



INSTITUTE ON LAKE SUPERIOR GEOLOGY 48TH ANNUAL MEETING

PROCEEDINGS VOLUME 48 PART 1 –PROGRAM AND ABSTRACTS



Kenora, Ontario – May 12-16, 2002



**INSTITUTE ON LAKE SUPERIOR
GEOLOGY
48TH ANNUAL MEETING**

PROCEEDINGS

VOLUME 48

PART 1 –PROGRAM AND ABSTRACTS

CONTENTS

Proceedings Volume 48 Part 1—Program and Abstracts

Editors: K. O’Flaherty, C. Storey

Institutes on Lake Superior Geology, 1955-2002.....	iii
Constitution of the Institute on Lake Superior Geology.....	v
By-Laws of the Institute on Lake Superior Geology.....	vii
Membership Criteria for the Institute on Lake Superior Geology.....	viii
Goldich Medal Guidelines.....	ix
Past Goldich Medalists.....	xi
Goldich Medal Committee.....	xi
Citation for 2002 Goldich Medal Recipient.....	xii
Eisenbrey Student Travel Awards.....	xv
Student Travel Award Application Form.....	xvi
Student Paper Awards.....	xvii
Student Paper Awards Committee.....	xvii
Board of Directors.....	xviii
Local Committees.....	xviii
Session Chairs.....	xix
Banquet Speaker.....	xx
Report of the Chair of the 47th Annual Institute Meeting.....	xx
Program.....	xxv
Abstracts.....	1

Cover Photo: Regina Mine, 1918. The Regina Mine produced intermittently from 1895 to 1943, yielding over 8,000 ounces gold and 1,460 ounces silver. The Regina was the first mine in North America to use cyanide for gold recovery.

INSTITUTES ON LAKE SUPERIOR GEOLOGY, 1955-2002

#	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
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

**CONSTITUTION
OF THE INSTITUTE ON LAKE SUPERIOR GEOLOGY**

(Last amended by the Board—May 8, 1997)

- 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 five persons, by reason of unwillingness or inability of any of the above persons to serve as directors, the vacancies on the board may be filled by the Chair so as to bring the membership of the board to five members.
- Article VII Officers

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

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

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-Treasurer to:
 - 1. Keep accurate attendance records of all annual meetings.
 - 2. Keep accurate records of all meetings of, and correspondence between, the Board of Directors.
 - 3. Hold all funds that may accrue as profits from annual meetings or field trips and to make these funds available for the organization and operation of future meetings as required.
- C. It shall be the duty of the Board of Directors to plan locations of annual meetings and to advise on the organization and financing of all meetings.

II. 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.

MEMBERSHIP CRITERIA FOR THE INSTITUTE ON LAKE SUPERIOR GEOLOGY

Approved May 8, 1997

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-Treasurer 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 mailings in different years are returned by the postal service as address unknown.

C. The Secretary-Treasurer 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-Treasurer 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-Treasurer.

F. The Secretary-Treasurer 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-Treasurer to avoid unintentional lapse of membership.

GOLDICH MEDAL GUIDELINES

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

Preamble

The Institute on Lake Superior Geology was born in 1955, as documented by the fact that the 27th annual meeting was held in 1981. The Institute's continuing objectives are to deal with those aspects of geology that are related geographically to Lake Superior; to encourage the discussion of subjects and sponsoring field trips that will bring together geologists from academia, government surveys, and industry; and to maintain an informal but highly effective mode of operation.

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

The first award was made by ILSG to Sam Goldich in 1979 for his many contributions to the geology of the region extending over about 50 years. Subsequent medalists 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 medalist, 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.

PAST GOLDICH MEDALISTS

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

2002 *Ernest K. Lehmann*

GOLDICH MEDAL COMMITTEE

Ron Sage (2002) Ontario Geological Survey, Thunder Bay

Rod Johnson (2002) Rod Johnson and Associates, Negaunee, Michigan

Frank Luther (2003) University of Wisconsin, Whitewater

James D. Miller, Jr., as out-going senior member of Institute Board of Directors, is liaison between Goldich Medal Committee and the Board through 2001 meeting.

Citation
Ernest K. Lehmann
2002 Goldich Medal Recipient

Ladies and Gentlemen:

Thank you for being here tonight for this presentation of the 2002 Sam Goldich Medal Award.

I don't know if any of you remember the late Ben Dickerson. He was one of the premier exploration geologists of his time and wrote a column in Skillings Magazine. The column was called "News and Rumor" from the Bush". It described current exploration activity particularly in the U.S. during those golden years of the 70's and 80's. At that time the exploration community was quite small and Ben seemed to know everyone. His column was cryptic in that he would commonly refer to people in coded names. For example there was the "Great Buawa" and the "Shallow". Ernie was referred to as the **"Bearded Sphinx of the North"**. I'm not sure where that came from, but know the "Sphinx" was "good copy" because he was so active in minerals exploration particularly in the Great Lakes region in those days as he certainly is today. I had the good fortune and privilege of working with Ernie for nearly two decades.

Over the years, his list of accomplishments in the field of economic geology and mineral exploration are many. It would take hours to go through them all. So I will focus on those related to the Lake Superior area. First some background.

Ernie was born in 1929 in Heidelberg, Germany. He was educated in the public schools of New Rochelle, N.Y., attended Williams College, in Williamstown, Massachusetts, where he graduated cum laude in geology in 1951. He attended graduate school in geology at Brown University, Providence, Rhode Island, and completed the Owners and Presidents Management Program of the Harvard Business School in 1984. He is married to Sally Willius Lehmann (his better half) and resides in Minneapolis, Minnesota.

Prior to founding Ernest K. Lehmann & Associates, Inc. in 1967, Ernie was an independent consultant and partner in a Minneapolis based geological consulting firm from 1958 to 1967. In 1950, he began his career by working first as a miner and then as geologist for the Signal Mining Company at Bannack, Montana. From 1951 to 1958, Ernie worked for Kennecott Copper Corporation and its exploration arm, Bear Creek Mining Company. Ernie served on active duty as a Terrain Intelligence Analyst in the U.S. Army Corps of Engineers from 1953 to 1955 and was awarded the Commendation Ribbon for his service.

As many of you know, Ernie is the founder and CEO of North Central Mineral Ventures Inc. and of Ernest K. Lehmann & Associates, Inc. Under his leadership, the firms have engaged in the planning, management and execution of mineral exploration programs, mineral deposit development, mine appraisal and mineral economic studies particularly in the Great Lakes region. These activities have spanned most important hard mineral commodities including ferrous, non-ferrous, precious and strategic metals, industrial minerals and fertilizer raw materials. In the course of their activities, he and his firms have been active in staffing and managing exploration and mine development projects and acquiring private and public mineral

lands in both the U.S. and abroad. The latter activities have included claim staking, mineral leasing of private, state and federal lands, and the creation and management of mineral joint ventures. In addition to extensive work in the US and Canada, he has conducted and managed exploration and consulted on mine development and evaluation Central and South America, Africa and Europe.

In the course of his activities, Ernie has specialized in exploration management and in mineral deposit appraisal evaluation. He has appeared extensively as an expert witness on mineral property appraisal and taxation and on mining claim related issues. He has served on advisory committees to the Office of Technology Assessment of the U.S. Congress on strategic and critical minerals and to the state of Minnesota on direct reduction of iron ores. On behalf of the American Institute of Professional Geologists, he has testified before Congress on strategic minerals issues and on the 1872 mining law. He has also testified before Congress on issues related to the Federal Land Management Policy Act. Before state legislative committees, he has testified on mineral property appraisal, mineral taxation, mineral leasing and mine permitting.

In 1985, he became president of the American Institute of Professional Geologists, also serving the Institute in various other capacities on a state and national level. In 1987, he was awarded the Ben H. Parker Medal, the Institute's highest award for service to the geological profession, and has been awarded Honorary Membership in the Institute in 1997. He currently serves as Chairman of the AIPG Foundation and is a member of numerous other technical and professional bodies including the Society of Economic Geologists, The Mining and Metallurgical Society of America, the Society of Mining Engineers, the Society for Geology Applied to Mineral Deposits, and the Northwest Mining Association. He is a registered geologist in Minnesota, California, Georgia, Delaware and Alaska and is accredited by the European Federation of Geologists. He is currently a director and president of the Minnesota Exploration Association and serves on various committees in Minnesota in this capacity, including the Blue Ribbon Committee on Minnesota Minerals, the advisory board to the Natural Resources Research Institute and the State Mapping Advisory Committee.

Ernie has also been actively involved in mining related environmental issues again particularly in the Great Lakes area. He was instrumental in initiating and executing the Minnesota Mining Permit Simulation Project, a joint state agency, environmental community and industry effort to examine the mine permitting process and problems for non-ferrous metal mining. He helped organize a workshop on financial assurance in the mining industry in cooperation with the Minnesota DNR, MPCA, and the Audubon Society. Ernie and the firm were consultants to the state of Maine charged with developing metal mining regulations, spanning activities from exploration through operation and closure. The firms were also involved in mine permitting activities in Wisconsin.

To this I would like to mention some of the major projects Ernie has initiated in the Great Lakes area. These include:

- 1) Exploration programs for Bear Creek in 1952, 1956 through 1957 for copper and copper nickel in the Duluth and Mellon Gabbro Complexes and Nonesuch Shale.

2) Copper and copper-nickel exploration projects carried out for Cerro Corp. from 1967-1969 in Wisconsin, Minnesota, Michigan and Ontario. He was one of the first explorationists to recognize the Wisconsin greenstone belts as an important VMS target .

3) VMS exploration joint ventures in Wisconsin that spanned from 1975 through 1993. Such notables as Getty, Chevron, Denison Mines and Asarco were involved with these projects. Under the supervision of the late Ned Eisenbrey, these programs resulted in three discoveries. Of these one, the Bend copper-gold deposit, is and remains potentially economic. The huge amount of geologic and geophysical data generated from these exploration projects also resulted in establishing a more detailed “geologic framework” that was previously lacking for the Wisconsin greenstone belts. This work culminated in several papers published in “Economic Geology” in 1990 and 1994.

4) At the same time Ernie was managing a major VMS program in Archean of northern Minnesota from 1979 through 1985 for Getty and Billiton.

5) From 1980 to 1982, Ernie was one of the first to seriously begin exploring the interior of the Duluth Complex for copper-nickel and PGMs through a joint venture with Billiton. His exploration efforts continue today with a focus on the Birch Lake PGM project that involves Impala.

I believe Ernie’s past and present exploration and political efforts in Minnesota today has resulted in the current brisk activity within the Duluth Complex and transformed the state to an attractive part of the world to conduct environmentally responsible mining projects.

Finally, with deep gratitude and respect, I would like to present this year’s Sam Goldich medal recipient, my mentor and friend, Ernest K. Lehmann.

Theodore A. DeMatties

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-Treasurer. Recipients will be announced at the annual banquet.

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

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

Successful applicants will receive their awards during the meeting.



Eisenbrey Student Travel Award Application

Student Name: _____ Date: _____

Address: _____

email: _____

Department Head-Typed

Educational Status: _____

Department Head-Signature

Are you the senior author of an oral or poster paper? YES_____ NO_____

Will any other students be traveling with you?

Who? _____

Statement of need (use additional page if necessary)

Please return to:

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 1997—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 and Secretary-Treasurer, but typically is in the amount of about \$300 US.
- 6) The Secretary-Treasurer 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

Peter Hollings Lakehead University, Thunder Bay

Neil Pettigrew Avalon Ventures Ltd., Thunder Bay

Connie Dickens U.S. Geological Survey, Reston, Virginia

BOARD OF DIRECTORS

Mike Mudrey, Chair Wisconsin Geological and National History Survey, Madison, Wisconsin

2000-2003

Steve Kissin, Department of Geology, Lakehead University, Thunder Bay, Ontario

1999-2002

Ted Bornhorst, Department of Geological Engineering and Sciences, Michigan Tech University Houghton, Michigan

1998-2001

Jim Miller, Minnesota Geological Survey, St. Paul, Minnesota

Secretary-Treasurer

Mark A. Jirsa, Minnesota Geological Survey St. Paul, Minnesota

LOCAL COMMITTEE

Peter Hinz,

Ontario Geological Survey, Resident Geologist Program, Kenora, ON

Richard C. Beard,

Northwest Mineral Development Services, Kenora, ON

Charles E. Blackburn,

Blackburn Geological Services, Kenora, ON

Christine Blackburn,

Blackburn Geological Services, Kenora, ON

Kevin O'Flaherty,

Kenora, ON

Carmen Storey,

Ontario Geological Survey, Resident Geologist Program, Red Lake, ON

Kathleen McGowan-Hinz,

Kenora, ON

SESSION CHAIRS

Alasdair Mowat Emerald Fields Resource Corp., Kenora

Philip Fralick Lakehead University, Thunder Bay

Mark Smyk Ontario Geological Survey, Thunder Bay

2002 BANQUET SPEAKER

L. Harvey Thorleifson
Geological Survey of Canada
Ottawa, Ontario

The Search for Diamonds in Canada

REPORT OF THE CHAIR OF THE 47TH ANNUAL MEETING

Michael G. Mudrey, Jr.

Chair ILSG 2001

The 47th Annual Institute on Lake Superior Geology was jointly hosted by the University of Wisconsin-Extension Geological and Natural History Survey and the University of Wisconsin-Madison, Department of Geology and Geophysics, in Madison, Wisconsin on May 9-12, 2001. Principal local committee members were M.G. Mudrey, Jr. and B.A. Brown, co-chairs, Robert H. Dott, Jr, and L.Gordon Medaris, Jr., Program-cochairs, and Kathleen M. Zwettler, Meeting Coordinator. Other principal individuals are listed in the Proceedings Volume.

Attendance at ILSG 2001

A total of 172 professionals and student professionals attended the meeting, 82 of whom pre-registered by the April 2, 2001 deadline. A total of 26 students were registered, ten of whom requested and received travel assistance and had registration fees for the meeting waived.

Eisenbrey Student Travel Awards 2001

Ten students requested and received travel assistance from the Eisenbrey Student Travel Award Fund established to support student participation at the Annual Institute. Details, including criteria and application forms are available at the Eisenbrey website.

Justin Johnson-	Lakehead University-Thunder Bay, Ontario - Fluid Inclusion Evidence for a Role for Hydrothermal Activity in the Roby Zone, Lac Des Iles Mine, Northwestern Ontario;
Becky Rogala-	Lakehead University-Thunder Bay, Ontario - A Metamorphosed Evaporite Sequence from the Sibley Basin ;
Dan Bihari-	Lakehead University-Thunder Bay, Ontario - Alteration and Pge-au Mineralization in the North Roby Zone, Lac Des Iles Mine, Northwestern Ontario;
Phillip Larson-	University of Minnesota-Duluth - Potential for Copper Mineralization in the Animikie Group, Minnesota;
Michael Nemitz-	University of Minnesota-Duluth - Mineralogical Variations in Iron-formation in the Thermal Metamorphic Aureole of a Diabase Dike;
Lisa Larson-	University of Minnesota-Duluth - ;
Muhammad Asif Soofi-	Purdue University, West Lafayette, Indiana - Post-rift Evolution of the Midcontinent Rift System: Some Numerical Experiments;
Jason Odette-	University of Wisconsin-Oskosh - Preliminary Evaluation of Hydrothermal Alteration Mineral Assemblages and Their Relationship to VMS-style Mineralization in the Five Mile Lake Area of the Archean Vermilion Greenstone Belt, Northeastern Minnesota ;

Trent Newkirk-	University of Wisconsin-Oskosh - Preliminary Lava Flow Morphology Studies at the Five Mile Lake Vms Prospect, Archean Vermilion District, Ne Minnesota: Implications for Volcanic Processes, Volcanic Paleoenvironments, and VMS Exploration ; and
Dan Schweitzer-	Kent State University-Kent Ohio - Results of Igneous Thermometry and Barometry on the East-central Minnesota Batholith: Evidence for Post-emplacement Exhumation and Cooling .

Meeting Summary

The 47th Annual Institute on Lake Superior Geology Annual Meeting was held at the Sheraton Madison Hotel, the same location as the 1973 meeting. The 2001 meeting focused on hydrogeologic aspects of arsenic in groundwater, completion of acquisition of detailed regional geophysical data; the evolution of the post-Penokean--pre-Keweenawan crystal terrane of North American in 36 poster displays and 32 oral presentations . The two days of technical sessions were preceded by Field Trip 1 - Sedimentologic, Tectonic and Metamorphic History of the Baraboo Interval led by L. Gordon Medaris, Jr. , and Robert H. Dott, Jr. (University of Wisconsin-Madison) , and followed by Field Trip 2 - Upper Mississippi Valley Zinc-Lead District led by M.G. Mudrey, Jr. (Wisconsin Geological and Natural History Survey) and Thomas C. Hunt (University of Wisconsin-Platteville) and Field Trip 3- Industrial Mineral and Aggregate Resources of the Baraboo Interval Quartzites lead by Bruce A. Brown (Wisconsin Geological and Natural History Survey), Frank R. Luther (University of Wisconsin - Whitewater), James W. Schmitt (D.L. Gasser Construction), Susan M. Courter (Michels Materials) and Jennifer Lien (The Kraemer Company)

The meeting began with regional geologic summaries of the Pleistocene of Southern Wisconsin by D.M. Mickelson (University of Wisconsin-Madison) and Lee Clayton (Wisconsin Geological and Natural History Survey), Sequence Stratigraphic Analysis of the Paleozoic by Charles E. Byers (University of Wisconsin-Madison), and Stratigraphic Metamorphic Analysis of the Baraboo Supracrustal Rocks of the Midcontinent by L. Gordon Medaris, Jr. , (University of Wisconsin-Madison). A series of invited presentations completed the morning of the first technical sessions three presentations on Aeromagnetic Investigations in the Midwest. An invited presentation on an Overview of Arsenic Occurrences and Processes Controlling Arsenic Mobility in Ground Water by D. Kirk Nordstrom (U.S. Geological Survey) kicked off a special session of four papers on the Hydrogeologic Setting of Elevated Arsenic and Heavy Metals in Public and Private Water Supplies. General geologic topics completed the first day. Three papers on the Midcontinent Rift started Friday morning, followed an invited symposium of eight papers on the Thermo-Thermo-Tectonic History of 1800 to 1200 Ma post-Penokean to pre-Keweenawan. The remaining significant presentations dealt with Archean and platinum-group element geology. The technical program was completed by 3:30 p.m. Proceeding including Part 1 (Programs and Abstracts) and Part 2 (Field Trip Guidebook) are available from the Institute .

Best Student Paper Awards for 2001 were presented to Alissa Naymark-University of Wisconsin-Madison (oral) Cash award plus chrome-plated drill bit donated by Layne Northwest Travis Sandland-Macalester College (poster) and Erin H. Phillips-Macalester College (poster) Jason D. Odette-University of Wisconsin-Oshkosh (poster) Trent T. Newkirk-University of Wisconsin-Oshkosh (poster)

After the break, Mike Mudrey and Bruce Brown regaled the remaining participants with previews of their field trips (Field Trip 3 was eventful in that a flat tire delayed the trip (How many ILSGers does it take to change a tire? Three! Frank Luther, Mark Jirsa and Bob Reszka), and Brad Singer and John Valley lead the group on an impressive tour of the isotope laboratories in the Department of Geology and Geophysics. The entire group of ILSG participants remaining in Madison joined the Department of Geology and Geophysics Geology Club for the annual Departmental Picnic courtesy of contributions from Steve Kircher, Crandon Mine Development, Nicolet Minerals, and William J. Cronk, Layne Northwest, directly to the Institute.

Annual Banquet and Goldich Award

At the Annual Banquet Bruce R. Doe prepared, and Michael G. Mudrey, Jr. delivered a biographic history of Samuel S. Goldich who passed away on 20 December 2000 in Applewood, Colorado. After the introduction of 6 of the surviving Goldich recipients, an upbeat Gene LaBerge presented John S. Klasner with the Goldich Medal for 2001 for his contributions to the Institute and Lake Superior Geology. Tom Hunt illustrated the successful reclamation of the Ladysmith Mine of Kennecott Mining for the after dinner address, and Peter Hinz of the Ontario Geological Survey invited participants to the 48th Annual Meeting in Kenora .

Best Student Paper Awards for 2001

Alissa Naymark-University of Wisconsin-Madison (oral) Cash award plus chrome-plated drill bit donated by Layne Northwest
Travis Sandland-Macalester College (poster)
Erin H. Phillips-Macalester College (poster)
Jason D. Odette-University of Wisconsin-Oshkosh (poster)
Trent T. Newkirk-University of Wisconsin-Oshkosh (poster)

Details of presentations are found in the Proceedings and Abstracts for the 47th Annual Meeting .

