



INSTITUTE ON LAKE SUPERIOR GEOLOGY

**55TH ANNUAL MEETING
MAY 5-10, 2009
ELY, MINNESOTA**

ORGANIZED BY:

**THE PRECAMBRIAN RESEARCH CENTER
UNIVERSITY OF MINNESOTA DULUTH**

**JAMES D. MILLER, JR., GEORGE J. HUDAK, AND DEAN M. PETERSON
Co-Chairs**

Proceedings Volume 55

Part 1 – Program and Abstracts

*Edited by George J. Hudak, University of Wisconsin-Oshkosh and
Precambrian Research Center, University of Minnesota Duluth*

Cover Photos: Various photos from Precambrian Research Center field areas over the past two years. Top row from left to right: Sunset over Ima Lake (BWCA), mapping anorthositic troctolite east of Jordan Lake (BWCA), moonrise over Ima Lake (BWCA). Center Row, left to right: Island within Twin Lakes (Superior National Forest), mapping north of Ima Lake. Bottom Row, left to right: Neoarchean pillow lavas in Ely, Soudan Member of the Ely Greenstone Formation east of Soudan Mine, and intermixed coarse-grained troctolite and medium-grained ophitic anorthositic olivine gabbro southwest of Alworth Lake (BWCA). Photos courtesy of George Hudak, Jim Miller, Dean Peterson and Eric Stifter.

55TH INSTITUTE ON LAKE SUPERIOR GEOLOGY

PROCEEDINGS VOLUME 55 CONSISTS OF:

PART 1: PROGRAM AND ABSTRACTS

PART 2: FIELD TRIP GUIDEBOOK

TRIP 1: CU-NI DEPOSITS OF THE DULUTH COMPLEX

TRIP 2: GLACIAL GEOLOGY OF THE VERMILION MORaine

TRIP 3: TOUR OF THE SOUDAN IRON MINE AND PHYSICS LAB

TRIP 4: PIONEER MINE CANOE EXCURSION

TRIP 5: GEOLOGY AND METAMORPHISM OF THE MESABI RANGE

TRIP 6: GEOLOGY OF THE LAKE ONE TROCTOLITE BY CANOE

TRIP 7: ARCHITECTURE OF AN ARCHEAN GREENSTONE BELT

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

Boerboom, T. J., and Green, J. C., 2009, Bedrock geological map of the Deer Yard Lake and Good Harbor Bay Quadrangles, north shore of Lake Superior, Minnesota [abstract]: Institute on Lake Superior Geology Proceedings, 55th Annual Meeting, Ely, MN, v. 55, part 1, p. 4-5.

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PREVIOUS INSTITUTES ON LAKE SUPERIOR GEOLOGY, 1955-2009

ILSG	YEAR	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 and 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 and 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 and 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. La Berge
31	1985	Kenora, Ontario	C.E. Blackburn
32	1986	Wisconsin Rapids, Wisconsin	J.K. Greenberg
33	1987	Wawa, Ontario	E.D. Frey and 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 and W. Meyer
44	1998	Minneapolis, Minnesota	J.D. Miller, Jr. and M.A. Jirsa
45	1999	Marquette, Michigan	T.J. Bornhorst and R.S. Regis
46	2000	Thunder Bay, Ontario	S.A. Kissin and P. Fralick
47	2001	Madison, Wisconsin	M.G. Mudrey, Jr. and B.A. Brown
48	2002	Kenora, Ontario	P. Hinz and R.C. Beard
49	2003	Iron Mountain, Michigan	L.G. Woodruff and W.F. Cannon
50	2004	Duluth, Minnesota	S.A. Hauck and M. Severson
51	2005	Nipigon, Ontario	P. Hollings and M.C. Smyk
52	2006	Sault Ste. Marie, Ontario	R.P. Sage and A.C. Wilson
53	2007	Lutsen, Minnesota	L.G. Woodruff and J.D. Miller, Jr.
54	2008	Marquette, Michigan	T.J. Bornhorst and J.S. Klasner
55	2009	Ely, Minnesota	J.D. Miller, Jr., G.J. Hudak, D.M. Peterson

SAM GOLDICH AND THE GOLDICH MEDAL

Sam Goldich received an AB from the University of Minnesota in 1929, a M.A. from Syracuse University in 1930, and a Ph.D. from the University of Minnesota in 1936. During World War II Sam worked for the U.S. Geological Survey in mineral exploration. In 1948, Sam returned to the University of Minnesota, and became Professor and Director of the Rock Analysis Laboratory the following year. He rejoined the U.S. Geological Survey in 1959 and was appointed as the first Branch Chief of the Branch of Isotope Geology. Sam returned to academia in 1964 when he went to Pennsylvania State University. He left PSU in 1965 and moved to the State University of New York at Stony Brook, where he stayed for 3 years. Restless yet again, he moved to Northern Illinois University in 1968 where he was a professor until his retirement in 1977. Sam's final move was to Denver where he became an emeritus at the Colorado School of Mines. Sam died in 2000, less than a month before his 92nd birthday.

