, flow-through magmatic system raises questions about mineralization. We note that there are active “smokers” above the proposed magma chambers on the East Pacific Rise. In view of this and assuming

the analogy suggested above is appropriate, comparative studies of the smokers and the sulfide mineralization in the intrusions adjacent to the Bald Eagle intrusion may be profitable.

Applying this approach, some of the attributes of the Duluth Complex copper-nickel-PGE sulfide deposits resemble those of deposits at Noril'sk, Russia and Voisey's Bay, Canada that are associated with sulfide mineralization in intrusive feeder zones. The common attributes include occurrence in shallow tholeiitic intrusions associated with plateau basalt volcanism, an external sedimentary source of sulfur, and openness to repeated magma influx and expulsion. A critical attribute of the high-grade Noril'sk-Talnakh and Voisey's Bay deposits, not yet positively identified in the Duluth Complex deposits, is the location of a magma conduit. A conduit that experienced repeated influxes of magma appears to be key to the formation of high-grade copper-nickel-PGE deposits (Naldrett, 1997). One of the difficulties in evaluating the potential for feeder zone mineralization in the Duluth Complex is determining whether intrusions were fed one-by-one by local magma conduits or by master conduits that sequentially fed several intrusions. Another long-standing question is the source of sulfur. In the case of the Noril'sk deposits, Jurassic sediments are obvious candidates as are the Virginia and Biwabik Iron formations for the mineralization at the base of the Duluth Complex. However, designation of these sources begs the question of how, when, and where the sulfur is delivered to the magmatic system. This is more straightforward with regard to smokers: circulating hydrothermal solutions deliver sulfur from sea water directly to magma chamber vents. We suggest that consideration of this mechanism in the Midcontinent Rift magmatic systems could provide new insights for exploration targets.

Field mapping (Green and others, 1966; Foose and Cooper, 1978) showed the Bald Eagle and the South Kawishiwi intrusions to be in direct contact. Petrologic observations and geophysical interpretations (Chandler, 1990; Chandler and Ferderer, 1989) suggest that the Bald Eagle and South Kawishiwi intrusions were emplaced by successive overplating of magmas from a common feeder centered on the northern Bald Eagle intrusion and extending along the trace of the macrodiike that links the Bald Eagle and South Kawishiwi intrusions. Another model relating the emplacement of the two intrusions to a single magma feeder has been presented by Miller and Severson (2002; their Fig. 6.15). This model further speculates that the Bald Eagle intrusion had a more complete differentiation sequence (this contrasts with the dynamic flow model of Vislova (2003) outlined above) that has been eroded away and that this magma system may have fed surface eruptions. At a more detailed level, Peterson (2001) interpreted the copper-PGE mineralization in the Maturi deposit and its extension to the east (Maturi Extension deposit) as indicative of magma input from the northwest via the arcing macrodiike that connects the Bald Eagle and South Kawishiwi intrusions. Peterson (2001) envisioned a confined magma flow model that invokes a change from laminar to turbulent flow beneath a pillar of older anorthositic series rocks, increasing the R-factor of the entrained sulfides, and resulting in higher metal contents of the exited (Maturi deposit) and remaining (Maturi Extension deposit) sulfide fraction. If correct, this model predicts that a Voisey's Bay-type copper-nickel-PGE massive sulfide body may exist in an area south of the Spruce Road deposit.

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Textural Examination of Kama Point Diabase Sill, Nipigon, Ontario

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The texture of an igneous rock provides valuable constraints on the cooling history of the magma from which it crystallized. When combined with mineralogical data, the sizes and abundances of crystals in a rock reflect the interactions between the thermal and chemical evolution of the parent magma. In order to avoid uncertainty relating to the absolute magnitude of kinetic parameters such as nucleation and growth rates, this study focuses on textural gradients. These gradients reflect differences in crystallization history and magma composition, and are related to differences in the thermal and compositional state of the magma.

The lowermost 35 meters of the 1100 Ma olivine diabase sill at Kama Point, approximately 25 km east of Nipigon, Ontario, has been sampled at ~3 meter intervals from the basal contact upwards. For each sample, textures were quantified using crystal size distributions (CSDs) as well as measurement of mean crystal size. As expected, the CSDs exhibit a clear coarsening-inwards trend through the lowermost 25 meters of the sill. However, above 25 meters, the texture becomes finer-grained. Above this, the coarsening-inwards trend continues, but with a lesser gradient (Figure 1). In this study, analysis of plagioclase CSD data is shown to provide a method for quantitatively evaluating hypotheses for magmatic processes as well as important constraints on crystallization kinetics.