After the break, Mike Mudrey and Bruce Brown regaled the remaining participants with previews of their field trips (Field Trip 3 was eventful in that a flat tire delayed the trip (**How many** ILSGers does it take to change a tire? Three! Frank Luther, Mark Jirsa and Bob Reszka), and Brad Singer and John Valley lead the group on an impressive tour of the isotope laboratories in the Department of Geology and Geophysics. The entire group of ILSG participants remaining in Madison joined the Department of Geology and Geophysics Geology Club for the annual Departmental Picnic courtesy of contributions from Steve Kircher, Crandon Mine Development, Nicolet Minerals, and William J. Cronk, Layne Northwest, directly to the Institute.

Proceedings including Part 1 (Programs and Abstracts) and Part 2 (Field Trip Guidebook) are available from the Institute .

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**48th ANNUAL MEETING
INSTITUTE ON LAKE SUPERIOR GEOLOGY**

Program

Program of Events

Sunday, May 12

06:00 - 18:00 Field Trip 1: Tanco Rare-Element Pegmatite, Southeastern Manitoba

Monday, May 13

08:00 - 18:00 Field Trip 2: Quaternary Geology of Southeastern Manitoba

08:00 - 16:00 Field Trip 3: Structure and Sedimentology of the Seine Conglomerate, Mine Centre Area, Ontario

17:00 – 20:00 Registration – Best Western Lakeside Inn, Kenora, Ontario

19:00 – 21:00 Ice-Breaker Social and cash bar in Best Western Lakeside Inn
(Authors at poster from 19:30 to 21:00)

TUESDAY MAY 14

8:00 a.m. - 9:00 a.m. **REGISTRATION**

9:00 a.m. **INTRODUCTORY REMARKS**

P. Hinz Co-Chairman, *Ontario Geological Survey, Kenora, ON*

TECHNICAL SESSION I:

Session Chair: Mark Smyk, District Geologist, *Ontario Geological Survey, Thunder Bay, ON*

9:15 a.m. **K. O'Flaherty**, (*Consulting Geologist, Kenora, ON*)

A Brief History of Mining in Northwestern Ontario

9:40 a.m. **M. Sanborn-Barrie***, **T. Skulski**, **N. Rayner**, (*Geological Survey of Canada, Continental Geoscience Division, Ottawa, ON*) and **J.R. Parker** (*Ontario Geological Survey, Precambrian Section, Sudbury, ON*)

300 my evolution of the Red Lake greenstone belt, western Superior Province, Ontario: A synthesis of current constraints on volcanism, sedimentation, deformation, metamorphism and gold mineralization

10:05 a.m. **COFFEE BREAK AND POSTER SESSION**

10:30 a.m. **B. Nitescu***, **A. R. Cruden**, **A. R. Bailey**, (*University of Toronto, Toronto, ON*)
Crustal Models of the Western Superior Province from gravity and Lithoprobe seismic data.

10:55 a.m. **P. Fralick*** and **King**, (*Department of Geology, Lakehead University, Thunder Bay ON*)

Mesoarchean evolution of Western Superior Province: evidence from metasedimentary sequences near Atikokan

11:20 a.m. **M.A. Jirsa**, (*Secretary-Treasurer, ILSG, St. Paul, MN*)

A Report on the Secretary-Treasurer's Position

LUNCH BREAK

ILSG BOARD MEETING (*by invitation*)
POSTERS

TECHNICAL SESSION II:

Session Chair: Alasdair Mowat, Emerald Fields Resource Corp., Kenora, ON

- 1:30 p.m. **D. Peterson**, (*Natural Resources Research Institute, University of Minnesota-Duluth, Duluth, MN*)
Cu-Ni-PGE Mineralization in the South Kawishiwi intrusion; North Western Minnesota. Variation due to magmatic processes.
- 1:55 p.m. **B. Rogala*, P.W. Fralick, and G. Borradaile**, (*Department of Geology, Lakehead University, Thunder Bay, Ontario*)
New Information from the Sibley Group
- 2:20 p.m. **M.A. Jirsa**, (*Minnesota Geological Survey, St. Paul, MN*)
Archean and Paleoproterozoic mafic intrusions in Minnesota
- 2:45 p.m. **COFFEE BREAK AND POSTER SESSION**
- 3:15 p.m. **C. Sturm**, (*Geology Department, Oberlin College, Oberlin, OH*)
Petrographic study of the Otter Tail Pluton, Superior Province, Northwestern Ontario
- 3:40 p.m. **G. Ferguson* and A. Woodbury**, (*Department of Civil Engineering, University of Manitoba, Winnipeg, MB*)
Ground water and heat flow in an interlobate moraine in southwestern Manitoba.
- 6:00 p.m. **SOCIAL - Cash Bar**
- 7:00 p.m. **Annual Banquet and Award Presentation**
- **Announcement of 49th Annual Meeting Location**
 - **2002 Goldich Award Presentation to Mr. Ernie Lehmann, Citation by Ted Dematties**
 - **Banquet Speaker: Dr. L. Harvey Thorleifson, Geological Survey of Canada**
The Search for Diamonds in Canada

WEDNESDAY MAY 15

8:00 a.m. - 9:00 a.m. **REGISTRATION**

9:00 a.m. **INTRODUCTORY REMARKS**

R.C. Beard Co-Chairman, *Northwest Mineral Development Services, Kenora, ON*

TECHNICAL SESSION III:

Session Chair: Philip Fralick, *Lakehead University, Thunder Bay, ON*

9:15 a.m. **H.H. Woodard**, (*Department of Geology, Beloit College, Beloit, WI*)

Internal structures within crustal structural slabs, Quetico-Wawa subprovince junction, Quetico Provincial Park, Ontario

9:40 a.m. **R. Bernatchez**, (*Atikokan Resources Ltd., Atikokan, ON*)

Mesoarchean Base Metal Systems in the Atikokan Area, NW Ontario, Canada

10:05 a.m. **COFFEEBREAK AND POSTER SESSION**

10:30 a.m. **L.G. Medaris***, **B.S. Singer**, **P.E. Brown**, **B.R. Jiccha**, **M.E. Smith**, (*University of Minnesota-Duluth, Duluth, MN*)

Wolf River age brecciation in the Baraboo quartzite, Wisconsin: implications for Proterozoic tectonics in the Lake Superior Region.

10:55 a.m. **D.L. Southwick**, (*Minnesota Geological Survey Ret'd, Pacitas, NM*)

Inferences from the Hatterberger deep drill hole, Carlton County, Minnesota, pertinent to regional stratigraphy and mineral potential of the western segment of the Penokean Orogen

11:20 a.m. **J.C. Pedersen*** and **D. Bubar**, (*Avalon Ventures Ltd., Toronto, ON*)

Mineralogy and zonation of the Big Whopper Pegmatite, Separation Rapids, Kenora area, Ontario

11:45 a.m. **M.A. Jirsa** (*Secretary-Treasurer, ILSG, St. Paul, MN*)

Discussion on the Secretary-Treasurer's Position

12:00 **Presentation of Student Paper Awards**

LUNCH BREAK

3:00 p.m. **FIELD TRIP 6: Departs for Red Lake.**

Thursday, May 16

08:00 - 18:00 Field Trip 4: Industrial Minerals and Paleozoic Geology of Southeastern Manitoba

08:00 - 16:00 Field Trip 5: Separation Rapids Rare-Element Pegmatite Field, Ontario

08:00 - 18:00 Field Trip 6: Geology of the Red Lake Camp, Ontario

POSTER PRESENTATIONS

Boerboom, T. (*Minnesota Geological Survey, St. Paul, MN*)

The influence of Archean crustal structures on the margin of the Penokean orogen near Pope County, west central Minnesota.

Buchholz, T.W. (*Wisconsin Rapids, WI*); **Falster, A.U. and Simmons, Wm. B.**

(*University of New Orleans, New Orleans, LO*).

Heterogeneity in the nine mile pluton, wausau complex, in terms of high field strength element (hfse) and rare earth element (ree) bearing minerals

Cannon, W.F., (*USGS, Reston, VA*), **Laberge, G.L.** (*Oshkosh, WI*), **Klasner, J. S.**,

(*Macomb, IL*), **Dicken, C.**, (*USGS, Reston, VA*)

Geology of the western Gogebic Iron Range, northwest Wisconsin—a record of sedimentation and deformation across the northern margin of the Penokean orogen

Fein, E., (*Oberlin College, Oberlin, OH*)

Anisotropy of magnetic susceptibility in the Otter Tail Pluton, Northwestern Ontario

Hubin, J. and Cordua, Wm. (*University of Wisconsin, River Falls, WI*)

SEM imaging of fossil nannobacteria from the supergene zone, Flambeau copper mine, Ladysmith Wisconsin.

Johnson, J.R., Kissin, S.A. and Hollings, P. (*Lakehead University, Thunder Bay, ON*)

VHMS mineralization and alteration within the Lumby Lake Greenstone Belt, Northwestern Ontario

Kelso, I.S. and Kissin, S.A. (*Lakehead University, Thunder Bay, ON*)

Geology and fluid inclusion studies of the Thunder Bay Agate Mine, Northwestern Ontario

Miller, J.D. Jr.¹, Green², J.C., Severson³, M.J., Chandler¹, V.W., Peterson³, D.M., Hauck³, S.A., and Wahl¹ T.E., (¹*Minnesota Geological Survey, St. Paul, MN*, ²*University of Minnesota–Duluth, Duluth, MN*, ³*Natural Resources Research Institute, Duluth, MN*)

New geologic map and report of the Duluth Complex and related rocks, Northeastern Minnesota.

R.L. Patelke, (*Natural Resources Research Institute, University of Minnesota-Duluth, Duluth, MN*)

Digital Drill Logs for the Duluth Complex - Lithology and Assays

Peterson, D.M. (*Natural Resources Research Institute, University of Minnesota-Duluth, Duluth, MN*)

3-Dimensional View Through a Mineralized System: the South Kawishiwi Intrusion,
Duluth Complex

Severson, M.J. (*Natural Resources Research Institute, University of Minnesota-Duluth, Duluth, MN*)

The Mine Permitting Process in Minnesota - Who, What, Where, and When.

Sikkila, K. (*Wisconsin Department of Transportation, Superior, WI*)

Description of a pegmatite occurrence on the eastern margin of the Mellen Granite, State Highway 13, Ashland County, Wisconsin

Woodruff, L.G. (U.S. Geological Survey, Mounds View, MN), **W. F. Cannon, and C. Dicken,** (U.S. Geological Survey, Reston, VA)

Impact of fire on the forest floor and mineral soils, Snowbank Lake, Minnesota

COMPANY POSTERS

Avalon Ventures Ltd., 111 Richmond Street West, Suite 1116 Toronto, ON M5H 2G4

Emerald Fields Resource Corp., 1546 Pine Portage Road Kenora, ON P9N 2K2

Goldcorp Inc., Balmertown, ON P0V 1C0

Nuinsco Resources Ltd., 940 The East Mall, Suite 110 Toronto, ON M9B 6J7

48th ANNUAL MEETING
INSTITUTE ON LAKE SUPERIOR GEOLOGY

Abstracts

Mesoarchean Base Metal Systems in the Atikokan Area, NW Ontario, Canada

Bernatchez, R. (*Atikokan Resources Ltd., Atikokan, ON*)

A high grade silver-lead-zinc showing was discovered in the Lumby Lake Metavolcanic Belt in 1995 between Lumby and Herontrack Lake 100 meters north of the creek. Three grab samples taken from this showing returned an impressive 109, 189 and 416 oz Ag/ton with other samples assaying up to 25% lead and 8% zinc.

Since 1995, Atikokan Resources has carried out an extensive exploration program consisting of detailed geological mapping, a 2292 sample soil survey, a 150 whole rock geochemical survey, ground geophysical magnetic, electromagnetic and IP surveys (dipole-dipole and Gradient array) and seven diamond drill holes over a grided area 6.6 km E-W x 2 km N-S from the west end of Lumby Lake to Hutt Lake. All but one diamond drill hole was drilled on the main high grade silver discovery area located between Lumby and Herontrack Lake.

This work has been successful in defining a world class size VMS system. This VMS system is located near the base of the southern limb of the Lumby Lake Mesoarchean Syncline. The detailed geological mapping has identified at least three major eruptive cycles of predominantly intermediate to felsic pyroclastic and tuffaceous rocks. Each eruptive cycle has been terminated with the deposition of exhalative chert and sulphides. These three horizons have been identified as the Lumby-Spoon Lake (southern), Delos Lake and Pond Lake (northern) Horizon. Most of the mechanical stripping has been focused on the Lumby-Spoon Lake Horizon. The rocks along the top portion of the Delos and Pond Lake Horizon are poorly exposed. Limited portions of these two horizons were exposed by mechanical stripping near the west end of each lake.

The main high grade silver-lead-zinc discovery is located at the top of the Lumby-Spoon Lake Horizon. This horizon has now been traced from outcrop exposure and drilling for a distance of about 3 kilometers. This east-west striking horizon consists of four or more repeated sub-cycles of quartz-phyric rich tuff, lapilli tuffs (coarse and fine) and chert mineralized with sulphides. The mineralization is contained within the chert, tuff, lapilli tuff in the form of dissemination, stringers and semi-massive sulphide beds. The sulphide mineralization consists of sphalerite, galena, native silver, acanthite, pyrite, chalcopyrite and pyrrhotite. Each felsic cycle vary in thickness from a few meters up to 20-25 meters. The upper cherty portion of each cycle contains is usually mineralized with sphalerite, galena and acanthite and/or native silver. The tuff lapilli tuff section generally contains stringer mineralization of chalcopyrite, pyrite with minor sphalerite, galena acanthite and pyrrhotite. The main high-grade silver showing within the Lumby-Spoon Lake has been drill-tested with six diamond drill holes along an east-west strike length of 450 meters and down to a depth of about 400 meters. Mineralization has been intersected in drill holes over core length from 13 metres and up to 82 metres. Native silver was observed in all six holes drilled on the Lumby-Spoon Lake Horizon. The zone is still open at depth and on strike east and west. In total, the four or five sub-cycles forms a mineralized horizon measuring over 200 meters wide in the main showing area.

The geology, mineralogy and alteration of the mapped area have shown strong similarity with other VMS deposits found in the Archean, Proterozoic, and Mesozoic Eras. The drilling and litho geochemical rock sampling have shown the classic footwall chloritic and/or talc alteration, sericitic hanging wall alteration, zinc-lead-silver capping and footwall stringer mineralization. The litho geochemical rock sampling has shown areas of sodium depletion and potassium enrichment within the felsic rocks and magnesium enrichment within the footwall. This alteration appears to be parallel to sub-parallel to the stratigraphy. The felsic volcanoclastic rocks appear to have been derived from a highly fractionated sub-volcanic magma and have been classified as F2 and F3a type rhyolites.

A new exploration program of detailed geological mapping, litho geochemical sampling and ground geophysical magnetic and electromagnetic surveys carried out in the Richardson Lake area, 12 km east and on strike with the main high grade silver-lead-zinc showing, has identified similar thick felsic bi-modal volcanoclastic rock sequence. It appears to be the easterly extension of the island arc at Lumby Lake. Several new base metal occurrences have been discovered and are contained within similar quartz- spheric felsic volcanoclastic rocks similar to those found in the Lumby Lake felsic rocks.

K. Tomlinson of the GSC (2000) has identified island arc volcanism in both the southern and northern limb and at the base of the Lumby Lake Meta-volcanic Belt. The work carried out to date by ARI has shown that at least two island arc systems may exist within the lower portion of the southern limb of the Lumby Lake Meta-volcanic Belt. It is however, conceivable, that more than two island arc systems exist in this part of the belt.

Recent work by ARI in the upper portion of the belt, north of the synclinal fold axis in the northern limb, has identified a different style of mineralization contained within sulphide facies IF. It is unknown at this time if these two styles of mineralization are related to the same volcanic event of island arc building.

It is possible that the Lumby Lake Meta-volcanic Belt may contain world class size VMS deposits yet undiscovered. The results obtained to date by Atikokan Resources Inc. shows that potential. ARI continues to explore and find previously identified and unidentified VMS base metal style mineralization in the Lumby and Finlayson Lake Meta-volcanic Belts.

The influence of Archean crustal structures on the margin of the Penokean Orogen near Pope County, West-central Minnesota

Boerboom, T. J., (*Minnesota Geological Survey, St. Paul, MN (boerb001@umn.edu)*)

The western margin of the Paleoproterozoic Penokean Orogen in Minnesota is marked by a series of northwest-trending, sawtooth-like fault offsets, or tear faults, that correspond in space but not in orientation to major northeast-oriented block-bounding shear zones within the adjacent Archean Minnesota River Valley subprovince (Figs. 1A and 1B). The origin of these tear faults, whether reactivated Archean structures or structures formed strictly during the Penokean orogenic cycle is not clear, but they may be the result of scissors faulting focused on preexisting weaknesses in the crust during pre-orogenic extension.

Pope County was mapped as part of the Minnesota Geological Survey County Atlas geologic mapping program, supported by the Minnesota Department of Natural Resources, Division of Waters. The bedrock there is deeply buried beneath glacial drift, and there are only six drill cores available for the 720 square mile (1900 square kilometer) county. Considering this, it is obvious that any geological interpretation of the bedrock geology is more accurately described as an interpretation of geophysical characteristics; nevertheless, several prominent structural features can be recognized from the geophysical data.

The Minnesota River Valley subprovince has been subdivided into four blocks—the Benson, Montevideo, Morton, and Jeffers blocks, from north to south (Fig. 1B). Each of these crustal blocks is separated by straight and narrow east-northeast-trending geophysical lineaments that have been shown to be north-dipping shear zones (Southwick and Chandler, 1996; Southwick, 2002).

In Minnesota, the western margin of the Paleoproterozoic Penokean Orogen changes from a northeast orientation that is roughly parallel to the Wawa-Minnesota River Valley subprovince boundary, to a north-south orientation that is perpendicular to the regional fabric of the adjacent Minnesota River Valley subprovince (Figs. 1A and 1B). The major sawtooth-notched offsets, or tear faults, are most prominent in the north-south stretch, where they coincide spatially with the major block-bounding faults in the adjacent Minnesota River Valley subprovince.

The most prominent of these tear faults, which crosses southern Pope County, separates the Archean Montevideo block from Paleoproterozoic rocks on the east, but to the west is contained wholly within the Archean Benson block (Fig. 1B). The eastern extent of this fault is occupied by a continuous string of late- to post-tectonic, mafic to felsic intrusions (Fig. 1B) that have been verified by drilling to consist of intrusive rocks similar to those exposed in outcrops to the northeast, near St. Cloud. The concentration of these late, ovoid intrusions along the fault plane implies that the fault extends to deep crustal depths.

The tear faults may have formed strictly during Paleoproterozoic time, or they may be reactivated Archean structures that were oriented parallel to the direction of maximum extension and shortening of the Penokean deformational belt. In either case, the coincidence of the orogen-bounding tear faults with major northeast-trending shear zones in the adjacent Minnesota River Valley subprovince

implies that preexisting structures in the Archean crust provided zones of weakness which ultimately controlled the location of the tear faults.

- Boerboom, T.J., in prep., Bedrock geology of Pope County, Minnesota, plate 2 of Harris, K.L., project manager, Geologic atlas of Pope County, Minnesota: Minnesota Geological Survey County Atlas C-15, Part A, scale 1:200,000.
- Southwick, D.L., 2002, Geologic map of pre-Cretaceous bedrock in southwest Minnesota: Minnesota Geological Survey Miscellaneous Map M-121, scale 1:250,000.
- Southwick, D.L., and Chandler, V.W., 1996, Block and shear-zone architecture of the Minnesota River Valley subprovinces: Implications for late Archean accretionary tectonics: Canadian Journal of Earth Sciences, v. 33, no. 6, p. 831–847.

Heterogeneity in the Nine Mile Pluton, Wausau Complex, in terms of high field strength element (hfse) and rare earth element (ree) bearing minerals.

Buchholz, T.W., (1140 12th Street North, Wisconsin Rapids, Wisconsin 54494); **Falster, A. U.**, and **Simmons, Wm. B.**, (Department of Geology and Geophysics, University of New Orleans, New Orleans, Louisiana 70148).

The Nine Mile pluton is the youngest and most silica-rich of the four intrusive centers of the Wausau complex which is exposed in Marathon County, Wisconsin. The complex is approximately 1.5 Ga in age and locally abounds in pegmatitic veins, aplites, and miarolitic granite. Mineralization in these environments is commonly varied and complex, though in many cases restricted to small localized environments. Notable variation exists in minerals of HFSE (high-field strength elements such as Nb, Ta, Zr, Th, etc) and to a lesser extent in REE (rare earth elements). The type and size of these mineral-rich bodies varies throughout the pluton. In the northern portion of the pluton, large and well-defined pegmatitic bodies with sizeable miarolitic cavities containing a wealth of accessory phases are abundant. The size of pegmatitic veins and the size of miarolitic cavities are smaller in the central and southern parts of the pluton. Small miarolitic cavities in dikes and in granite typically host the accessory minerals in the northern area of the pluton. Significant variation also exists with respect to Nb, Ta, Ti and REE+Y mineralization. In the northern part of the pluton, titanium oxides such as anatase, brookite, and rutile are widespread but they are rare in the central and southern portions. Columbite-tantalite group minerals are most abundant in the central part of the pluton, but less abundant in the south and rare in the northern part. Conversely, Nb-dominant euxenite-group minerals which are rare to absent in the central portion of the pluton are more abundant in the southern and western parts. REE+Y mineralization appears to be more evenly distributed but may be slightly more abundant in the central part.