In the late 1970's, Geological Society of America Special Paper 182, which included seminal geochronological studies by Sam Goldich and coworkers on the Archean rocks of the Minnesota River Valley, was nearing completion. At this time various ILSG regulars began discussing the possibility of recognizing Sam for his pioneering work on the resolution of age relationships and thus the geology of Precambrian rocks in the Lake Superior region. Three members, R.W. Ojakangas, J.O. Kalliokoski and G.B. Morey, presented the idea to the ILSG Board of Directors in 1978. The Board approved the creation of an award, provided funding could be obtained. It was suggested that collecting one or two dollars at registration for a dedicated account would provide resources for striking the medal. A general request was made to the ILSG membership for donations and Sam himself offered a challenge grant to match the contributions. In total \$4,000 was collected and thus began the work of creating the Goldich Medal.

The initial Goldich Award was presented to Sam by G.B. Morey in 1979 and consisted of a large paper proclamation. For the actual medal, G.B. Morey consulted with the foundry on production details, while Dick Ojakangas and Jorma Kalliokoski worked on the design of the award, suggesting that it be given for "outstanding contributions to the geology of the Lake Superior region." Simultaneously, a committee of J.O. Kalliokosi, W.F. Cannon, M.M. Kehlenbeck, G.B. Morey, and G. Mursky developed the Award Guidelines that were approved by the ILSG Board. By 1981 all the elements of the Goldich Award had come together, and the

second recipient, Carl E. Dutton, Jr., received the Goldich Medal for 50 years of significant contributions to the understanding of the geology of the Lake Superior region. Since the beginning, the Awards Committee has consisted of individuals representing industry, government and academia, with each member of the Committee serving for three years. The medal is now awarded every year at the annual ILSG meeting.

Reference:

Morey, G.B. and Hanson, G.N. (editors). 1980. Selected studies of Archean gneisses and Lower Proterozoic rocks, southern Canadian Shield. Geological Society of America, Special Paper 182, 175 p.

Prepared by various Goldich Medal Awardees, 2007



INSTITUTE ON LAKE SUPERIOR GEOLOGY GOLDICH MEDAL

PAST GOLDICH MEDALISTS

1979	Samuel S. Goldich	1994	Cedric Iverson
1980	<i>not awarded</i>	1995	Gene La Berge
1981	Carl E. Dutton, Jr.	1996	David L. Southwick
1982	Ralph W. Marsden	1997	Ronald P. Sage
1983	Burton Boyum	1998	Zell Peterman
1984	Richard W. Ojakangas	1999	Tsu-Ming Han
1985	Paul K. Sims	2000	John C. Green
1986	G.B. Morey	2001	John S. Klasner
1987	Henry H. Halls	2002	Ernest K. Lehmann
1988	Walter S. White	2003	Klaus J. Schulz
1989	Jorma Kalliokoski	2004	Paul Weiblen
1990	Kenneth C. Card	2005	Mark Smyk
1991	William Hinze	2006	Michael G. Mudrey
1992	William F. Cannon	2007	Joseph Mancuso
1993	Donald W. Davis	2008	Theodore J. Bornhorst

2009 GOLDICH MEDAL RECIPIENT

L. Gordon Medaris, Jr.

University of Wisconsin
Madison, Wisconsin

GOLDICH MEDAL COMMITTEE

Serving for the meeting year shown in parentheses

Richard Ojakangas (2006-2009)
Terry Boerboom (2007-2010)
Allan MacTavish (2008-2011)

Academic representative
Government representative
Industry representative

CITATION FOR GOLDICH MEDAL RECIPIENT

L. Gordon Medaris, Jr. - 2009 Goldich Medal Recipient

Gordon Medaris's many and diverse contributions to the geology of the Lake Superior region, as well as his long-continued participation in ILSG over the past five decades, are appropriately recognized by the Goldich Medal. Medaris's broad interests make him difficult to pigeonhole. He is best known internationally as an igneous and metamorphic petrologist who has emphasized the study of eclogites and orogenic peridotites of the North American Cordillera, the Caledonides of Scandinavia, the Variscides of the central European Bohemian Massif and the Variscides of the southern Carpathians. He has also studied mantle xenoliths from California, central Europe and the



Middle East. Gordon's European contributions have been recognized with two awards from Charles University of Prague, the Gold Medal of Science in 1998 and the Boricky Medal in 2006. It is fair to say that Gordon has developed a Bohemian love affair.

Better known to us is Gordon's research in the Lake Superior region that began in the 1970s with a ground breaking study of the Wolf River batholith of east-central Wisconsin, which is part of a continental-scale Geon 14 magmatic event. That work was initiated in collaboration with Randy Van Schmus and Phillip Banks and was continued and expanded by his student J. Lawford Anderson. Next, Medaris studied with geochemist Robert Cullers the rare earth elements of the Seabrook Lake carbonatite and cogenetic alkaline rocks. By the 1980s, we find Gordon, Van Schmus, and student Randy Maass publishing syntheses of Penokean deformation and metamorphism across Wisconsin and adjacent areas. In 1983, Gordon was the principal convener and editor for an international symposium on Proterozoic Geology, which resulted in two GSA Memoirs, Number 160 being *The Early Proterozoic Geology of the Lake Superior Region*. Gordon, Dave Moecher, and others then studied the metamorphic conditions of Sam Goldich's favorite high-grade gneisses in the Minnesota River Valley.