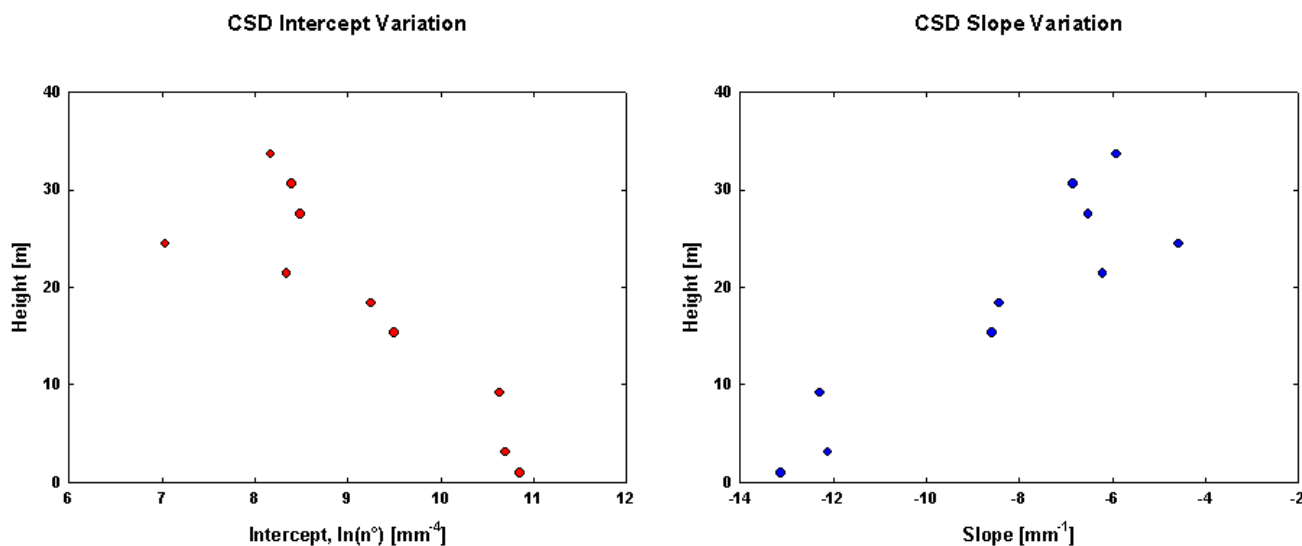


Figure 1. Variations in CSD intercept and slope. Intercept is related to the number of crystals per unit volume; slope is related to the mean length of the crystals in the sample. With increasing height above the base of the sill, the number density decreases and the mean length increases. These trends are consistent with increasing cooling durations. These

The measured textural gradients have been compared to calculated magmatic cooling durations, based on conductive cooling of an instantaneously injected 200 meter thick diabase sill. The initial conditions for the cooling model are an initial magma temperature of 1200°C and an initial country rock temperature of 100°C; far-field temperature is held at 100°C. The model is used to calculate the length of time required for the magma to cool to a temperature of 1000°C, which is the approximate solidus of the Nipigon diabase. Measured textures were compared to the calculated cooling durations (Figure 2), which yields a bulk growth rate of 1.8×10^{-10} mm/s ($R^2 = 0.925$). The total number of crystals decreases with cooling duration, consistent with a nucleation rate controlled by the degree of undercooling, which is maximized during rapid cooling.

The break in textural gradient at 25 meters is attributed to a recharge event in which a second pulse of

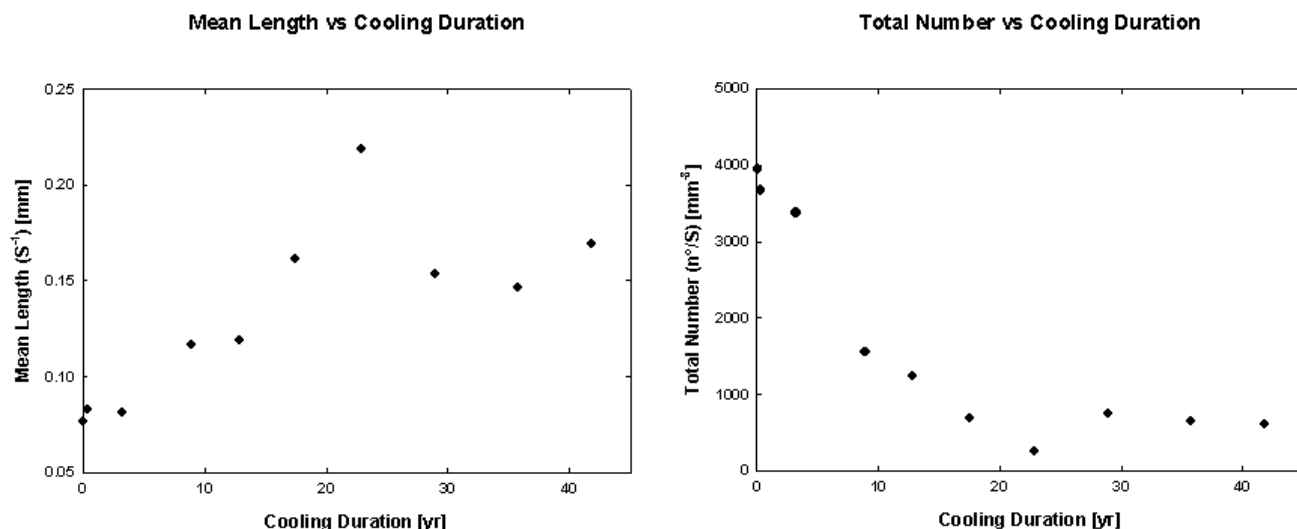


Figure 2. Variations in textural parameters obtained from CSD intercept and slope. Textural parameters are related to calculated cooling durations. 25-m break in texture corresponds to 22-yr cooling duration.

magma is injected into the magma chamber, which had at that point crystallized a thickness of 25 meters. This event is believed to have taken place approximately 22-25 years after the initial injection. Cooling of the new batch of magma was slower than cooling in the initial injection because of the cooler, previously crystallized diabase located between the fresh magma and the cold country rock. This new cooling environment qualitatively explains the change in textural gradient above the 25-m discontinuity. Additional modeling will focus on relating this discontinuity to a specific set of recharge conditions.

Further field investigation of the sills in the Nipigon area is planned. This work will extend the sampling transect higher into the sill and will include samples from higher in the sill. Goals of this research include a more thorough understanding of the injection history and original dimensions of this intrusion, as well as empirical relationships between intrusion dimensions, initial and boundary conditions, and textural profiles.

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