Zircons are widespread in small amounts throughout the pluton and show Hf-enrichment, particularly in close proximity with fluorite. This enrichment occurs mainly in the central portion of the pluton, although isolated instances have been noted in the south and west. Cassiterite is exceedingly rare but has been noted in the central, western, and northern parts of the pluton.

Fluorite is most abundant in the central portions of the pluton where it is commonly intimately associated with the Nb-Ta-oxide minerals microlite, manganotantalite and tapiolite. The link of high fluorine activity and more highly evolved geochemical fractionation of Nb-Ta oxides is obvious. Such highly fractionated oxides generally do not occur in NYF-type (NYF = Nb-Y-F enriched pegmatites typical of anorogenic origin) pegmatitic environments. The localized niches of high F activity are where these uncommon HFSE and REE phases occur. In all cases of exotic mineralogy, the central portion of the Nine Mile pluton differs from the rest of the pluton; it is also only here that several high-Sc phases have been found. These observations may indicate that the central portion of the Nine Mile pluton may actually be a fifth intrusive center.

Buchholz, T. W., Falster, A. U. & Simmons, Wm. B. 1999. Ta, Nb, U, Y, and REE Minerals of the Koss Quarry, Marathon County, Wisconsin: The 26th Rochester Mineralogical Symposium, Abstracts of Contributed Papers. p. 6.

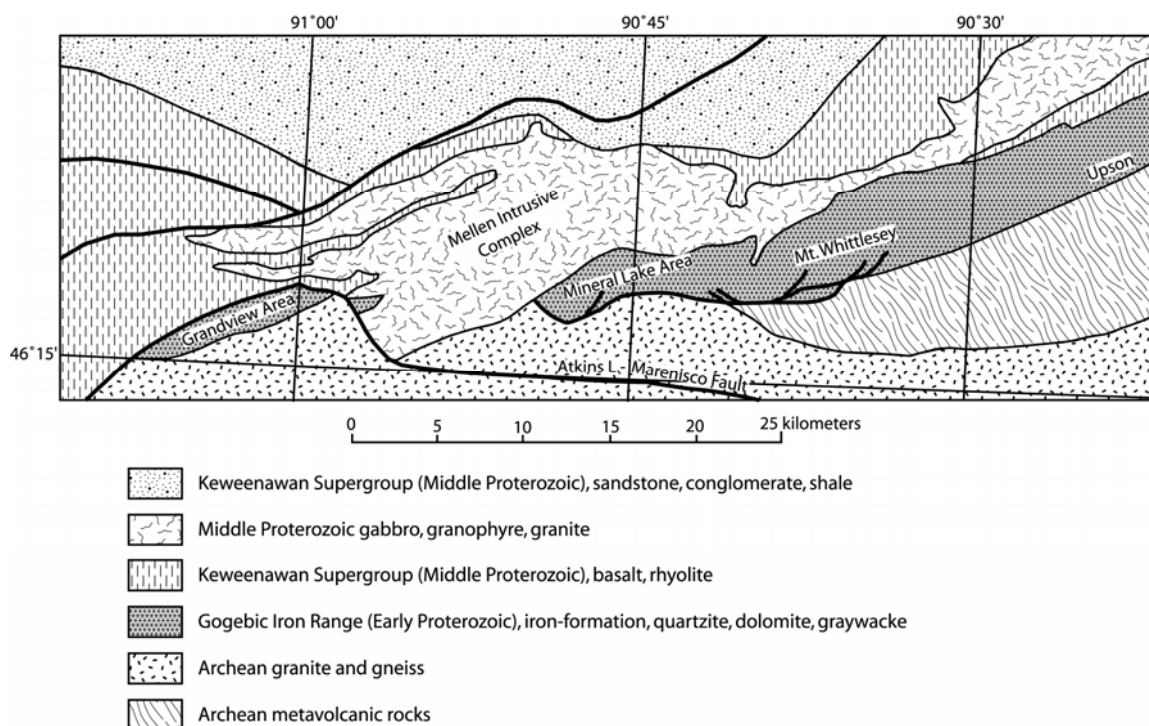
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- Buchholz, T. W., Falster, A. U. & Simmons, Wm. B. 2001. Minerals of the Ladick East Quarry, Marathon County, WI: The 28th Rochester Mineralogical Symposium, Abstracts of Contributed Papers. p. 7.
- Falster, A. U., Simmons, Wm. B., Webber, K. L., & Buchholz, T.W. 2000. Pegmatites and Pegmatite Minerals of the Wausau Complex, Marathon C., Wisconsin: Memorie della Societa Naturali e del Museo di Storia Naturale di Milano, V. 30, p. 13-28.
- Hanson, S.L., Falster, A.U., Simmons, W.B., Webber, K.L., Buchholz, T. 1998. Rare-Earth-Element (REE) Mineralization of Pegmatites in the Wausau Complex, Marathon County, Wisconsin: The 25th Rochester Mineralogical Symposium, Abstracts of Contributed Papers. p. 12.
- Keppler, Hans. 1993. Influence of fluorine on the enrichment of high field strength trace elements in granitic rocks: Contributions to Mineralogy and Petrology, V. 114, p. 479-488.
- Myers, P.E., Sood, M.H., Berlin, L.A. & Falster, A.U. 1984. The Wausau Syenite Complex, Central Wisconsin: Thirtieth Annual Institute On Lake Superior Geology, Field Trip Guidebook 3.

Geology of the western Gogebic Iron Range, northwest Wisconsin—a record of sedimentation and deformation across the northern margin of the Penokean orogen

Cannon, W. F., (USGS, Reston, VA), Laberge, G. L. (Oshkosh, WI), Klasner, J. S., (Macomb, IL), Dicken, C., (USGS, Reston, VA)

Between 1991 and 1994 we examined most bedrock exposures of the iron-bearing strata and adjacent units of the western Gogebic Iron Range. We also compiled previously mapped features from both published and unpublished sources, including very detailed but unpublished mapping performed by iron mining companies in the 1950's.

The Gogebic Iron Range is a steeply north-dipping monocline of Early Proterozoic strata. The monocline formed at about 1.1 Ga (Cannon and others, 1993) by crustal-scale thrusting on faults such as the Atkins Lake-Marenisco fault that tilted gently south-dipping rocks formed during the Penokean orogenic cycle at approximately 1.9-1.8 Ga. The map pattern therefore is a cross section of the Penokean features that passes from a weakly deformed depositional and deformational foreland in the east to parts of the Penokean orogen toward the west that were more tectonically active both during deposition and deformation.



Early Proterozoic strata lie unconformably on Late Archean granitic and metavolcanic rocks. The Bad River Dolomite, the oldest of the Early Proterozoic strata, is thin and discontinuous in the east but forms a continuous unit several hundred meters thick in the Grandview area in the west. Eastward from the Mt. Whittlesey area the basal unit of the Palms Formation commonly is a chert breccia composed of a residuum of chert fragments formed by dissolution of the cherty dolomite of the Bad River. Elsewhere, basal argillite beds of the Palms lie directly on the Bad River or Archean basement. The Palms Formation maintains uniform character and thickness

across the mapped area. It consists of thin-bedded argillite and argillaceous quartzite in the lower part and thick-bedded quartzite in the upper part.

The Ironwood Iron-formation lies conformably on the Palms. Near Upson and eastward the Ironwood displays a five-fold internal stratigraphy (Huber, 1959) of wavy-bedded jaspillitic iron-formation interlayered with even-bedded carbonate and silicate iron-formation. This stratigraphy cannot be traced far west from Upson. Jaspillitic and hematitic units are rare from Mt. Whittlesey to the west where the iron-formation has more reduced mineral assemblages and scarcer cherty units. The westernmost exposures in the Grandview area are banded grunerite-magnetite iron-formation, which becomes progressively leaner and more argillaceous to the west. The iron-formation in the Grandview area is roughly 2,000 feet thick as opposed to 500-1000 feet farther east. In the westernmost part of the Grandview area drill holes show that the iron-formation becomes interbedded with black shale. The Tyler Formation overlies the Ironwood, probably with low angle unconformity, and is predominantly a thick sequence of graded-bedded turbidites. Most Early Proterozoic rocks were variably metamorphosed at about 1.1 Ga in the broad contact aureole of the Mellen intrusive complex.

The Early Proterozoic stratigraphic section records deposition in a relatively shallow stable basin through the time of deposition of the Palms Formation. Beginning with deposition of the Ironwood, there are indications of tectonic instability and variations of depositional setting across the area. In the east iron-formation appears to have accumulated under tectonically quiescent conditions allowing widespread deposition of similar lithologies and thicknesses. To the west, deposition appears to have been in progressively deeper water and to have had a greater input of fine-grained clastic material. Also, in the Grandview area, sills of diabase as much as 1,000 feet thick occur in the iron-formation and enigmatic beds of breccia, possibly of volcanic derivation, suggest a proximity to tectonically and volcanically active parts of the Penokean orogen. The situation may be similar to the eastern end of the Gogebic Range where sills and volcanic rocks interfinger with the Ironwood. Finally, deposition of the turbidites of the Tyler Formation marks the transgression of a deep-water foreland basin in advance of accreting volcanic arcs of the Wisconsin magmatic terranes to the south.

Penokean structures are much more intensely developed in the west than the east. Near Upson, structures are limited to rare outcrop-scale folds in the iron-formation and to moderately to weakly developed cleavage in more argillaceous units of the Tyler Formation. From near Mt. Whittlesey to the Mineral Lake area folding and faulting are much more intense. Folds with wavelengths of hundreds of meters are discernable in the iron-formation. Bedding plane faults and other originally low angle faults are also common including a basal decollement that separates the Early Proterozoic strata from Archean basement. Folds appear to have been mostly asymmetrical to recumbent and north-verging, but Middle Proterozoic tilting has rotated these so that they are now mostly overturned structures. Likewise, original low angle thrusts are now tilted toward the north and have the appearance of down-to-the-north normal faults.

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Anisotropy of magnetic susceptibility in the Ottertail pluton, Northern Ontario.

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INTRODUCTION

In this project, we studied the structural and magnetic fabrics of the Ottertail Pluton, a small, granitic body within the Superior Province of Northern Ontario. The Ottertail, part of the Algoman suite of quartz monzonites and granodiorites, intruded surrounding rocks along the Wabigoon- Quetico subprovince boundary around 2.7 Ga (Davis et. al, 1989). From field observation, the emplacement of the Ottertail Pluton has been considered to be post-deformational due to the lack of obvious deformation fabrics evident in other types of rocks at the subprovince boundary (e. g. Davis et. al, 1989; Poulsen, 2000) . This interpretation has been used to constrain the timing of final deformation along the Wabigoon- Quetico boundary associated with microplate collision.

PROBLEM

On a much smaller scale, within deformed conglomerates, such as the nearby Seine River conglomerates, rigid clasts often display evidence of much less deformation than do more yielding clasts. Could a similar situation have occurred on a much larger scale in the case of the Ottertail Pluton? The relatively rigid granite body could appear to be relatively undeformed in the field, even if the timing of its emplacement was pre- or syn- tectonic. This situation, where a pluton appears undeformed despite being present during deformation, has been shown to occur in some modern tectonic regimes (e. g. Paterson & Tobisch, 1988). A more detailed study of plutonic fabrics and relationships is needed to conclusively determine whether a pluton is truly “post deformational.”

METHOD

In August of last year, we sampled an E-W (and a shorter N-S) transect across the Ottertail Pluton traveling along Highway 11, west of Mine Centre, Ontario. Thirty-one sites were sampled resulting in a total of 218 oriented cores. The anisotropy of magnetic susceptibility (AMS) of these granitic cores was measured to learn about the history of pluton emplacement. The measurements were conducted at the Institute of Rock Magnetism at the University of Minnesota in Minneapolis in January of this year. In general, the samples have a significant AMS signal contributed by multi-domain magnetite. The AMS data has been compiled to describe the attitude of the variations in magnetic fabric within the Ottertail Pluton. To determine the relative timing of pluton emplacement with respect to the deformation, we need to show whether the magnetic fabric is concordant with preserved, regional patterns of strain. The AMS study will be combined with our field observations and a detailed petrographic study.

RESULTS

Regional deformation fabrics have already been well documented in the literature (e. g. Poulsen, 1986; Poulsen, 2000; Czeck, 2001). Preliminary results of our study suggest that the magnetic fabrics preserved in the Ottetail are related to the pattern of regional strain fabrics in the surrounding rocks. Further work will be conducted to analyze the magnetic fabrics to determine if, indeed, the Ottetail Pluton is pre- or syn- tectonic. If it can be shown to be pre- or syn- tectonic, this will have major implications for the relative timing of larger, regional, tectonic events. In particular, if the Ottetail is representative of other Algoman plutons and the deformation is truly regional, it may not be possible to constrain the end of regional deformation using the date of the intrusion of Algoman granites.

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Groundwater and Heat Flow in an Interlobate Moraine in Southeastern Manitoba.

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Significant deviations from conductive heat flow occur in the Sandilands area of southeastern Manitoba as a result of groundwater flow. The main geological feature of this area is an interlobate moraine that coincides with the subcrop belt of the Ordovician Winnipeg Formation, which is composed primarily of sandstone and shale. The sandstone of the Winnipeg Formation acts as a regional aquifer and regional hydraulic head distribution and hydrogeochemistry suggest that the Sandilands area is an important source of recharge to this aquifer. The sandstone aquifer of the Winnipeg Formation is hydraulically separated from overlying hydrostratigraphic units west of the subcrop belt by a layer of low permeability shale that is thought to be continuous [Betcher, Third Canadian Hydrogeological Conference (1986)]. Overlying the Winnipeg Formation is the Ordovician Red River Formation, consisting of dolomitic limestone in the study area. The Red River Formation contains an aquifer in its upper extent, and previous studies have suggested that the Sandilands is an important recharge area for this aquifer as well. However, Sandilands recharge is likely less important as this carbonate aquifer is also recharged through the tills between the moraine and the Red River [Render, Cdn. Geotech. Journal, v.7, 243-274 (1970)]. Till is also present at the base of the moraine and acts as a semi-confining layer.

Deviations from conductive heat flow provide a means of determining the direction and magnitude of groundwater flow, and are an efficient method of investigating the interaction between the groundwater in the surficial glaciofluvial sediments and the underlying bedrock aquifers. The geothermal gradient in the Superior Province of southeastern Manitoba is approximately $0.01\text{ }^{\circ}\text{C/m}$, which corresponds to a heat flow of approximately 40 W/m^2 . Temperature profiles through the moraine in the Sandilands area show geothermal gradient as low as $0.006\text{ }^{\circ}\text{C/m}$ below the depth of penetration for seasonal variations. One-dimensional analytical models indicate that downward flow of groundwater must be occurring at a rate of approximately 10^{-8} m/s to produce the observed curvature seen in the temperature profiles. Analysis of temperature profiles in areas adjacent to the moraine has also aided in interpreting the hydrostratigraphy of the area. Temperature profiles through the upper shale unit of the Winnipeg Formation are linear, indicating that this layer does act as an effective confining layer for the underlying sandstone aquifer. Discharge areas and areas of predominantly horizontal flow are present in the area surrounding the moraine, suggesting that not all of the water infiltrating into the moraine reaches the underlying bedrock aquifers.

Mesoarchean Evolution of Western Superior Province: Evidence from Metasedimentary Sequences near Atikokan

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Paleogeographic reconstructions based on data supplied by metasedimentary sequences provide a basis for understanding plate movements which create sedimentary basins. This combined with geochronology allows sequential developmental stages of a craton to be deciphered. Thus, by interpreting environment of deposition from outcrop data, inferring provenance from composition of the metasedimentary units, and determining the age of detrital zircons and zircons in interstratified or intrusive igneous rocks insight will be gained on the plate movements which caused a basin to subside.

The above was applied to a Mesoarchean sequence of metasedimentary and metavolcanic rocks to evaluate the degree basin subsidence could be explained by lateral plate motions similar to those of today. The succession is on the southern margin of Wabigoon Subprovince in the Atikokan area. It consists of, along an eighty kilometre belt from southwest to northeast, 1) the Steep Rock Group, 2) the Little Falls assemblage, 3) the Finlayson Lake greenstone belt, and 4) the Lumby Lake greenstone belt. The oldest rocks exposed in the sequence are pre 3014 Ma tholeiitic basalts (Figure 1), the dominant rock type in the entire assemblage. The lowermost sedimentary units at Little Falls and Finlayson consist of felsic agglomerates and tuffs laterally transitional into resedimented sandstones and conglomerates. Transport was via high density mass flows, though some beds are possibly traction current deposits. Mafic ash layers are present throughout. Age determinations of the resedimented, pyroclastic zircon population gave 2996.9 ± 0.8 Ma, almost identical to the compositionally similar (Stone et al, 1992) Marmion Batholith which intrudes the area. Felsic volcanism also occurs in the Lumby Lake belt at this time. Plume derived (Hollings et al, 1999; Hollings and Wyman, 1999; Tomlinson et al, 1999) mafic and ultramafic volcanism continued in these belts until some time after 2828 Ma (age determination of Tomlinson et al, 2001) when eruptions ceased and a coarsening upward sedimentary sequence of iron formation, DE turbidites, classic turbidites, wave reworked coarse sandstones, and conglomerates was deposited at Finlayson. The geochemistry and detrital zircon population (2997 to 3002 Ma) of the Finlayson sandstones is similar to Wagita Formation sandstones, a fluvial unit deposited in incised paleovalleys at the base of the Steep Rock Group (Wilks and Nisbet, 1988). Eroded basalt and tonalite detritus moved through Steep Rock paleochannels building out the shoreline in the Finlayson area. The sequence at Lumby consists of classic turbidites interbedded with lenses of mass flow conglomerates near the top, overlain by carbonate and finally iron formation. Although sedimentation was probably synchronous in the Lumby area, geochemistry indicates komatiites were important source material here. Clastic sedimentation in the entire area was ended by transgression causing backfilling of Wagita fluvial channels followed by rapid drowning of the entire source area. Stromatolitic carbonates were deposited in the shallow ocean, but as subsidence continued the carbonate was replaced by iron formation. At 2780 Ma (Tomlinson et al, in press) the next volcanic cycle began with eruption of the komatiitic Ashrock Formation.

The mafic and ultramafic volcanic units which dominate the sequence have been ascribed to plume generated melts erupting in an ocean plateau environment (Tomlinson et al, 1999; Hollings and Wyman, 1999; Hollings et al, 1999); the presence of the tonalites being ascribed to slab melting in a proximal subduction zone (Hollings et al, 1999). Though this model is elegant the new age determinations render it unworkable. Generation of felsic melts by plume induced heating at the base of the overthickened basaltic plateau is compatible with tonalite geochemistry (Smithies, 2000). The sedimentary sequence is consistent with an ocean plateau environment, but definitely not representative of a continental rift or cover sequence as previously suggested (Thurston and Chivers, 1990). Partial melts generated in the lower basaltic crust formed magma chambers 2 to 4 km below surface. This magma fed felsic eruptions which, in turn, supplied most of the material for clastic layers lower in the volcanic pile. Eruption of the enclosing basalts was probably sporadic, as the area was effected by pulses of plume activity (Tomlinson et al, 1999). These events lasted for over 185 Ma, into the Neoarchean, until finally terminated by a hiatus in volcanic activity. With the end of plume driven crustal heating, thermal decay induced subsidence lead to subareal to shallow water clastic sedimentation and shallow to deep water chemical sedimentation.

The existence of an ocean plateau for over 185 Ma, and possibly over 235 Ma, calls into question the operation of plate tectonics in the Mesoarchean, and especially fast spreading, multiple ridge-subduction zone configurations proposed for this time period. If the plateau was undergoing lateral plate motion subduction zones must have been well spaced and movement slow to allow for its activity over such a long time period. This is difficult to reconcile with a hotter earth requiring greater heat dissipation capacity than today. The other alternative: conventional plate tectonics did not operate in the Mesoarchean, but rather heat loss was achieved through vigorous plume activity, possibly similar to the early history of Mars, needs to be explored further.

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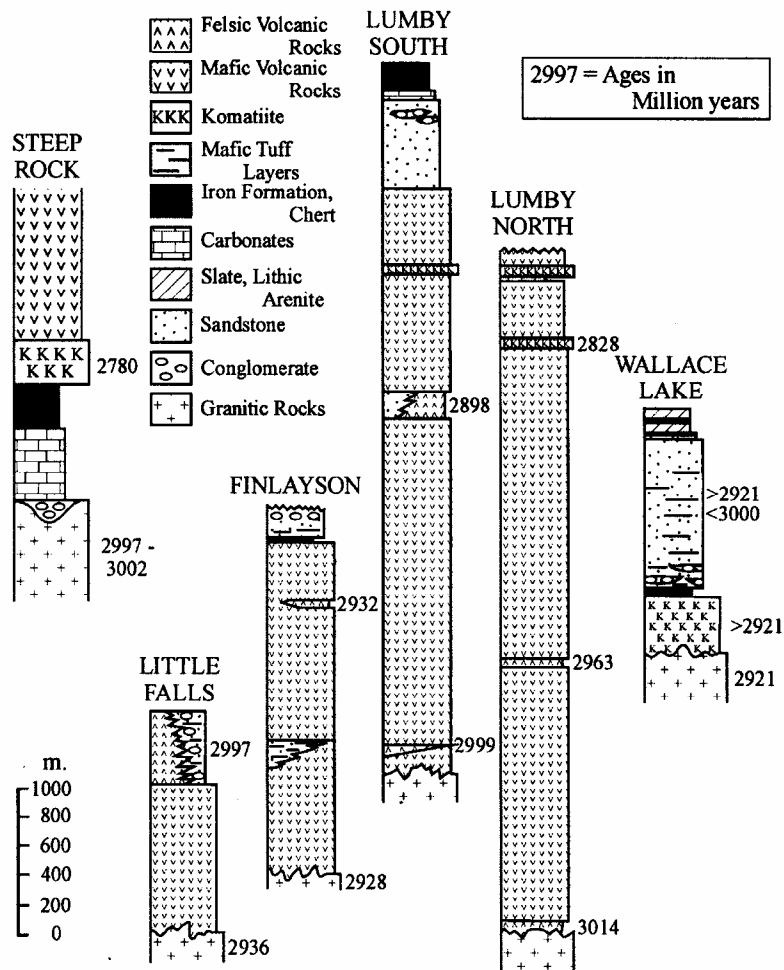


Fig. 1. Stratigraphic sections of Mesoarchean rocks in the Atikokan area, and Wallace Lake in the Uchi Belt for comparison. Geochronology mainly from Tomlinson et al and Stone et al.

SEM Imaging of fossil nanobacteria from the supergene zone, Flambeau Copper Mine, Ladysmith, Wisconsin

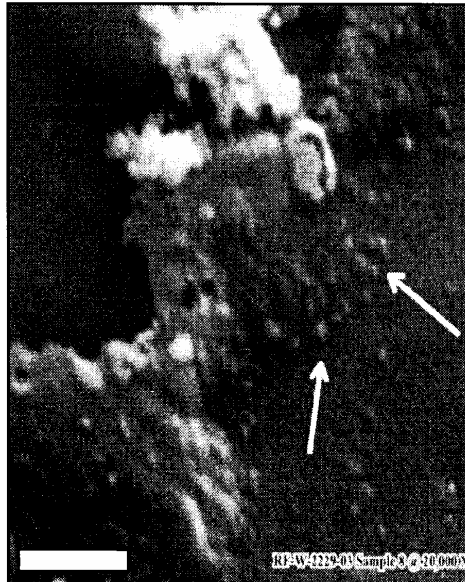
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The discovery of nanobacteria fossils in Eocene supergene zones in Chilean copper deposits (Sillitoe et. al. 1996) suggested that similar, but older, nanobacteria may be found in the Cambrian to Precambrian supergene zone of the Flambeau Copper Mine in Rusk County, Wisconsin. A scanning electron microscope study of samples from the Flambeau Mine focused on the interface between pyrite and replacing chalcocite. Images revealed several sites where spherical clusters 0.1 to 0.3 microns in diameter are present (fig. 1). Through visual comparison with existing studies and elimination of other possible explanations, these clusters are interpreted as being nanobacteria. The age of supergene mineralization at the Flambeau Mine predates the 525 million year old Mt. Simons sandstone (May and Dinkowitz, 1996), and may pre-date the deposition of the Barron quartzite (1750 - 1650 m.y.) (Medaris, 2000). If these are fossil nanobacteria rather than recent contaminants, it suggests that the involvement of nanobacteria in the supergene enrichment processes spans a considerable proportion of geologic time. Acknowledgements: We are indebted to Jeff Thole and his assistants for their help in using the SEM facilities at Macalester College for this study.

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Figure 1. Suspected nannobacteria (arrows) at pyrite-chalcocite interfaces, Flambeau Mine, Ladysmith, Rusk County, Wisconsin. 20,000x. White bar = 5 microns.



Archean and paleoproterozoic mafic intrusions in Minnesota

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Exploration for platinum group elements (PGEs) in Minnesota has been restricted largely to mafic intrusions of the Mesoproterozoic Duluth Complex for obvious reasons—the complex contains known PGE occurrences associated with previously outlined copper-nickel deposits. A new study by the Minnesota Geological Survey and the Natural Resources Research Institute is looking beyond the Duluth Complex to describe and analyze the varied mafic, ultramafic, and alkalic intrusions in the northern, western, and east-central parts of the state. Although geochronologic data are sparse, field and geophysical evidence implies that most of these intrusions are Archean and Paleoproterozoic in age. Figure 1 shows some of the major mafic intrusions and intrusive complexes for which some “ground truth” (drill core or outcrop) exists. They have been identified by surface and geophysical mapping and drilling; however, few have been thoroughly described and analyzed, and almost none have been analyzed for PGE content. Some of the intrusions are lithologically similar to the so-called “Quetico” and “Atikokan” intrusions that are the targets of exploration in Canada. The geologic settings of significant PGE deposits worldwide include mafic to ultramafic plutons associated with volcanic arc terranes in linear orogenic belts (Ural-type), differentiated sill complexes, ophiolitic complexes, syn- to late-orogenic layered complexes (Bushveld and Stillwater), and alkalic to subalkalic composite plutons. This study is designed to characterize the various types of mafic intrusions in Minnesota and perhaps broaden the exploration horizon to similarly diverse terranes throughout the state.

At present, an inventory containing the pertinent facts from more than 150 individual intrusions and thousands of diabasic dikes has been compiled and sampling work has begun. As an initial classification, the known intrusions are grouped below first according to the age of host rocks into which they were emplaced, and secondly on the basis of perceived temporal, mineralogic, and geometric attributes.

ARCHEAN HOST ROCKS

Layered mafic-ultramafic complexes—Pre-tectonic with respect to the main metamorphic and foliation-forming deformation event. The rocks are variably metamorphosed and have tholeiitic to komatiitic compositions. The presence of layering and cumulate textures indicates differentiation. Rock types include peridotite, pyroxenite, gabbro, anorthositic gabbro, and diorite. Examples: Deer Lake Complex and Newton Lake Formation.

Subvolcanic mafic sills—Pre-tectonic, variably metamorphosed, presumably hypabyssal intrusions associated with greenstone sequences. They typically are tholeiitic in composition. Rock types include gabbro, pyroxenite, and diorite. Example: Thistledew Lake sequence.

Amphibolitic sills and dikes—Typically schistose, metamorphosed, and folded, narrow sills emplaced into schists and granitic intrusions of the Quetico subprovince. Example: Ash River amphibolite.

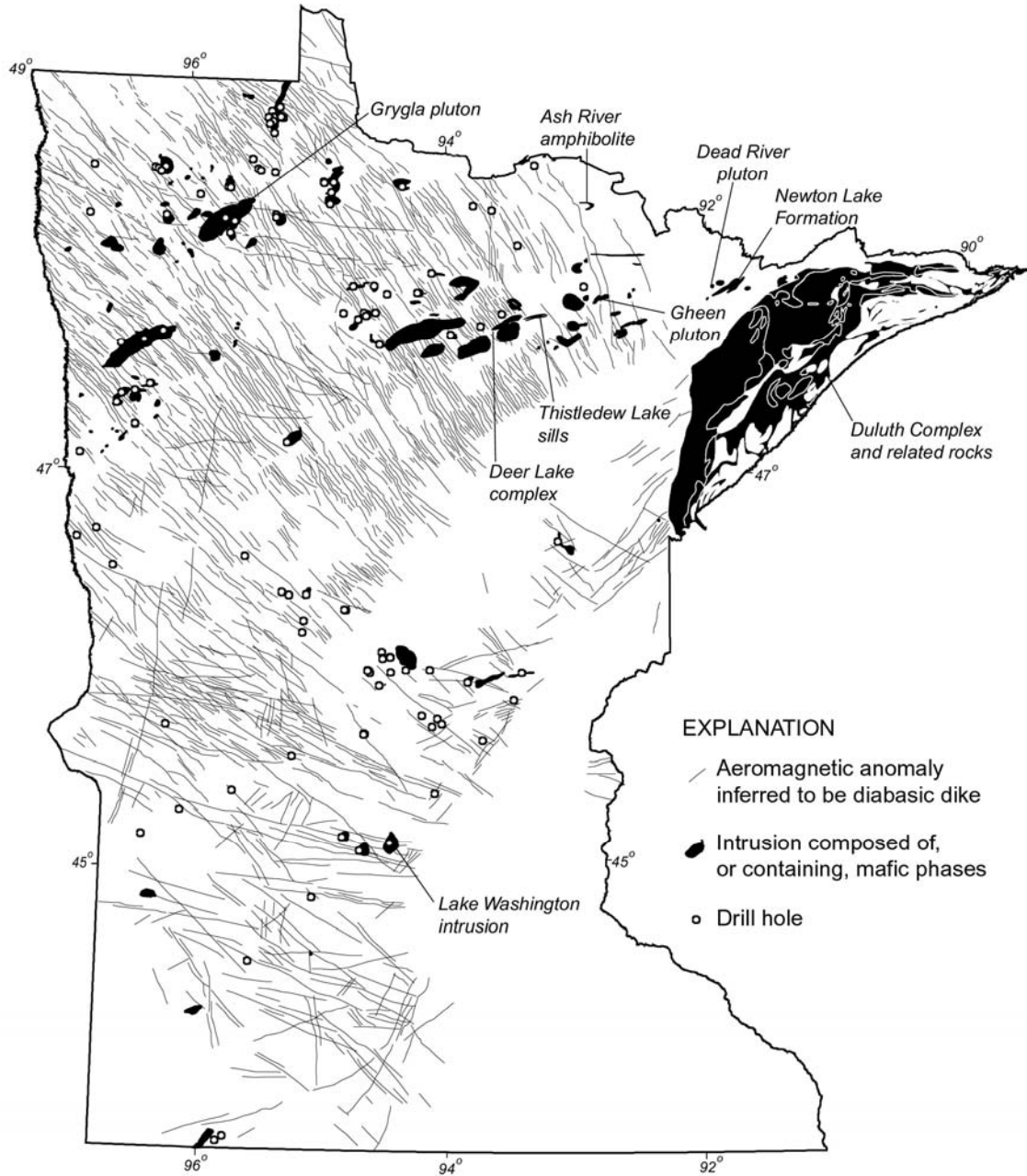


Figure 1. Generalized map of Minnesota showing the distribution of mafic intrusions and drill holes that intersect mafic intrusive rocks. Many of the drill holes encountered intrusions too small to be depicted. Intrusions discussed in the text are labeled.

Lamprophyric, pyroxenitic, peridotitic, and hornblendic intrusions—Syn- to post-tectonic dikes and small, irregular bodies. They typically are coarse-grained, oxide-rich, and strongly magnetic. Example: Dead River pluton.

Sanukitoid composite stocks—Discrete, post-tectonic intrusions of the diorite-monzodiorite-monzonite-syenite suite. They typically are quartz-poor to quartz-absent. Most contain intrusive phases and enclaves of amphibole-pyroxene-mica-bearing diorite, locally of lamprophyric affinity. Example: Gheen pluton.

Tonalite-diorite intrusions—Discrete, probably post-tectonic intrusions that contain magmatic phases varying from tonalite to diorite and gabbro. Example: Grygla pluton and associated intrusions.

PALEOPROTEROZOIC AND ARCHEAN HOST ROCKS

Gabbroic intrusions—Discrete, typically semicircular intrusions containing gabbro, troctolite, anorthositic gabbro, and pyroxenite. Typically show as magnetic and gravity highs. Example: Lake Washington intrusion.

Pyroxenite and peridotite plugs and stocks—Small, circular to irregularly shaped bodies having strong magnetic signatures. Commonly occur along linear geophysical discontinuities. Examples include many of the small intrusions in central Minnesota shown on Figure 1 by drill hole locations. Age is uncertain, but one is known to intrude ~1780 Ma granite.

Diabasic to gabbroic dikes—Northwest-trending dikes are part of the Kenora–Kabetogama swarm of Paleoproterozoic age, other dike orientations are both Paleoproterozoic and Mesoproterozoic in age. Outcrop mapping indicates dike widths between 30 and 100 meters. Larger dikes commonly are composite and have central zones composed of granodiorite and leucogabbro.

This classification will undoubtedly be modified with the addition of new petrographic and geochemical data.

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VHMS mineralization and alteration within the Lumby Lake Greenstone Belt, Northwestern Ontario

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The Lumby Lake greenstone belt, located approximately 40 km northeast of Atikokan, Ontario or 165 km northwest of Thunder Bay, Ontario, has been a focus of exploration activity for the past one hundred years. The belt is located within the Wabigoon Subprovince of the Superior Province. The Wabigoon Subprovince is interpreted as a collage of 3 – 2.7 Ga plutonic and volcanic terranes (Blackburn et al, 1991), where as Tomlinson et al. (1999) have shown that the Lumby Lake belt ranges in age from 2898-3001 Ma.

Mapping done by Jackson (1985a, b) showed the belt to be dominated by mafic metavolcanic units that occur as massive to pillowed flows. Thin felsic volcanics and clastic sedimentary units were found throughout the belt along with less common ultramafic flows, located only towards the top of the stratigraphic sequence. The Marmion Lake Batholith intrudes the southern portion of the belt. In the past the belt has been discounted as a possible base metal camp due to the relative absence of felsic material.

Hollings and Wyman (1999) documented that the mafic volcanic rocks of the belt are similar to those of modern ocean plateau tholeiites (associated with plume related volcanism), consistent with the presence of komatiites. These authors invoked a complex model of plume arc interaction to account for the presence of arc related felsic volcanics within the plateau related mafic pile.

Hollings and Wyman (1999) reported the presence of two distinct types of felsic volcanic rock, and comparable plutonic phases, within the Lumby Lake belt. One suite characterized by fractionated heavy rare earth elements (HREE) are comparable to the nonprospective F1 of Leshar et al (1996), the second suite with unfractionated HREE are similar to the variably prospective F2 of Leshar. The F2 felsic horizons are found within the Lumby Lake-Spoon Lake area and further to the south within the Marmion Lake Batholith. Tomlinson et al. (1999) found that the felsic volcanics of belt, in general, give the oldest ages, ~3 Ga.

Additional exploration, by Atikokan Resources Inc. (ARI) in the last decade, and mapping done, in conjunction with ARI, in the last year has identified the presence of additional extensive felsic flows, tuffs and breccias, predominately in the southern portion of the belt. Areas of base metal mineralization, such as the stratabound pyrite, sphalerite, galena, chalcopyrite, native silver and silver sulphides found in the Lumby Lake-Spoon Lake area (0.2 to 9.2% Zn, #0.25% Cu, 1.0% Zn and 37 – 60 g Ag/t) and the pyrite, sphalerite, galena, pyrrhotite and chalcopyrite located near Richardson Lake, have been revealed. It should be noted that there is a scarcity of volcanic hosted massive sulphide deposits of 3 Ga or older

Examination of the area near Richardson Lake indicates that silicification and chloritization of the rocks is common with sericite alteration less prominent. This alteration is consistent with that found in the footwalls of volcanogenic massive sulphide deposits (Franklin, 1993). Additional mapping and geochemical work, involving the classification of newly located felsic horizons and the relative enrichment and depletion of elements, will lead to further defining these zones of alteration and enable the location of additional base metal targets. In addition geochemical analyses will be utilized to further define the tectonic setting of the Lumby Lake belt.

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Geology and fluid inclusion studies of the Thunder Bay Agate Mine, Northwestern Ontario

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The Thunder Bay Agate deposit, located northeast of Thunder Bay at the junction of Highway 11/17 and Highway 527, was discovered in 1989 and developed into the presently operating Thunder Bay Agate Mine in 1996. The deposit is hosted by carbonate units of the Gunflint Formation and is 50m NE of the contact with olivine diabase of a Logan sill. The deposit has a surface exposure of approximately 160 x 200m. Throughout the area of the deposit, intermittent open spaces within the host-rock are filled by agate. Where the agate-filled spaces are larger than ~50cm high and 1m wide, there is evidence of collapse brecciation of the host-rock. The largest agate-filled space observable is 2m wide and 0.8m high.

Thunder Bay agate consists of three mineral phases: chalcedony, quartz, and graphitic carbon. The chalcedony can be subdivided into three varieties: dark amorphous silica (opal-A?), light amorphous silica (opal-CT?), and translucent chalcedony. A consistent sequence of mineralization is observed throughout the deposit. From nucleation against the host-rock, the sequence is rhythmic bands of dark amorphous silica, light amorphous silica, translucent chalcedony, and quartz-encased, carbon-filled vugs. As mineralization radiates from several points of nucleation, interference patterns generate complex, sinuous structures in the sequence. Although graphitic carbon is not always present, where it does occur it is never observed to be in direct contact with the host-rock or chalcedony. Quartz is often the final stage of mineralization and is rarely observed to be in direct contact with the host-rock. The rhythmic bands of each stage vary from <1mm to >1cm in width.

Three types of fluid inclusions, according to the terminology of Roeder (1984), were found:

Type I: Single-phase inclusions containing liquid or vapour only. A number of Type I inclusions in quartz were examined; however, no change on freezing was observed.

Type II: Two-phase liquid + vapour inclusions. These are the most common type of inclusion in quartz. Eutectic, final melting and homogenization temperatures were obtained.

Type III: Three-phase liquid + vapour + solid(s) inclusion. Not observed in this study.

Type IV: CO₂-rich inclusions. These homogenized at <31°C and decrepitated when heated above homogenization.

Type II Two-phase inclusions (liquid and vapour) are the most numerous type of primary inclusion within the quartz. These inclusions range in size from 4 to 50µm along their greater axis and have a vapour content of 2% to 7% by volume. All Type II inclusions in the quartz homogenized to liquid in the range of 70 - 190°C with the majority homogenizing within the range of 100-130°C. The eutectic and final melt temperatures of the inclusions clustered around two ranges. Inclusions with eutectic temperatures of

approximately -52°C exhibited final melt temperatures of -34 to -27°C; inclusions with eutectic temperatures of approximately -25°C exhibited final melt temperatures of -7 to -2°C. The higher temperature cluster corresponds to the NaCl-H₂O eutectic temperature of -22°C. The lower temperature cluster of inclusions likely contain minor amounts of CaCl in solution with NaCl. The chalcedony is almost exclusively devoid of inclusions; however, one cluster of about 10 Type IV inclusions containing liquid CO₂ were observed in translucent chalcedony. In these inclusions the frozen CO₂ displays visible melting at -45°C and homogenized at 30.2°C.

Fluid inclusion studies indicate the quartz was emplaced in a low-temperature, low-pressure hydrothermal environment. The timing of deposition is delimited between the age of the Gunflint Formation (1878 ma; Fralick et al., in press) and the Logan sills (1109 ma, Davis and Sutcliffe, 1985) which have been seen to contain xenoliths of typical agate (J. Scott, pers. com., 2001).

The deposition of agate appears to be related pervasive, early silicification of the Gunflint and other Lake Superior-type iron formations, as summarized by Simonson (1987). He proposed that silicification most likely could be attributed to siliceous thermal springs located nearer the axis of the depositional basin. Compaction could expel the siliceous solutions to the margins of the basin.

Rimstidt and Barnes (1980) showed that silica precipitation in response to declining is most effective in a decrease from 300 to 100°C, the approximate mean homogenization temperature observed in quartz-hosted inclusions. Silica solubility also decreases sharply with a drop in pH. Organic matter producing CO₂ at the site of agate deposition would both cause silica precipitation and dissolution of carbonate host rocks through lowering of pH. Evidence of such CO₂ production is seen in the presence of Type IV CO₂-rich inclusions. Organic matter also is believed to provide a favourable nucleation site for silica (Knoll, 1985). Thus, the occurrence of the agate deposit in carbon-rich carbonate rocks can be explained.

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WOLF RIVER-AGE BRECCIATION IN THE BARABOO QUARTZITE, WISCONSIN: IMPLICATIONS FOR PROTEROZOIC TECTONICS IN THE LAKE SUPERIOR REGION

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Breccia zones in Baraboo Quartzite, consisting of angular red quartzite fragments cemented by a stockwork of white quartz veins (Fig. 1), are distributed sporadically throughout much of the Baraboo Range. Larger breccia zones tend to be parallel with associated bedding, although thin quartz veins with incipient breccia features are commonly crosscutting. The most prominent breccia zone, which is well exposed in Ableman's Gorge, is ~100 meters thick and can be traced for ~20 kilometers along the north limb of the Baraboo syncline.



Figure 1. Quartzite breccia, Martin-Marietta Quarry, north limb, Baraboo syncline

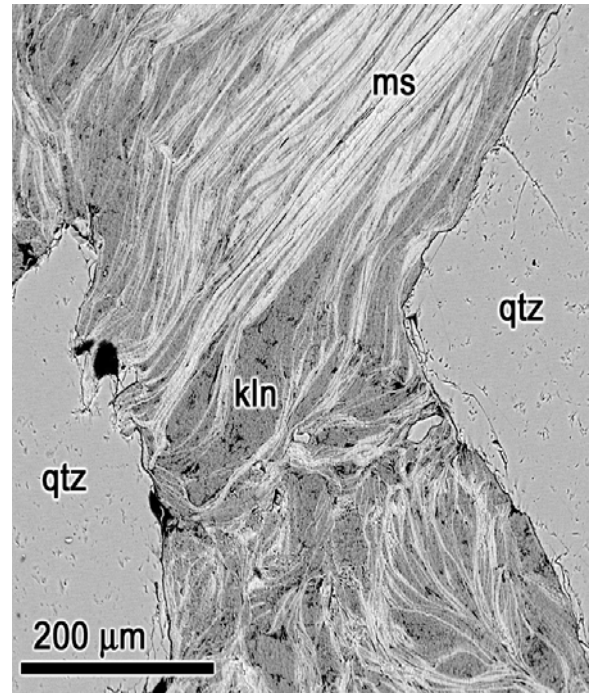
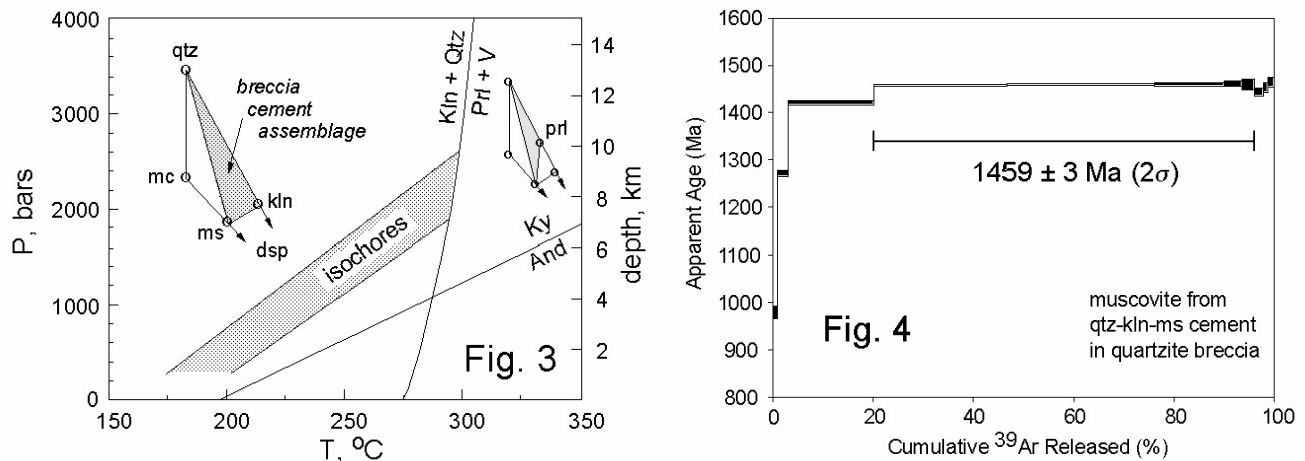


Figure 2. Back-scattered electron image of muscovite (light gray), kaolinite (dark gray), and quartz (medium gray) in breccia cement

The breccia cement is composed predominantly of massive vein quartz, which is occasionally accompanied by small amounts of specular hematite. Locally, euhedral quartz crystals occur in vugs, some of which are partly to completely filled by kaolinite. Muscovite is rare in the breccia cement, but muscovite was recently discovered by Phil Fauble in an outcrop of breccia in the bluffs east of Devil's Lake on the south limb of the syncline. At this locality, prominent flakes of muscovite appear to be in textural equilibrium with kaolinite and quartz (Fig. 2).

The stable coexistence of quartz, kaolinite, and muscovite is limited to temperatures below $\sim 300^{\circ}\text{C}$ by the reaction, kaolinite + quartz = pyrophyllite + H_2O (Fig. 3). Quartz in the muscovite bearing sample contains abundant H_2O -rich fluid inclusions, which yield homogenization temperatures from 160 to 186°C and freezing point depressions from -1.2 to -6°C , corresponding to maximum salt contents of ~ 6.8 wt%. The fluid inclusion isochores, combined with phase equilibrium constraints, indicate that brecciation occurred in the range, 200 to 280°C and 500 to 2000 bars (depths of 2 to 8 kms). Such a temperature range is lower than that for the predominant quartz + pyrophyllite assemblage in the Baraboo Quartzite, which is stable between about 300 and 375°C at 2000 bars.



Step-heating, using a defocused CO_2 laser, of a single muscovite grain (ca. 0.01 mg) from the breccia cement yielded a discordant $^{40}\text{Ar}/^{39}\text{Ar}$ age spectrum with a well-defined plateau at 1,459 $\pm$ 3 Ma (Fig. 4), representing $\sim 75\%$ of the gas released during the heating experiment. This result is concordant with $^{40}\text{Ar}/^{39}\text{Ar}$ plateau ages of 1,456 $\pm$ 11 and 1,467 $\pm$ 11 Ma for muscovite from metasaprolite and muscovite-pyrophyllite-diaspore hydrothermal veins in the Baraboo Quartzite (Naymark et al., 2001).

Results of this investigation provide additional evidence for post-1,630 Ma hydrothermal activity in the Baraboo Range, which was first recognized by Naymark et al. (2001) and attributed to the influence of 1,465 Ma Wolf River magmatism (Medaris, 2001). We suggest that emplacement of the 1.5-1.4 Ga transcontinental belt of A-type granites, of which the Wolf River batholith is part, provided the heat flux necessary for promoting regionally extensive fluid flow and accompanying hydrothermal alteration along permeable channels. It now appears that such hydrothermal activity extended far beyond the Baraboo Range, including the Sioux Quartzite in Minnesota (Naymark, et al., 2001) and the Athabasca Basin in northern Canada (Kotzer, et al., 1992). Further research may reveal that much of the Paleo- and Mesoproterozoic crust of the Lake Superior region was affected by areally extensive, but stratigraphically restricted, hydro- thermal alteration at 1.5-1.4 Ga.

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**New geologic map and report of the Duluth Complex and related rocks,
Northeastern Minnesota.**

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The Minnesota Geological Survey (MGS), in collaboration with the Natural Resources Research Institute, recently published a 1:200,000-scale map of the Duluth Complex and related rocks of northeastern Minnesota (Miller and others, 2001). A companion report (Miller and others, 2002) describes the geology and mineral potential of the map area; a CD-ROM included in the report contains the digital map and related field data. This ambitious project was funded by a grant from the Minnesota State Legislature on the recommendation of the Minerals Coordinating Committee. The two products constitute the largest and most complete summary of the Duluth Complex ever produced and, undoubtedly, will serve as a benchmark for future exploration and research.

Several developments in the last 20 years led to the regional compilation. Gravity and high-resolution aeromagnetic data were used in conjunction with test drilling to map the vast, poorly exposed central part of the Duluth Complex. Detailed mapping in the better exposed part of the complex, as well as core logging along its base, led to a greater understanding of the petrologic, structural, and stratigraphic relationships in the intrusive sequence. High-resolution radiometric dating aided the unraveling of the intrusive history of the complex, and advances in Geographic Information Systems (GIS) greatly enhanced our ability to produce complicated geologic maps. Finally, and perhaps most importantly, the sharp upturn in PGE exploration in the Duluth Complex created an urgent need for an improved geologic framework.

The new geologic map (Miller and others, 2001) has two major components: a 1:200,000-scale geologic map that delineates over 270 rock units, and a more generalized 1:500,000-scale geologic map that classifies the rock units into 72 time–stratigraphic entities. Additional information on the two sheets include (1) a map that shows the relative density of outcrops and drill-out locations; (2) a 1:500,000 gray-scale image of the first vertical derivative of the aeromagnetic data; (3) an index to 64 published and unpublished mapping projects used in the present compilation; (4) a correlation diagram for the 72 generalized time–stratigraphic units; (5) brief descriptions of rock units; and (6) a list of references. Because of the importance of gravity and magnetic data to this compilation, a related map that presents the second vertical derivative of gravity data (color) superimposed on reduced-to-pole, first vertical derivative of magnetic data (black and white) is available at a scale of 1:200,000 (Chandler, 2001). The maps can be purchased from the Minnesota Geological Survey in paper form; they are also available

as PDF files from the Minnesota Geological Survey web site (<http://www.geo.umn.edu/mgs>).

The new 1:200,000-scale geologic map is a greatly improved representation of the Duluth Complex and related rocks; for example, the southern and northwestern parts of the complex are depicted as a composite of several intrusions consisting of troctolitic and gabbroic cumulates. Much of the PGE exploration has focused along the base of the complex in two cumulate bodies, the South Kawishiwi and Partridge River intrusions, but several similar bodies defined by the new map may become exploration targets. The map refines our understanding of the geology of the upper part of the complex, which consists of a partially disrupted cap of anorthositic rocks and several felsic intrusions. Improvements have also been made in mapping the Beaver Bay Complex and other hypabyssal intrusions in the volcanic roof of the complex. One of the bodies, the Sonju Lake intrusion, is being explored for PGE potential, and the new map identifies other mafic cumulate and gabbroic bodies in the roof zone that may be worthy exploration targets. Finally, the North Shore Volcanic Group, which forms the roof (and locally the footwall) of the complex, has for the first time has been subdivided into informal formational entities on a geologic map.

The companion report (Miller and others, 2002) provides a general description of the Duluth Complex and related rocks as portrayed on the map and assesses the potential for nonferrous mineral deposits. The following is a summary of each of the 8 chapters and appendix: 1, Formal definition of nomenclature and stratigraphic and rock-type classifications used to describe the Mesoproterozoic (Keweenawan) rocks of northeastern Minnesota; 2, History of geologic mapping and mineral exploration of the complex; 3, Geophysical attributes of the complex and related rocks; discussion of how data aid interpretation of the buried bedrock geology and deeper geologic structure of northeastern Minnesota; 4, Geology and structure of the Archean and Paleoproterozoic rocks that form the footwall of the complex; 5, Volcanic stratigraphy and structure of the comagmatic North Shore Volcanic Group, into which the Duluth Complex and related intrusions were emplaced; 6, Geologic, structural, and stratigraphic relationships of various intrusions of the complex; 7, Geology of the Beaver Bay Complex and related hypabyssal intrusions; 8, Types of mineralization that are known to occur or may occur in the complex and related Keweenawan rocks; identification of new exploration target areas; and Appendix, Description of digital image and data layers included in the CD-ROM (back pocket) and an explanation of how to access the GIS layers within the ArcView[®] program.

The CD-ROM accompanying the report contains ArcView[®]-based digital compilations of the geologic map and related field data, as well as base maps and geophysical images. Attribute tables identify the source and character of data that accompany the geology layers (map units, geologic faults, and contacts) and the related field data layers (outcrops, structure measurements, drill holes, and field samples). An MGS-created

extension, GeMS (Geologic Mapping System) allows the abbreviated attribute data to be decoded. Compilation of all pertinent field data was not possible under the time constraints of the two-year project. Priority was given to data from explorable areas of the Keweenaw in northeastern Minnesota. Updated versions of this digital compilation will be produced as warranted by new mapping and additional archiving of older field data.

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Crustal models of the Western Superior Province from gravity and Lithoprobe seismic data

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The western part of the Superior Province (WS) is characterised by a regional pattern of linear, EW-trending, fault-bounded belts containing distinctive rock types, structures, ages, metamorphic conditions, and geophysical attributes. Detailed geological, geochemical and geochronological studies in the past two decades have led to the formulation of the “accretion hypothesis” in which the WS is interpreted to have assembled progressively from north to south by collisions with various arc, oceanic and continental fragments. To test this hypothesis at depth a Lithoprobe transect was established in the WS, and acquisition of seismic refraction and reflection data, as well as detailed gravity observations were made along several profiles crossing the WS subprovinces. The refraction/wide-angle reflection data indicate a crustal thickness of 40-43 km and relatively high average crustal velocities of 6.6-6.7 km/s (White et al. 1997). A high velocity basal crustal layer (7.5-7.7 km/s) was imaged west of Lake Nipigon in the southern WS beneath the Wawa, Quetico and central Wabigoon subprovinces (White et al. 2001). In general, on the seismic reflection sections the lower crust is homogeneously reflective, the middle crust is heterogeneous and strongly reflective, and the upper crust is heterogeneous and often weakly reflective. The Moho is well imaged and shows a flat or slightly dipping geometry below the Berens River Subprovince, a crustal root below the Uchi Subprovince and an upwarp beneath the metasedimentary English River Subprovince (ERS) and its along strike continuation in the Wabigoon indenter. The Bouguer gravity data in the WS show variations between -10 and -90 mgal, gravity highs occurring over the metavolcanic belts, and gravity lows in most of the areas underlain by felsic intrusions. An exception is represented by the metaplutonic Berens River Subprovince, which is characterised by a regional gravity high. The most outstanding gravity feature observed in the WS is a prominent Bouguer gravity high (>20 mgal) coincident with the length of the metasedimentary ERS. The lack of detailed correspondence between this anomaly and the surface distribution of the metasediments suggests a deep linear source (Nitescu and Cruden 2001). A significant positive anomaly also occurs in the Winnipeg River Subprovince east of Kenora, and broadly parallels the surface distribution of the Lount Lake batholith. It is not clear whether this anomaly is related to the ERS gravity anomaly, or some other deep-crustal feature.

The aim of the present study is to investigate the crustal structure of the WS based on gravity models constrained by seismic information and to infer the processes responsible for its present-day configuration. We present results obtained from a gravity inversion algorithm (Pilkington and Crossley 1986) employed for the determination of the Moho topography in the WS, and 2.5-D gravity forward models of the WS crust obtained along N-S seismic lines 1 and 2b.

The inversion model of the Moho topography reveals the existence of EW-trending crustal roots below the Uchi and Wabigoon subprovinces (Moho depths of 43-44 km) separated by a parallel rise of the Moho to depths of 37-39 km below the ERS. In the

region underlain by the high velocity basal slab the Moho deepens from 41 km below central Wabigoon Subprovince to 47 km below the northern Quetico Subprovince. These results generally agree with the Moho geometry observed along the seismic profiles, although in detail there are differences. For instance, the N-S extent of the Moho upwarp below the ERS is overestimated in the inversion model, which clearly demonstrates that the ERS gravity anomaly cannot be accounted for only by the Moho rise as observed on the reflection sections.

The 2.5D gravity forward model along reflection line 2b extends from the Winnipeg River Subprovince to the Berens Subprovince along the Red Lake road. The model indicates that north of the ERS the observed Bouguer gravity field combines the effects of the Moho topography and upper crustal structures (greenstone belts and various intrusive bodies), with no major density variations occurring at the mid- and lower crustal levels in this segment of the crust. Due to poor reflectivity below the ERS, the seismic data does not constrain well the location at depth of the ERS anomaly source, which may correspond to a transparent region observed between 2-4 s TWT, above a zone of weak mid-crustal reflectivity. The lower density of the rocks exposed at surface in the region of the Winnipeg River Subprovince anomaly indicates that its source is also buried. This anomaly could be caused either by a dense body, which may be related to the source of the ERS anomaly, or by uplifted mid-crustal rocks as suggested by the seismic fabric at the southern end of line 2b. In the latter case the modelling results show that the uplifted Winnipeg River Subprovince mid-crustal rocks should extend to the south below the northern Wabigoon Subprovince.

The 2.5D forward gravity model of the WS crust along reflection corridor 1 extends for 500 km from the northern Wawa Subprovince to the Sachigo Subprovince. In the model, Moho topography and the interface relief between major crustal layers (as revealed by the refraction data) cause long wavelength gravity anomalies. Short wavelength anomalies are generated by upper crustal metavolcanics and granitoids. The high-density (3.1-3.2 g/cc), high-velocity basal slab imaged in the southern half of the corridor is not reflected in the long wavelength gravity field as a maximum, since the effect of the positive density contrast created in the lower crust is cancelled by the combined effects of the southward deepening of the Moho and the downward depression of the intra-crustal interfaces above the slab.

The present study shows that the gravity field in the WS can be successfully modelled in accord with seismic reflection/refraction data by upper crustal density variations and undulations of the Moho and the interfaces between major crustal layers. The structural grain of the subprovincial configuration is not paralleled by density variations in the middle and lower crust, but is reflected in the Moho undulations. The cause of the crustal roots beneath the granite-greenstone subprovinces is not clear. They may be related to greenstone belt loading, but this depends on whether the lower crust was strong enough after the formation of the greenstone belts to prevent the relaxation of the initial Moho depressions through flow. The Moho upwarp below the ERS may be preserved from a ca. 2710-Ma-old extensional episode in the WS which led to the uplift of the Winnipeg River Subprovince and the formation of sedimentary basins on its flanks (Nitescu and Cruden

2001). The deepening trend of the Moho towards the Quetico and Wawa subprovinces is probably related to the load imposed at the lower crustal level by the observed high-velocity/high density basal slab. This slab was previously interpreted as a remnant of a subducted Archean oceanic plate (White et al. 2001), but it could alternatively represent a Proterozoic igneous underplating episode related to Mid-continental rift magmatism. It is likely that the crustal structure of the WS contains not only elements preserved from Kenoran tectonism, but also younger post-orogenic effects. Therefore caution should be used when interpreting the features revealed by the seismic data solely in terms of processes responsible for the accretionary stage of the Superior Province.

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Digital Drill Logs for the Duluth Complex - Lithology and Assays

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Since 1988 the Natural Resources Research Institute (NRRI) staff has logged 950 Duluth Complex drill holes of the about 1,500 holes with core available (of the approximately 2,200 holes recorded as penetrating the Complex).

This project involves transcribing all of the NRRI logs, plus our interpretation of company logs for drill holes with no core remaining, into a consistent digital format. This downhole “from-to” interval format includes logged rock type, map unit (reconciled from cross-sections and geologic maps where available), and the interval distance up from footwall. This is combined with other data tables, being consolidated from older reporting and projects, which will include: all drill hole specific information (location, company, year drilled, etc.); down hole survey data; all original assays (usually copper-nickel +/- sulfur); secondary assays on selected intervals; all available PGE plus gold assays; and eventually all whole rock geochemistry and microprobe data. The format will allow this data to be sorted and filtered geographically, by deposit, by company, by depth or distance from footwall, or other criteria.

This data format is intended primarily for use in 3-D mining software and is available on CD-ROM as Excel spreadsheet files, ASCII text files, and as a Gemcom for Windows (Microsoft Access) database. NRRI staff will also format this database to the users needs if practical. The database will also be posted on the NRRI Economic Geology Group website at: <http://www.nrri.umn.edu/egg/>.

The ultimate purpose of this work is to improve the ability to do statistical and spatial analysis of Duluth Complex geology by rapidly combining lithological and assay data for both scientific study and deposit evaluation. This analysis breaks down into two broad categories. Simple 2-D comparisons, such as: comparisons between intrusions or deposit areas; rock type versus grade; ratio of a particular rock type which is mineralized versus part not mineralized; assay grade of a particular unit; or grade as a function of distance from footwall (see Table 1 for examples from Babbitt and Serpentine deposits). More complex 3-D analysis can also be done by using this data to create lithological and grade surfaces, solids, or block models, then intersecting these models; compositing grade by rock type, map unit, level, or distance from a particular point or surface; assessing linear and 3-D variography; contouring by level or distance from a point; and other manipulations of the raw data.

Most mining software is very flexible, and the overall data layout will allow NRRI or others to add distance or point data (distance from collar, such as a thin section location) or from-to interval data (such as alteration, grain size, or other assayed elements) as separate tables that can then be compared to the existing data set. The utility in this is the time savings in answering the numerous small questions that arise as well as easing modeling efforts on the Duluth Complex Cu-Ni sulfide and Fe-Ti oxide deposits

Table 1: Consolidated Rock type versus Copper, Nickel, Sulfur, and Copper:Nickel ratio, for Babbitt and Serpentine Deposits, St Louis County Minnesota. Surface drill holes only. "Consolidated Rocktypes" are condensed from over 1,000 individual rock types over about 25,000 lithological intervals. "Percent Mineralized" assumes that company sampled all mineralized zones. This is essentially true at Babbitt-Serpentine, but not always true for other deposit areas. Grades are only for the mineralized portions, no unsampled footage (zero value?) was included in the average.

"Consolidated Rocktype"	Total footage of rock type	Percent of rock type in deposit	Total mineralized footage of rock type	Total unmineralized footage of rock type	Percent mineralized of rock type	Average copper grade of rock type	Average nickel grade of rock type	Average sulfur grade of rock type	Average Cu:Ni ratio
Overburden (glacial drift)	10,122	1.8			0				
OUI (Oxide Ultramafic Intrusions)	2,824	0.5	447	2,377	16	0.31	0.10	1.92	3.29
Anorthositic rocks	63,510	11.3	18,151	45,359	29	0.31	0.09	0.66	3.32
Augite Troctolites	63,210	11.2	28,443	34,767	45	0.42	0.10	1.14	4.02
Contaminated Rocks	30,792	5.5	18,248	12,544	59	0.44	0.11	2.25	4.06
Gabbroic Rocks	3,022	0.5	1,348	1,674	45	0.33	0.08	0.85	4.32
Mixed Duluth Complex (not logged)	166,344	29.5	70,695	95,649	42	0.39	0.10	1.03	3.74
Pegmatitic Rocks	710	0.1	139	571	20	0.36	0.10	0.71	3.53
Ultramafic Rocks	24,473	4.3	7,732	16,741	32	0.36	0.11	0.74	3.17
Troctolitic Rocks	143,059	25.4	63,929	79,130	45	0.38	0.10	0.90	3.62
Dikes, Basaltic	698	0.1	181	517	26	0.08	0.02	0.35	2.58
Veins, Granitic	2,428	0.4	870	1,558	36	0.29	0.08	1.04	3.51
Massive Sulfides	415	0.1	413	2	100	2.02	0.57	12.68	3.86
Semi-Massive Sulfides	343	0.1	341	2	99	1.45	0.43	9.69	4.17
Virginia Formation	24,760	4.4	6,279	18,481	25	0.38	0.10	2.43	3.04
Bedded Pyrrhotite Unit	3,834	0.7	2,928	906	76	0.13	0.04	4.25	2.50
Virginia Sill	1,686	0.3	311	1,375	18	0.09	0.05	0.35	1.58
MG Sill	9,537	1.7	1,129	8,408	12	0.10	0.03	0.49	2.45
Sill in Biwabik Iron Formation	284	0.1	4	281	1	0.03	0.01	0.14	2.67
Biwabik Iron Formation	6,976	1.2	507	6,469	7	0.11	0.03	0.44	3.05
Pokegama Quartzite	20	0.0		20	0	0	0	0	0
Giants Range Granites	420	0.1	119	301	28	0.14	0.05	0.29	2.34
Basalts	2,951	0.5	547	2,404	19	0.20	0.08	0.85	2.65
Massive Chlorite	12	0.0	8	4	67	0.19	0.06	0.34	2.75
Faults	630	0.1	187	443	30	0.36	0.10	1.15	3.66
Massive Graphites	10	0.0	6	5	60	0.41	0.08	1.31	4.58
Hybrids (Hornblendite, etc.)	505	0.1	93	412	18	0.31	0.12	1.67	2.86
Orthopyroxenites	111	0.0	91	20	82	0.44	0.14	2.29	3.79
Massive Oxides (not in OIUs)	49	0.0	27	23	55	0.52	0.13	0.56	4.40
Serpentinities	76	0.0	19	57	25	0.47	0.11	1.62	4.72
deposit total:	563,811	100	223,192	330,500	40				
deposit averages:						0.39	0.10	1.29	3.66
maximums:						24.40	5.20	37.10	47.00
number of assayed intervals:						34,742	34,314	34,532	34,414
number of unassayed intervals:						25,445	25,873	25,655	25,773
total number of intervals:						60,187	60,187	60,187	60,187

Mineralogy and Zonation of the Big Whopper Pegmatite, Separation Rapids area, Kenora, Ontario

Pedersen, J. C. P. Geo., (*Consulting Geologist, Avalon Ventures Ltd.*) and **Bubar, D. S.** (*President and CEO, Avalon Ventures Ltd.*)

The Big Whopper pegmatite is the largest in a field of rare metal pegmatites occurring in the Separation Lake metavolcanic belt, situated approximately 60 km north of Kenora, Ontario. This greenstone belt occurs at the boundary of the English River and Winnipeg River sub-provinces of the Superior structural province. It is interpreted to be the eastern continuation of the Bird River Greenstone belt in Manitoba, which hosts the Cat Lake rare metal pegmatite field and the famous Tanco pegmatite. The Big Whopper pegmatite is 100% owned by Avalon Ventures Ltd. Exploration work to date has defined indicated and inferred resources totalling 11.6 million tonnes grading 1.34% Li_2O , 0.30% Rb_2O and 0.007% Ta_2O_5 . The deposit is now at the feasibility study stage as a potential producer of lithium-rich feldspars, tantalum and mica.

The Big Whopper is a vertically-oriented pegmatite dyke hosted by deformed metavolcanic rocks of lower to middle amphibolite facies metamorphism (amphibolite). A north-directed compressional tectonic event produced flattening and a strong vertically oriented regional schistosity striking WNW at the Big Whopper. This schistosity is folded about a sub-vertical axis. The Big Whopper itself exhibits high-strain features and a tight S-fold geometry, with the thickened central portion of the pegmatite coinciding with the hinge zone, and attenuated limbs extending to the east and west. The pegmatite has been traced over a strike length of 1.5 km and ranges from 10 to 80 m in width.

The dominant economic minerals in the deposit are petalite and columbite-tantalite, the principal ore mineral of tantalum. Petalite is a rare lithium aluminosilicate mineral used in certain specialty glass and ceramics applications, such as thermal shock resistant cookware. Tantalum finds its major use (approximately 60%) in the manufacture of miniature tantalum capacitors, which are currently in high demand for use in popular electronics products such as computers and cell phones. The deposit also contains significant quantities of rubidium potash (Rb-K) feldspar and albite, (both used in the glass and ceramic industries); lepidolite, an important source of rubidium in the chemicals industry, as well as the tin mineral cassiterite. Other potentially valuable industrial minerals include muscovite mica (some with elevated lithium) which may comprise up to 15% of the ore, spodumene averaging 3-5% occurring as SQUI (spodumene-quartz intergrowth) replacement rims on petalite, cassiterite, pale pink spessartine garnet and high-purity quartz. Minor accessory minerals include apatite, zircon, gahnite, monazite, xenotime, rare sulphides, sulphosalts, and thorite.

Mineralogical zoning observed in the Big Whopper is characteristic of highly evolved rare metal pegmatites, with well-developed wall zones and internal intermediate zones classified according to their dominant constituent minerals (Figure 1). The mineralogical zones of the Big Whopper identified to date are Wall Zone (predominantly albitite), Megacrystic Feldspar and Quartz-Mica marginal Zones and Petalite (intermediate) Zone. The Petalite Zone is the largest zone defined to date, comprising approximately 80% of the volume of the Big Whopper. Its essential mineralogy consists of petalite, Rb-K-feldspar, albite, quartz and mica. Sub-zones are defined based on subtle textural and mineralogical variations such as the presence of lepidolite mica.

Lepidolite-rich zones tend to occur on the periphery of the deposit and are typically enriched in tantalum.

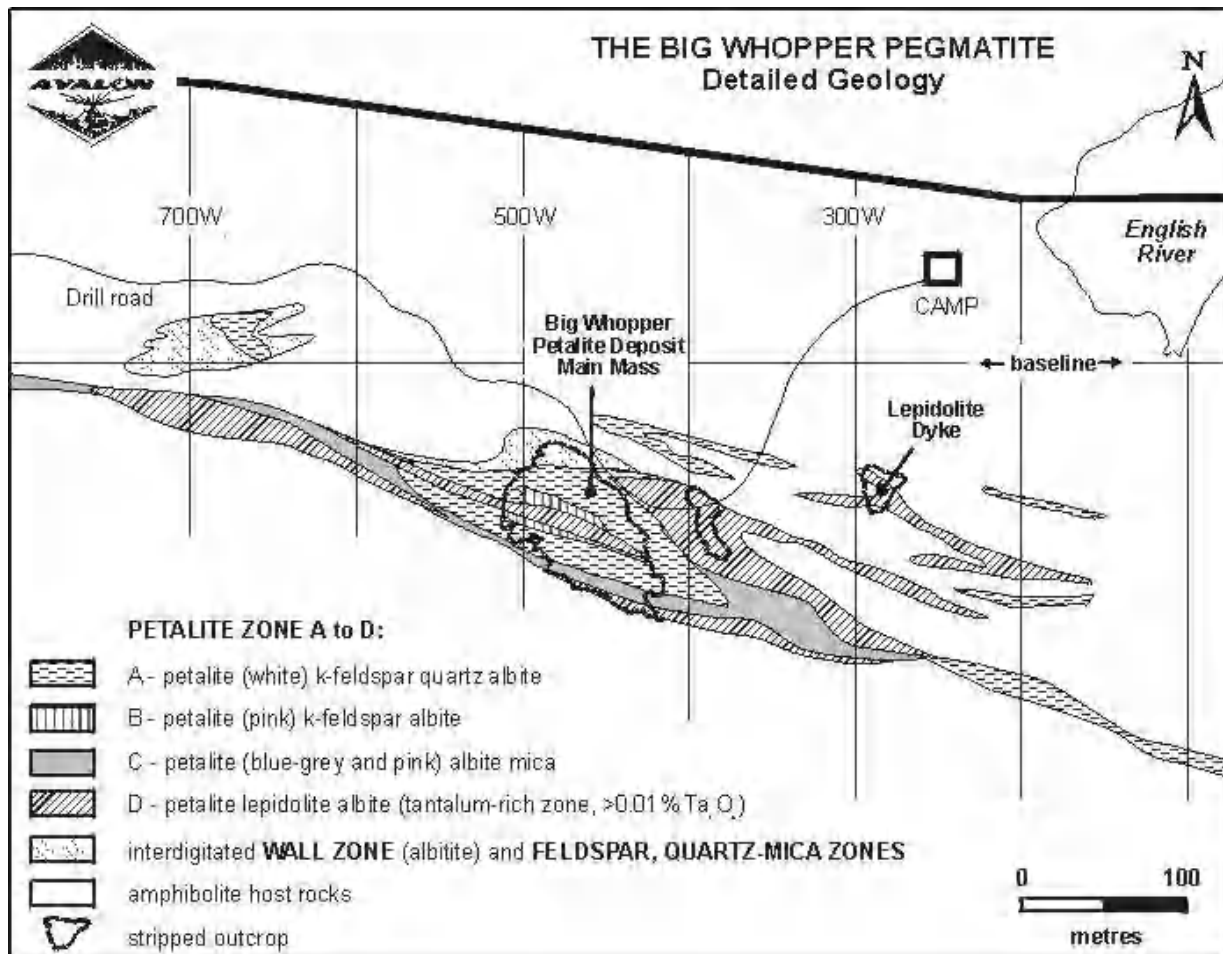


Figure 1: Big Whopper Geology

Cu-Ni-PGE Mineralization in the South Kawishiwi Intrusion, Northeastern Minnesota Variation due to Magmatic Processes

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INTRODUCTION

The Mesoproterozoic South Kawishiwi intrusion (SKI), which is exposed in a 32 x 8-kilometer arcuate band along the northwestern margin of the Duluth Complex, is composed dominantly of troctolitic cumulates. Footwall rocks to the intrusion include, from north to south, the Paleoproterozoic Virginia and Biwabik Iron Formations, and the Late Archean Giants Range batholith. Regional crosscutting features and remnant pillars and xenoliths indicate that the SKI intruded along the boundary between Mesoproterozoic volcanic and Anorthositic Series rocks and the older footwall strata. The SKI abuts the troctolitic Partridge River intrusion on the southwest, is inferred to be semi-conformable to the later Bald Eagle intrusion to the east, and abuts and cuts older Anorthositic Series rocks to the northeast. The basal mineralization within the SKI occurs dominantly in heterogeneous zones of troctolitic, gabbroic, noritic, and ultramafic rocks. This heterogeneity is a function of many factors, including footwall assimilation, dehydration and volatile fluxing from the footwall strata into the overlying magmas, chilling, and repeated magma injection.

Miller and Severson (2002) subdivide the intrusion into five major map units from the base upwards: 1) a heterogeneous basal contact zone of sulfide-bearing troctolitic, gabbroic, and noritic rocks; 2) ophitic augite-troctolite; 3) poikilitic leucotroctolite; 4) ophitic troctolite; and 5) homogeneous troctolite. Severson (1994) and Zanko et al. (1994) have further subdivided the marginal zone of the intrusion into 17 different units, with sulfide mineralization dominantly confined to four units: the Basal Augite-Norite (BAN), Basal Heterogeneous (BH), Updip Wedge (UW), and Ultramafic 3 (U3) units. Minor mineralization higher up in the igneous stratigraphy of the intrusion occurs locally in the Ultramafic 1 (U1) and Ultramafic 2 (U2) units. Recent research has identified two dominant styles of mineralization (“Open” and “Confined”) within the intrusion that have distinctive differences in their igneous stratigraphy, metal contents, timing, and mode of origin. Simplified regional geologic and mineralization style maps for the SKI are presented in Figure 1.

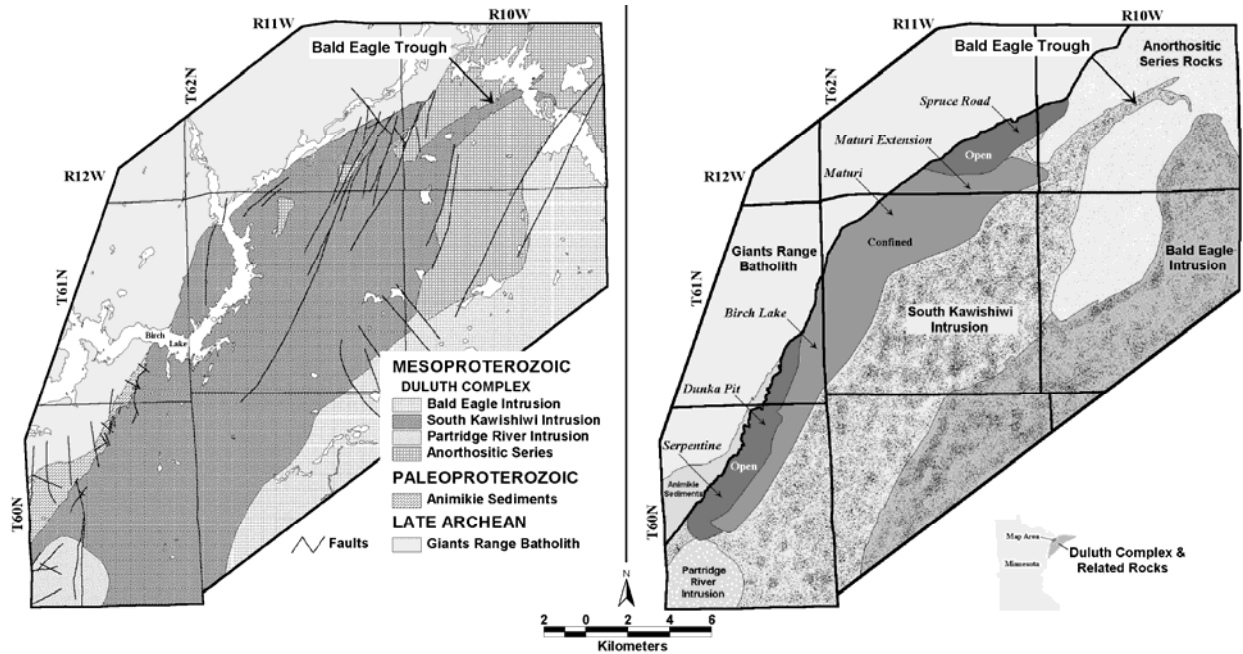


Figure 1. Simplified regional geologic (left) and basal mineralization style (right) maps of the South Kawishiwi intrusion.

Disseminated basal mineralization within the SKI has traditionally been divided into five distinct deposits: 1) Serpentine, 2) Dunka Pit, 3) Birch Lake, 4) Maturi, and 5) Spruce Road. The disseminated sulfides occur as interstitial grains that average about 1-5% (visual estimation) and range from trace amounts to 10%, with local zones of massive sulfide at the basal contact. Major sulfides are pyrrhotite, chalcopyrite, cubanite, and pentlandite. Pyrrhotite is generally the dominant sulfide, especially closer to the basal contact. Recent work by Wallbridge Mining Company and the author have defined a potential additional deposit area east of the Maturi deposit, informally named the Maturi Extension deposit. Although the style of mineralization in all of the deposits is dominated by disseminated Cu-Ni sulfides, differences occur between the deposits in igneous stratigraphy, Cu-Ni and PGE grade, mineralization thickness, and contained tonnes. Regional analysis of the drill hole assay data for all of the deposits of the South Kawishiwi intrusion has led to the identification of two main styles of mineralization associated with the base of the intrusion (Fig.1). These mineralization types include:

1. **“Open”** – vertically extensive (> 450 meters) mineralization with low - moderate Cu-Ni grade and low Au+PGE grades. Cu-Ni grades typically increase towards the basal contact although the mineralized zones are typically erratic in their spatial extent and grade and commonly interfinger in a random pattern with zones that are barren of sulfides. Restricted zones of massive sulfide occur locally at the basal contact. This erratic pattern of mineralization, in part, mirrors the lithologic heterogeneity of the basal units. Examples of this open style include the Spruce Road, Serpentine, and Dunka Pit deposits.
2. **“Confined”** – vertically restricted (< 150 meters) mineralization with moderate - high Cu-Ni grades and moderate to very high (locally) Au+PGE grades. Cu-Ni grades typically are the highest near the top of the mineralized zone (units U3 and BH) and gradually decrease with

depth toward the basal contact, and no zones of massive sulfide at the basal contact have been identified. For example, the upper portion of the mineralized zone within the Maturi deposit consistently exhibits copper values in excess of 1.0% that decrease to ~0.25% at the basal contact. Examples of the confined style include the Maturi, Maturi Extension, and the Birch Lake deposits.

The differences between the styles of mineralization reflect the different histories for the rocks hosting the mineralization. It is hypothesized that the early Open-style of mineralization reflects repeated small injections of sulfur-saturated, highly contaminated magma. In contrast, the Confined-style of mineralization reflects much larger batches of more primitive magma that may have incorporated much of its sulfur by assimilation of Open-style mineralized rocks (or remnant magma).

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3-Dimensional View Through a Mineralized System: the South Kawishiwi Intrusion, Duluth Complex

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A 35x8x2 km three-dimensional AutoCAD™ model of the basal contact surface of the South Kawishiwi intrusion (SKI) has recently been completed. The model is based on the location of ~ 800 drill hole piercing points into footwall strata and geophysical data (Figure 1). Integration of regional geological, geophysical, and geochemical features with the 3-D model has led to new ideas on possible feeder channels for magmas of the northern SKI. The interpreted master magmatic feeder channel of the northern SKI is fed from the central Mid Continent Rift through the Bald Eagle Intrusion gravity high, into a dike-like body of troctolitic rocks (herein termed the BEI Trough) cutting older Anorthositic Series rocks (Fig. 1).

The 3-D model has been instrumental in the development of new ideas on the location and origin of the Cu-Ni-PGE mineralization within the SKI. Integration of the magmatic feeder channel concept with lineament analysis and recent PGE assays has led to the development of conceptual

models for the formation of the Spruce Road (Peterson, 2002) and Maturi (Peterson, 2001) deposit areas. Early, contaminated magmas that formed the Spruce Road deposit were deflected to the north by a pillar of older Anorthositic Series rocks (Fig. 1) that is located at depth within the northern portion of the SKI (Fig. 2). Moreover, PGE-enriched Cu-Ni mineralization of the Maturi Extension deposit is located beneath the pillar, and a conceptual model for the formation of this deposit area is given in Figure 3.

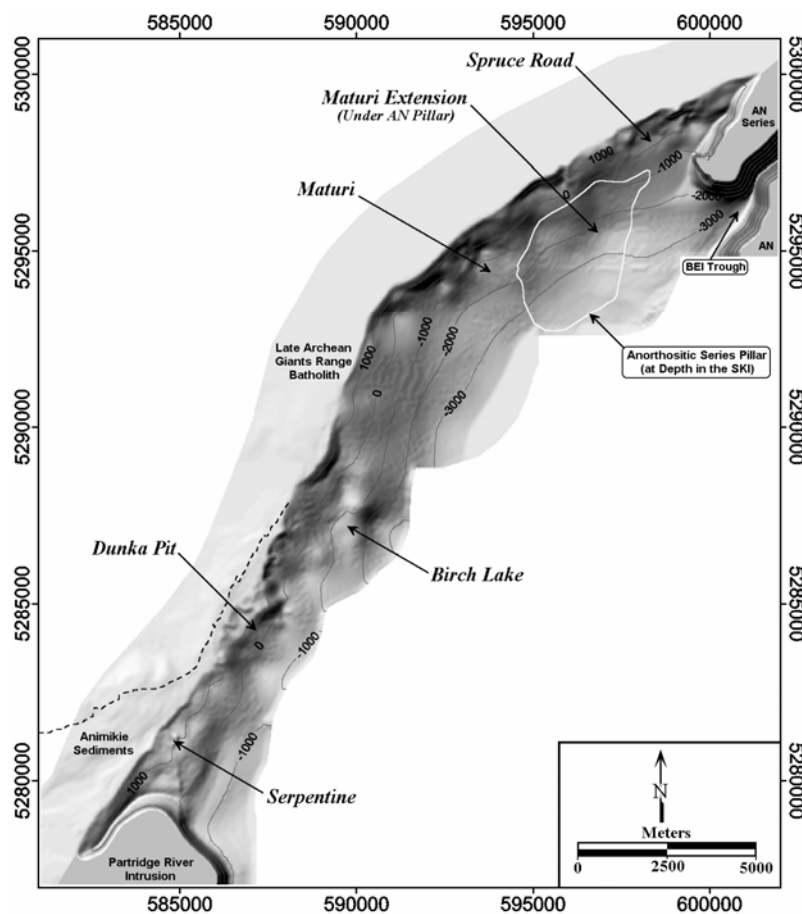


Figure 1. Regional shaded relief 3-D model of the SKI

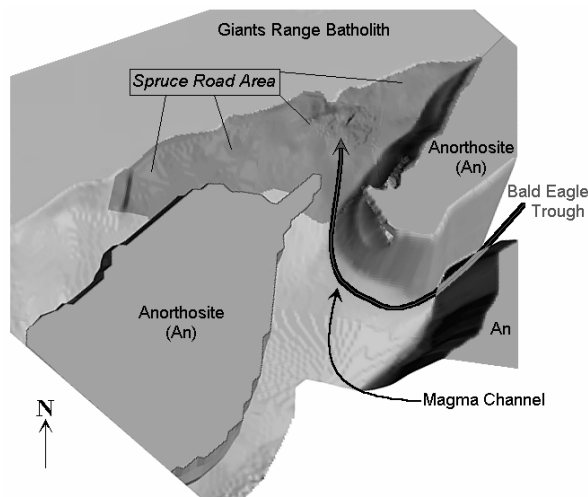
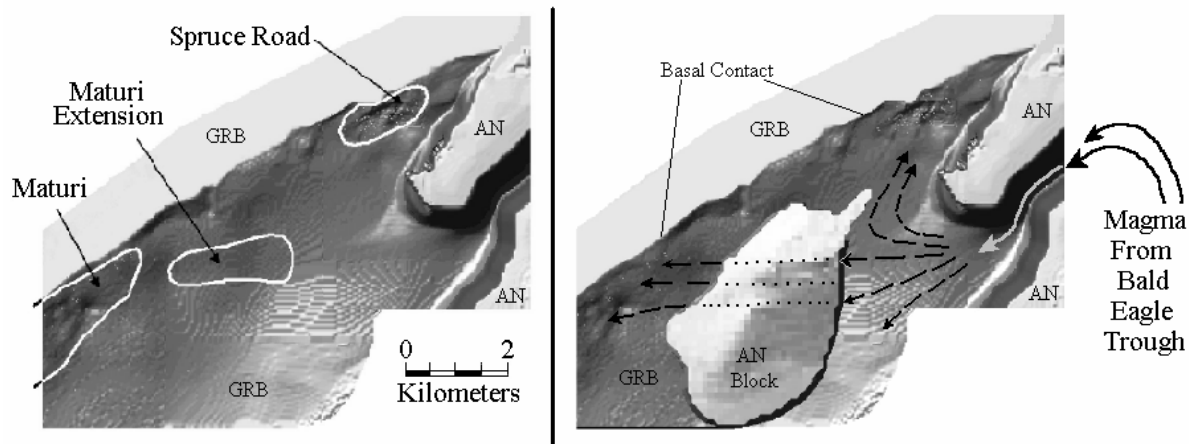


Figure 2. Conceptual magma flow model for the Spruce Road area.



Turbulent Magma Flow Regime of the Maturi Extension

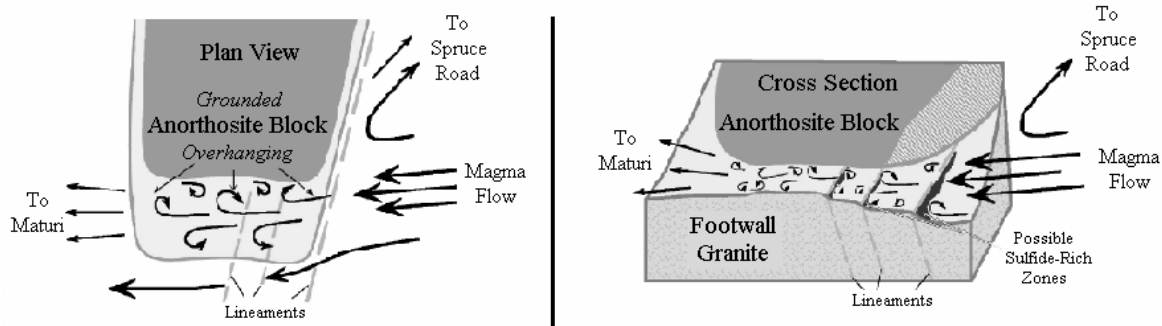


Figure 5. Conceptual model for the formation of the Cu-Ni deposits of the northern SKI. Sheet-like mineralization of Maturi located to the left of the diagram, and the PGE-enriched Maturi Extension located under the Anorthositic Series block.

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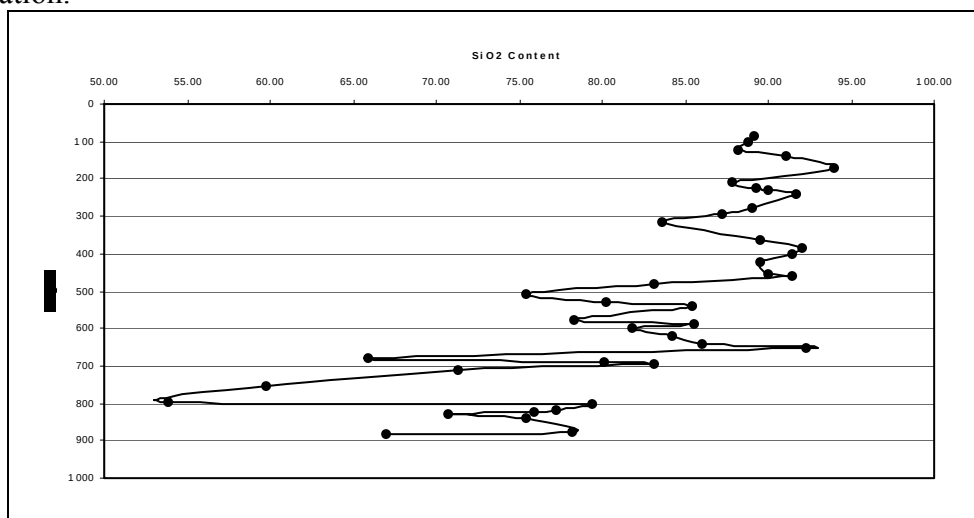
New Information from the Sibley Group

Rogala, B., Fralick, P.W., and Borradaile, G. (*Department of Geology, Lakehead University, Thunder Bay, Ontario*)

The Sibley Group sediments were deposited in a subsiding intracratonic basin (Fralick and Kissin, 1995) between 1537 ± 10 –2 Ma (Davis and Sutcliffe, 1984) and 1339 ± 33 Ma (Franklin *et al.*, 1980). It is presently thought that these sediments were deposited closer to 1537 Ma. The Group was previously divided into three main Formations: Pass Lake, Rosspoint, and Kama Hill. The Pass Lake Formation consists of the conglomeratic Fork Bay Member and the sheeted sandstones of the Loon Lake Member, representing a braided fluvial environment (Cheadle, 1986). The Rosspoint Formation is separated into the Channel Island, Middlebrun Bay, and Fire Hill Members. The Channel Island Member is a cyclic dolomite-shale unit interpreted to be playa lake sediments (Cheadle, 1986). The Middlebrun Bay Member is a stromatolitic unit, considered a marker bed for the Sibley Group. It represents a period of relatively stable water and salinity levels. The Fire Hill Member consists of mudcracked red silt with mudchip conglomerates and sand sheet incursions. It signifies a time of tectonic tilting of the basin. The Kama Hill Formation is not subdivided, and is composed of purple shales and siltstones interpreted as mud flat deposits (Cheadle, 1986).

The Nipigon Bay Formation is a new addition to the Sibley Group, overlying the Kama Hill Formation. The exposure of this unit is quite limited. It has only been found to crop out on some of the islands in Nipigon Bay, in particular Quarry Island and Vert Island. The Nipigon Bay Formation has also been found in several holes drilled by Falconbridge Limited in 1997. These holes intersected approximately 500 m of well-sorted medium sandstone. The colour of the sandstone can be buff, red, orange, or purple. The sandstone has cross-stratification, which varies from low- to high-angle. The thickness of cross-stratification sets is also variable, ranging from 20 cm to 300 cm, with an average thickness of 100 cm.

Figure 1 SiO₂ content varies through the Sibley stratigraphy. The upper 500 m is the Nipigon Bay Formation.

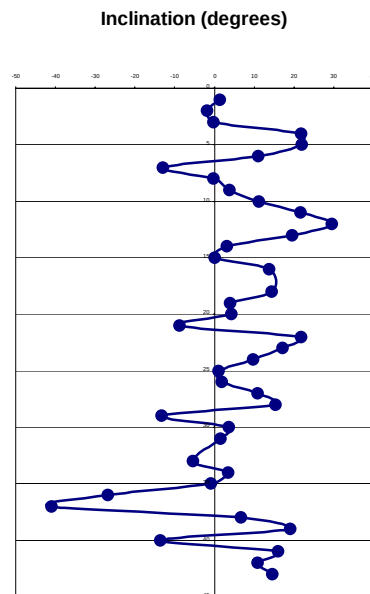


Extensive geochemistry was conducted on the sandstones throughout the Sibley stratigraphy, from the Pass Lake Formation to the Nipigon Bay Formation. The geochemistry shows an

interesting series of element peaks within the Pass Lake Formation, indicating sharp, contrasting influxes of source material. However, source-rock modeling has not proven conclusive at this point. The geochemistry indicates an abrupt change at the base of the Nipigon Bay Formation. This Formation is much less variable and shows a different source-rock character than that of the Pass Lake Formation. This is portrayed in Figure 1, using SiO₂ content, although the same pattern is repeated in all of the elements that were used for this analysis.

The Channel Island Member of the Rosspoint Formation has also produced some interesting information. Paleomagnetic analysis was conducted on a 50 cm section of core from Noranda's NI-92-7 drill hole. The inclinations were calculated and graphed to show the variations. The result was the chart in Figure 2 (left), which defines a curve that is believed to represent secular variation. This work will be followed up with isotope geochemistry and scanning electron microscopy for further interpretations.

Figure 2 Paleomagnetic inclinations measured at 1 cm intervals along a 50 cm length of core.



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300 my evolution of the Red Lake greenstone belt, western Superior Province, Ontario: A synthesis of current constraints on volcanism, sedimentation, deformation, metamorphism and gold mineralization.

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The Red Lake gold camp preserves an extensive record of magmatic and sedimentary activity from 3.0-2.7 Ga, and evidence of multiple episodes of deformation, hydrothermal alteration and metamorphism. The oldest volcanic rocks, which host its major lode gold deposits, are komatiite and tholeiitic basalt of the Balmer assemblage which includes minor 2.99-2.96 Ga intermediate to felsic volcanics and chemical metasedimentary rocks. Some of these basaltic rocks have trace element compositions (Th/Nb) reflecting local interaction with a differentiated crust, however, continental basement has not yet been observed in the belt. A thick sequence of 2.94-2.91 Ga intermediate to felsic calc-alkaline flows and pyroclastic rocks, interbedded with basalt, komatiite and stromatolitic carbonate comprise the overlying Ball assemblage. Ball volcanic rocks show trace element variations (e.g. Th/Nb) in mafic to felsic volcanic rocks that are also consistent with contamination by differentiated crust. Relatively juvenile ϵ_{Nd} values of +0.8 to +1 in these felsic rocks suggest that the contaminant was relatively young (~3 Ga) crust. Ball ultramafic rocks have depleted ϵ_{Nd} values of +2.2 and may reflect intra-arc extension and upwelling of depleted mantle-derived magma. Quartz-rich fuchsite-bearing clastic rocks of the c. 2.9 Ga Slate Bay assemblage have detrital zircon profiles (GSC SHRIMP, n=140 grains; and Corfu et al., 1998) that indicate derivation from predominantly Ball (with lesser Balmer) sources. This clastic sequence, which extends the length of the belt, overlaps the Ball/Balmer contact, however, north of Red Lake (McInnes Lake), Ball-age volcanic rocks and iron formation are in depositional contact with the Balmer assemblage (Corfu et al. 1998).

Ball volcanism was followed by the deposition on Balmer substrate of the 2.894 Ga Bruce Channel assemblage comprising calc-alkaline intermediate pyroclastic rocks overlain by an upward-fining sequence of clastic sediments and chert-magnetite iron formation. Felsic tuff has depleted ϵ_{Nd} values of +2 (Henry et al. 1999), reflecting a change between 2.99 and 2.89 Ga toward isotopically depleted magmatism that may reflect crustal growth at a juvenile continental margin (cf. Henry et al. 2000). The overlying Trout Bay assemblage comprises a lower sequence of basalt, 2.85 Ga intermediate pyroclastic and epiclastic rocks, iron formation and an upper sequence of pillowed tholeiitic basalt. The upper basalt sequence has depleted, MORB-like trace element profiles reflected in positive ϵ_{Nd} values of +2, similar to model Archean depleted mantle. The Trout Bay and Ball assemblages face toward each other across an interpreted tectonic contact that may reflect telescoping across the continental-oceanic interface.

Following a hiatus of some 100 my, the onset of extensive calc-alkaline volcanism is recorded by the Confederation assemblage with c. 2.75-2.74 Ga shallow marine to subaerial calc-alkaline mafic to felsic volcanic rocks of the McNeely sequence, overlain and interstratified by c. 2.74 Ga submarine, mixed calc-alkaline and tholeiitic basalts and FIII-type rhyolite of the Heyson assemblage. McNeely volcanic rocks have an ϵ_{Nd} value of +1 to +0.8, whereas Heyson volcanic rocks have depleted ϵ_{Nd} values of +2.9. These geochemical and isotopic data are consistent with establishment of a Neoproterozoic shallow marine arc (McNeely) on the existing Mesoproterozoic

continental margin sequence, with local intra-arc extension and eruption of high temperature F3 rhyolite and submarine tholeiitic basalt (Heyson). A depositional relationship between the Confederation and Mesoarchean assemblages is supported by a c. 2.75 Ga felsic dyke that cuts the Balmer assemblage, and by Mesoarchean inheritance in c. 2.74 Ga volcanic rocks (Corfu et al., 1998). An angular unconformity is indicated by opposing facing of Balmer and Confederation strata in the Madsen area, consistent with overturning of the Balmer (D_0) prior to Confederation volcanism. Local occurrences of coarse clastic rocks, such as ironstone-derived conglomerate on Wolfe Bay, may represent basal conglomerate marking this unconformity. Typically, however, the interface between Neoarchean and Mesoarchean volcanic rocks is covered by a c. 2.735 Ga clastic sequence, the Huston assemblage. Detrital zircon populations from conglomerate samples of the Huston assemblage from the Balmertown and Madsen areas show single, prominent (50-60 grains), c. 2.74 Ga detrital age peaks that indicate derivation from the Confederation assemblage. Undated conglomeratic rocks that underlie the youngest volcanic assemblage in the belt (c. 2.733 Ga Graves) are correlated with the Huston assemblage, as are argillaceous to turbiditic rocks that conformably overlie c. 2.744 Ga McNeely volcanic rocks in central Red Lake. Shallow marine to subaerial, 2.73 Ga calc-alkaline, intermediate to felsic volcanic rocks and synvolcanic plutons of the Graves assemblage reflect Andean-style arc magmatism that culminated in the c. 2.72-2.70 Ga Kenoran orogeny.

The youngest supracrustal rock in the belt is a pebble conglomerate, once thought to correlate with the “Austin tuff” ore horizon. This garnetiferous metasedimentary rock yielded a diverse detrital zircon population profile ($n=56$ grains), with ages that correspond to the Balmer, Ball, Trout Bay and Confederation assemblages, and younger. The maximum depositional age of this sample is 2700 ± 6 Ma, the upper intercept of a 5-spot regression for the youngest detrital zircon analysed. This young supracrustal sequence provides a new maximum age for penetrative deformation and amphibolite-facies metamorphism in the Red Lake area. Its relationship to gold mineralization is no longer certain.

The Red Lake greenstone belt displays evidence of several episodes of deformation, interpreted to be closely linked with extensive hydrothermal activity and gold mineralization. Nonpenetrative deformation (D_0) appears to have involved overturning of the c. 2.99 Ga Balmer assemblage, possibly related to recumbent folding, prior to Neoarchean volcanism. The main stages of penetrative deformation were imposed after ca. 2.74 Ga volcanism. These resulted in northerly trending, south-plunging F_1 folds and associated S_1/L_1 fabrics, superimposed by east-to northeast-trending D_2 structures ($F_2/S_2/L_2$) in western and central Red Lake, and by southeast-trending folds and fabrics (the “mine trend”) in eastern Red Lake. D_1 may be bracketed between 2.744 Ga, the age of Confederation volcanic rocks in central Red Lake that contain F_1 structures, and c. 2.733 Ga, the age of the Graves volcanic sequence that does not appear to have been affected by D_1 . It seems probable that deposition of the Huston assemblage took place synchronous with, and as a response to deformation (D_1) and that D_1 is linked to a change in plate dynamics that took place between Confederation and Graves volcanism. An important constraint on the timing of D_2 is provided by the relationship of regionally extensive D_2 fabrics to the 2718 ± 1 Ma Dome Stock. Supracrustal rocks adjacent to the stock, and occurring as xenoliths within the stock, contain a penetrative S_2 fabric. The stock itself contains a weak throughgoing NE-striking foliation coplanar to S_2 observed elsewhere. These fabric relationships suggest that the main cleavage-forming stage of D_2 predated intrusion of the Dome stock at 2718 Ma, but that shortening was sustained beyond its emplacement. Penetrative strain

appears to have outlasted $c. 2700 \pm 6$ Ma, the maximum age of young unconformably overlying conglomeratic rocks that display a penetrative tectonic foliation coplanar to D_2 fabrics throughout central Red Lake. Metamorphic mineral assemblages within this sample and surrounding rocks include staurolite-cordierite-garnet-bioite from pelitic compositions and orthoamphibole-garnet from mafic compositions, indicating that amphibolite facies metamorphism also outlasted $ca. 2700 \pm 6$ Ma.

We interpret tectonometamorphism of the Red Lake belt between $c. 2.718$ and 2.7 Ga to be the result of orogenic activity related to collision between the $c. 3$ Ga North Caribou terrane and the $c. 3.6$ - 3.0 Ga Winnipeg River terrane, to the north and south of the Red Lake belt, respectively. If the dated “Austin tuff” sample represents an intact relict of the gold ore horizon mined from the Madson area, these new data would suggest gold mineralization of young, unconformably overlying clastic rocks after $ca. 2.7$ Ga. However, this is in contrast to the timing of gold mineralization in the Balmertown area, which has been shown to predate 2714 ± 4 Ma, the age of a post-ore porphyritic dyke from the New Red Lake (formerly A.W. White) mine (Corfu and Andrews, 1987).

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The Mine Permitting Process in Minnesota - Who, What, Where, and When.

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Interest in the Cu-Ni-PGE deposits of the Duluth Complex has been recently renewed due to advances in hydrometallurgical processes and increased PGE metal prices. Economic evaluations are currently being conducted for several of the deposits, and in some cases, initial steps have also been taken in order to obtain the various permits to mine. In Minnesota, the permitting process for a non-ferrous, metallic mine is complicated; involves dealing with numerous different federal, state, and local agencies; and as yet, has not been carried through to completion for establishment of either an open pit or underground mine. This project outlines each of the necessary permitting steps that are needed to develop a metallic mine, and provides time lines, or length of the various determination processes, for each type of permit that would be required. Also included are lists of agencies, contact persons, phone numbers, and e-mail addresses. All of the data generated in this project will be used to produce a report, and supplemental pamphlet, that fully describes what each permit entails.

At the forefront of the mine permitting process in Minnesota is an environmental review process consisting of preparation of an Environmental Impact Statement (EIS), and because an EIS is mandatory, it must be preceded by preparation of a scoping Environmental Assessment Worksheet (EAW). Many of the permits that are mining-related require this process to be completed (Table 1). The scoping EAW is designed to identify potentially significant issues (including possible environmental, sociological, economic, and health risk impacts) that will be associated with a proposed mine and will need further study in the EIS. Thus, the EAW is a “blueprint” for the EIS because it sets limits on what will be discussed further and at what level of detail. It is a standardized six-page questionnaire (31 questions), accompanied by numerous supplemental pages to fully answer the questions, and “typically” takes 90-120 days to complete. The EIS, which typically takes 280 days to complete (legally mandated time), is a thorough study of the issues defined in the EAW and provides information regarding environmental impacts and how they can be avoided/minimized. It considers and sets forth a series of “reasonable” alternatives (including the “no-build” alternative), possible permit conditions, and possible mitigation measures. The EIS does not approve or disapprove of a project; rather, it provides information and alternatives. A determination on the adequacy of the information provided in the EIS must be made before it can be used in determining whether to grant or deny any mine-related permit applications.

The Minnesota Department of Natural Resources (DNR) is the Responsible Government Unit (RGU) for both the scoping EAW and EIS. The EAW/EIS process should begin as soon as possible because the entire process could take around 1.5 years before a final adequacy decision can be made. Furthermore, no decisions on most mine-related permits can be made until after the EIS process has been completed (actually 25-90 days after the adequacy decision). It is extremely important to make early contact with all of the agencies that are responsible for granting permits for several reasons that include: 1. to insure that all issues relating to the various permits are included for study in the EIS; 2. to begin preparation on some of the permits so they can be issued as quickly as possible after the EIS is complete (some permits can take up to 1.5 years (or more) before decisions to grant or deny can be made); 3. to avoid duplication of efforts

for the various permits and establish cooperation between the agencies; and 4. to get the public informed and involved to hopefully minimize later delays in the permitting process.

Table 1: List of potential permits required to establish a non-ferrous, metallic mine in Minnesota.

Permit	Agency	Approximate Application determination time*
Permit to Mine**	DNR Minerals	7-8 months
WCA-Wetlands Replacement Plan**	DNR Minerals	4-6 months
Water Appropriation Permit**	DNR Waters	< 2 months
Public Waters Work Permit**	DNR Waters	< 2 months
Dam Safety Permit**	DNR Waters	< 2 months
Part 70 - Air Quality Permit**	MPCA	1.5 years
NPDES/SDS Stormwater Permits (two - for Construction and Industrial Activity)	MPCA	< 2 months?
NPDES/SDS Wastewater Permits** (two - for industrial process wastewater and sewage)	MPCA	1.5 years
Hazardous Waste Permit**	MPCA	1-3 years
Section 404 Permit (discharges to wetlands)**	ACOE	120 days (unless Fed. EIS required?)
Section 10 Permit ? (Affects to “navigable” waters of the US)	ACOE	?
Section 401 Certification (wetland certification needed before 404 permit can be issued)	MPCA	60-120 days ?
Water Treatment Plant Permits	MPCA	?
Local Permits - zoning, construction, bonding, etc	varies	“short” period

* = Minimum time to complete (assuming optimal conditions) after all data that are required to be submitted for the permit are complete

** = Permit that by itself may require a mandatory EAW and/or EIS.

Abbreviations: DNR = Department of Natural Resources; MPCA = Minnesota Pollution Control Agency; ACOE = Army Corps of Engineers; NPDES = National Pollutant Discharge Elimination System; SDS = State Disposal System; WCA = Wetland Conservation Act.

Description of a pegmatite occurrence on the eastern margin of the Mellen Granite, State Highway 13, Ashland County, Wisconsin.

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A highway construction project supervised by the Wisconsin Department of Transportation, District 8 office took place during the 2001 field season on State Highway 13 immediately north of the City of Mellen in central Ashland County. Construction activity began at the intersection with State Highway 169, extending northward for 3480 meters. The project consisted of a realignment within the existing right-of-way and necessitated the blasting, excavation and removal of approximately 33000 cubic meters of rock.

Bedrock geology in the project area consists of intrusive rocks of the Lower Keweenawan (approximately 1.1 Ga) Mellen Complex. The highway right-of-way is positioned over the contact between two discrete rock bodies within the Complex: the gabbroic rocks of the Potato River Intrusion (to the east); and the younger Mellen Granite (to the west). A previously existing roadcut along the right-of-way indicated the presence of an intrusive breccia at this intrusive contact. The primary lithology of the breccia matrix in this previously existing roadcut appears to be granodiorite, with xenoliths of gabbro, lesser amounts of mafic volcanic rocks, and minor amounts of metasediments of probable Lower Proterozoic age.

New exposures resulting from construction activity indicate an additional complexity to this brecciated contact margin, culminating in the presence of a small pegmatite body approximately 520 meters to the north of the original intrusive breccia exposure. The petrography of the pegmatite itself appears to consist primarily of coarse-grained potassium feldspar (perthite), quartz and biotite, with accessory epidote, apatite and other currently unidentified minerals. An irregular central “core” contains abundant quantities of myrmekite, various unidentified phosphates(?), and an unidentified pale lilac-colored mineral. Analyses will be performed on these minerals in the near future. The intrusive breccia in the areas proximal to the pegmatite displays moderate to strong potassium metasomatism, with plagioclase altered to potassium feldspar/perthite/myrmekite and the generation of epidote as a residual by-product, the alteration of mafic minerals in gabbroic xenoliths to biotite and/or phlogopite and hornblende, etc. Anastomosing swarms of small irregular felsite (aplite?) dikes also occur in this zone. Evidence for later-stage cataclasis and a retrograde chlorite event is represented by occurrences of chloritized mafic fault gouge and the presence of books of chlorite replacing biotite phenocrysts in areas proximal to these gouge zones. Irregular localized bodies of intrusive rocks of intermediate composition (syenite, monzonite, monzonite porphyry, monzogabbro, quartz diorite, etc.) also occur along the perimeter of this breccia/pegmatite zone. Widely disseminated sulfides (pyrite/chalcopyrite) are also noted.

Inferences from the Hattenberger deep drill hole, Carlton County, Minnesota, pertinent to regional stratigraphy and mineral potential of the western segment of the Penokean Orogen

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The Hattenberger core hole, drilled vertically to a depth of 7,440 feet (2,268.3 meters) near Kettle River in Carlton County, Minnesota, penetrates a sequence of metamorphosed and deformed sedimentary and volcanic strata of Paleoproterozoic age within the fold and thrust belt of the Penokean orogen. Continuous core recovered from the depth interval 803 to 7,440 feet (244.8 to 2,268.3 meters) provides a rare depth-dimensional view of the lithostratigraphy and structures in rocks that are not well exposed at the surface.

The cored interval below depth 4,780 feet (1,457.3 meters) consists predominantly of quartz-rich mica schist, calcareous mica schist, and dolomitic marble that are interstratified on coarse to fine scales. Relatively minor amounts of mafic volcanic rock (both flows and fragmental types) and recrystallized cherty iron-formation are interstratified with the dominant quartzose, micaceous, and calcareous metasedimentary rocks in the upper part of this lowermost major division of the core. In the upper major division of the core, above depth 4,780 feet, the predominant rock types are (1) dark-colored, thinly bedded graphitic mica schist and phyllite; (2) non-magnetic, graphitic, silicate-carbonate-sulfide iron-formation, parts of which are characterized by prominent porphyroblasts of Fe-rich garnet and amphibole; and (3) an assortment of mafic volcanic rock types that in general form thin stratigraphic units interbedded with the metasedimentary components. Sills of metadiabase chemically identical to the volcanic rocks occur throughout the whole core, in both the lower sequence of quartzose and calcareous schists and the upper sequence of graphitic and iron-rich rocks. Altogether, the sills and allied metavolcanic rocks amount to about half of the total footage drilled, with the greater part being sills.

The lithologic and structural attributes of the lower sequence of rocks in the Hattenberger core match well with those of the Denham Formation at its type locality (Morey, 1978; Boerboom and Jirsa, 2001). Likewise, the attributes of the upper sequence match well with those of the Glen Township Formation, the type section for which is contained in several cores drilled about 23 miles (37 kilometers) along regional strike to the west of the Hattenberger locality (Morey, 1978). The assumed Denham–Glen Township contact in the Hattenberger core is occupied by a thick sill of metadiabase, the margins of which are strongly sheared. This leaves the nature of the formational contact open to question. It could be a conformable contact invaded by the sill, with the shearing at sill margins due to mechanical contrasts during complex, multi-stage regional deformation, or it could be a tectonic contact invaded by the sill that was later reactivated.

Highly deformed, variably metamorphosed stratotectonic complexes of calcareous metasedimentary rocks, carbonate-silicate-sulfide iron-formation, and mafic metavolcanic rocks are the regional hosts for economic mineral deposits in several important mining camps, including the Homestake district in South Dakota (Caddey and others, 1991) and the Broken Hill and Mount Isa districts in Australia (Ashley and others, 1998; Painter and others, 1999). The mechanical contrasts among the various rock types in these complexes, together with the geochemical reactivity of the calcareous and iron-rich strata, provide fertile ground for mineral deposition from spatially associated hydrothermal systems. Clearly, the geological attributes revealed in the Hattenberger core are not of themselves meaningful indicators of mineral-deposit probability. However, those attributes taken in conjunction with mineralogical evidence of hydrothermal activity in the Cuyuna mining district (McSwiggen and others, 1995; Melcher and others, 1996) and the presence of barren massive sulfide deposits in the Glen Township area (Han, 1968) suggest that broad areas of east-central Minnesota are intrinsically prospective for a variety of ore-deposit types.

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Petrographic Study of the Ottertail Pluton, Superior Province, Northwestern Ontario

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INTRODUCTION

This study concentrates on the Ottertail Pluton at the Wabigoon-Quetico subprovince boundary in the western Superior Province near Mine Centre, Ontario. The Ottertail is one of the Algoman plutons dated at 2686 Ma (Davis et. al, 1989), which have been used to constrain the termination of deformation at the subprovince boundary (e. g. Davis et. al, 1989; Poulsen, 2000). Our goal is to study the mineralogy and microstructures of the pluton in thin section. At the macroscopic level the pluton seems largely undeformed because of the general lack of macroscopic deformation fabrics. This has led many researchers to interpret the Ottertail Pluton to be post-tectonic. However, it has been shown that determining the relationship between pluton emplacement and deformation requires more detailed analysis (Paterson and Tobisch 1988). We are using petrographic analysis combined with a magnetic fabric study to better determine the relationship between the pluton emplacement and deformation at the Wabigoon-Quetico boundary.

ANALYSIS

Using optical petrography and a vibrating sample magnetometer (VSM), we determined the mineralogy and magnetic mineralogy of the pluton. In general, the pluton ranges from quartz monzonite to granite to granodiorite. Mineralogy consists of: quartz, plagioclase, microcline, microcline perthite, hornblende, myrmekite, and some zircon. There are also minor amounts of sericite, clinozoisite, magnetite (and other opaque minerals) in some portions of the pluton. The grain sizes vary. Many quartz crystals have undulose extinction and some have subgrains, which suggest slight deformation by dislocation processes. Minor metamorphism is indicated by sericite in plagioclase crystals, and microcline perthite.

At the macroscopic level, the pluton seems largely undeformed, but our study of anisotropy of magnetic susceptibility (AMS) and microstructures show that there is some evidence for deformation.

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Internal structures within crustal structural slabs, Quetico-Wawa subprovince junction, Quetico Provincial Park, Ontario

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The rocks of the Wawa subprovince, adjacent to the Quetico-Wawa subprovince junction, in the region between Agnes Lake and McKenzie Lake in Quetico Provincial Park, Ontario can be grouped into two discrete structural slabs. Detailed mapping of the ductile borders of these slabs indicates that the slabs are approximately 2 km thick and probably form the limbs of major recumbent folds. The base of each slab is defined by a ductile structural discontinuity, possibly representing the lower limb of a nappe or thrust surface. The northeastern McKenzie Lake slab rests upon the underlying Agnes Lake slab. The rocks which make up these structural slabs are amphibolite-grade, migmatitic, mica-quartz-feldspar-garnet schists, amphibolite, and tonalite-granodiorite.

All of these rocks contain major deformational structures which were formed before, during and after the emplacement of the enclosing crustal slabs. The earliest recognizable structures are found only in the tonalite-granodiorites. These structures are layers of centimeter-scale thickness, and most are only recognized on outcrop surfaces where the layers are accentuated by superficial weathering. These layers are probably caused by centimeter-scale shearing within the tonalites. Both field measurements and aerial photo interpretation demonstrate that these centimeter-scale layers occur in "structural packages" which often have thicknesses on a scale of hundreds of meters. Hundreds of strike and dip measurements made on these layers, in conjunction with interpretation of large-scale, detailed, aerial photographs, demonstrate that the layers are deformed into a complex series of folds with typical wave lengths ranging from one to two kilometers. Many of the folds appear overturned, but some are upright, and most plunge northeastward, with occasional reversal of plunge. Interlayered and infolded with the tonalites are schists and amphibolites, and primary structures in these meta-sedimentary and meta-volcanic rocks sometimes allow determination of stratigraphic top. All of the internal layers and folds are cut and smeared by the last recognizable ductile deformation along the subprovince junction.

The internally folded rocks are later broken into individual kilometer-scale structural blocks which are bounded by steeply dipping faults. These faults are rarely exposed in outcrop, but some cut and offset the Quetico-Wawa subprovince ductile junction. Thus, a brittle phase of deformation followed the last ductile deformation at the subprovince junction and the emplacement of the crustal slabs. These faults, which cut the internal folds of the McKenzie Lake crustal slab, appear unrelated to the Burntside Lake brittle fault zone. This fault has been traced in outcrop about 100 km northeastward from its type locality on Burntside Lake, Minnesota and is mapped as terminating against the Quetico-Wawa junction in the vicinity of McKenzie Lake. The internal faults typically lack the intense centimeter-scale brecciation and the intense hydrothermal oxidation so characteristic of the Burntside Lake fault zone. Further, the strike orientation of seventy-five mapped internal faults appear geometrically related to the ductile folding of the Quetico-Wawa junction (and crustal slab development) rather than to the northeast-striking Burntside Lake fault.

Thus, the internal structures within the McKenzie Lake crustal slab initially appear to record intense centimeter-scale shearing within all the rocks. This shearing is followed by ductile folding and complete recrystallization and then by recumbent overfolding of the sheared and folded sequence to produce the crustal slab. Following slab emplacement, the rocks are broken into kilometer-scale fault blocks, the strikes of which suggest a relationship to a later stage of compression across the subprovince junction. The latest ductile deformation along the Quetico-Wawa subprovince junction cuts the crustal slabs, and all their rocks and internal structures.

The Agnes Lake structural slab, which underlies the McKenzie Lake slab, contains a similar suite of rocks and has similar internal structures to the above-described McKenzie Lake slab. However, within the Agnes Lake slab the internal structures are dominated by a series of northeast-striking, gently northwest-dipping, ductile shear zones chiefly at the contacts with tonalite and schistose rock units. These ductile shears are themselves recumbently folded and overturned toward the southeast. Although fieldwork continues on the Agnes Lake slab, the current interpretation of these internal ductile shears is that they represent folded sections of an earlier Quetico-Wawa subprovince junction, which have been sheared and folded into the Agnes Lake slab.

Impact of fire on the forest floor and mineral soils, Snowbank Lake, Minnesota

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We are investigating the geochemical effects of fire on the forest floor and mineral soils in an area of the Superior National Forest near Snowbank Lake that was burned in a fuel reduction prescribed fire by the USDA Forest Service on October 11, 2000. The forest around Snowbank Lake, in northern Minnesota, is a mixed stand of older-aged balsam fir, spruce, aspen, red pine and jack pine. Many trees, particularly mature balsam and spruce, were blown down by a severe storm in July 1999. The scheduled Snowbank Lake fire gave us the opportunity to establish 10 study sites in the proposed burn area. At each site we described and collected soils prior to the fire, immediately after the fire, and seven months after the fire to quantify physical and chemical changes in the forest floor as a result of the burning. Initial sampling was in July 2000. At each site, forest floor material (living moss, forest litter, and/or humic layers) and mineral soil horizons (A-, E-, B- and C-horizons as available) were collected for analysis. The thickness of each layer was measured, and representative samples were collected for density calculations.

The fire burned much of the fine fuel at the surface and affected 8 of the 10 sample sites. On October 12, prior to any post-fire rainfall, we resampled the sites. Burn severity (a qualitative assessment of the heat pulse directed towards the ground during a fire) was estimated and where possible samples comparable to pre-burn samples were collected. The sites were resampled seven months later in May 2001, following a winter of moderate snow cover. The fuel load at the surface and the moisture content of the forest surface controlled the major impact of the fire on the forest floor. Fire severity was high (100% of organic forest floor material consumed, mineral soil exposed) at 4 sites, moderate at 1 site (some forest floor material burned, mineral soil not exposed), and light at 3 sites (surface material charred with minimal loss at the forest floor). Two sites were untouched by fire.

One of the elements of interest in this study was mercury. Gaseous elemental mercury in the atmosphere is transferred into a forest environment by wet and dry deposition onto the forest floor, creating a repository of mercury that is bound to organic carbon compounds. Recent studies show that smoke plumes from forest fires carry substantial mercury, but the origin of that mercury was in question (Friedli et al., 2001). Our preburn sampling shows that much of the mercury at the forest surface is bound to organic material on the forest floor and in organic mineral soils. Severe fire can vaporize much of this mercury as the organic compounds are combusted. Based on pre-burn analyses and measured thickness and density of organic material and assuming that all mercury in the organic layer is emitted during high severity burns when the forest floor is burned down to the mineral soil, average mercury emissions from the Snowbank Lake burn were about 2 mg/m² of burned surface. This estimate only takes into account mercury bound to organic material on the forest floor and does not include burned foliage or woody fuels. Mercury bound to organic material in A-horizon mineral soils was not lost, even at sites of high burn severity, indicating that the fire's thermal pulse did not heat soils above the 357°C vaporization temperature of mercury.

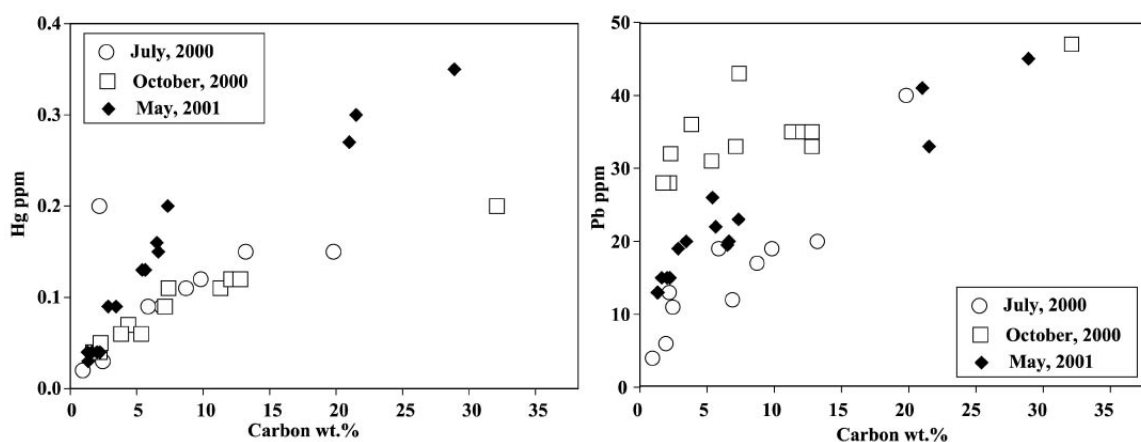
Because the footprint of an historic fire was apparent in our study of soil geochemistry in Isle Royale National Park (Woodruff and Cannon, 2001) we anticipated that exposure of mineral

soils by fire would lead to loss of both mercury and carbon over time. Loss of organic matter should be accelerated by solar heating of previously shaded soils and by lower input rates of organic matter because of loss of forest canopy. Interestingly, analyses of A-horizon soils collected at Snowbank Lake in May 2001 show no carbon loss and marked increases in mercury rather than decreases (Figure 1A). The reasons for this increase are unknown, although we speculate that it may be the result of leaching of mercury from the overlying ash layer or possibly from enhanced sorption of mercury by exposed organic material in mineral soils. The fact that carbon does not increase concomitant with mercury suggests that physical incorporation of ash and adsorbed mercury is not the cause of higher mercury concentrations.

Lead, which much like mercury has an atmospheric source and is enriched in the forest floor and organic mineral soils, is enriched in the uppermost mineral soil samples collected in October after the fire compared to preburn values (Figure 1B), but comparable soil samples collected the following May show a slight decrease in lead, although most values are still higher than July 2000 levels. The increase of lead in soils immediately following the fire may be the result of the concentration of residual lead remaining after the burning of forest vegetation. Lead sorbed onto organic material may not volatilize in the fire, but could collect on surface soils.

Additional sampling is planned for May 2002 to monitor the evolving geochemistry of the forest surface. This research shows that there are both immediate and long-term impact from fire, including loss of volatile elements and profound element movement at the forest surface.

Figure 1. Mercury and lead versus carbon in A-horizon soil samples from the area of the Snowbank Lake prescribed fire.



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