Since retiring in 1998, Medaris has redoubled his research efforts in the Lake Superior region with collaborations that culminated in 2003 in the benchmark *Journal of Geology* article about the age, composition, and metamorphism of Baraboo Interval rocks and their tectonic significance. Gordon's discovery of a paleosol beneath the Baraboo Quartzite and the previous recognition of paleosols beneath the Barron and Sioux Quartzites have important paleoclimatic implications, which he has discussed. He also has helped archaeologists to resolve pipestone artifact provenance by characterizing two distinct mineral assemblages in pipestone quarries -- hematite-quartz-kaolinite in the Barron and hematite-muscovite-pyrophyllite-diaspore in the Sioux and Baraboo Quartzites. Six journal articles have appeared from these Baraboo Interval investigations and we are still counting.

Besides the full-length publications alluded to above, Gordon has contributed talks at no less than 21 ILSG meetings beginning in 1973. He also has been a major organizer of three different ILSG field trip guidebooks (1973, 1986, and 2001) and all of us have seen him on many other ILSG field trips. As many of you know, Gordon is a superb field and laboratory petrologist and mineralogist. Like Sam Goldich, he is gifted with the vision to spot a significant problem, to work out a research strategy, and to pursue it by whatever techniques are needed to answer critical questions. Gordon likes collaborative research, so does not hesitate to recruit colleagues from any specialty to work with him. All of us who have had the privilege to work with Gordon appreciate his vision and encouragement in these joint efforts. He never tries to dominate and is quick to give encouragement and credit, all with a wonderful quiet dignity. I know that I speak for many other co-workers in thanking Gordon for sharing the pleasure of his collaborations.

For his many, varied and fundamental contributions to our knowledge of Lake Superior Geology and for his stimulation of the efforts of others, Randy Van Schmus, Daniel Holm, and Brad Singer join me in presenting L. Gordon Medaris, Jr. as the 2009 recipient of the Goldich Medal.

R. H. Dott, Jr.
April, 2009

ILSG STUDENT RESEARCH FUND

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

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

In 2008 the ILSG Board of Governors awarded four \$500 awards from the Student Research Fund.

Dan Costello (University of Minnesota - Duluth) - *Geology of the Tuscarora Intrusion, northeastern Minnesota, and its relationship to the Anorthositic Series of the Duluth Complex*

James Hiller (California State University Chico) - *Detailed petrographic analysis of anthraxolite morphology in the Biwabik Iron-Formation, northern Minnesota*

Angela Hull (Kent State University) – *Preliminary results of $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology from the Central Yavapai Province, U. S. Midcontinent*

Andrew Jansen (University of Wisconsin Oshkosh) - *Lithogeochemical evaluation of Neoproterozoic mafic volcanic rocks comprising the footwall of the Soudan Member of the Ely Greenstone Formation, northeastern Minnesota*

STUDENT PAPER AWARDS

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

- The contribution must be demonstrably the work of the student.
- The student must present the contribution in-person.
- The Student Paper and Poster Committee shall decide how many awards to grant, and whether or not to give separate awards for poster vs. oral presentations.
- 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.
- The total amount of the awards is left to the discretion of the meeting Chair in conjunction with the Secretary, but typically is in the amount of about \$500 US (increase approved by Board, 10/01).
- The Secretary maintains, and will supply to the Committee, a form for the numerical ranking of presentations. This form was created and modified by Student Paper and Poster Committees over several years in an effort to reduce the difficulties that may arise from selection by raters of diverse background. The use of the form is not required, but is left to the discretion of the Committee.
- 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 are noted on the Program.

In 2008 the ILSG Student Paper Committee presented three awards from the ILSG Student Paper Fund. Each of the following recipients received a \$200 award:

Elizabeth Drommerhausen (Minnesota State University) for her poster titled: *Properties of fluid involved in formation of natural ores in the Mesabi Iron Range, Minnesota*

Carissa Isaac (Lakehead University) for her talk titled: *Stable isotope geochemistry of the Musselwhite Au Mine, north Ontario: Implications for mineralization*

Natalie King (Colorado State University) for her talk titled: *Using mineralization to evaluate small-scale controls on shale permeability in the Nonesuch Formation*

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 annual Chair in consultation with the Secretary-Treasurer determines the number of awards and value. Recipients will be announced at the annual banquet. The student travel award application is available on the ILSG website.

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

- 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.
- Students who are the senior author on either an oral or poster paper will be given favored consideration.
- It is desirable for two or more students to jointly request travel assistance.
- In general, priority will be given to those in the Institute region who are farthest away from the meeting location.
- 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.
- Successful applicants will receive their awards during the meeting.

In 2008 the ILSG awarded 11 travel awards from the ILSG Eisenbrey Student Travel Fund. The awards were made to:

Terra Anderson – University of Wisconsin Milwaukee

Ding Xin – Indiana University

Elizabeth Drommerhausen – Minnesota State University

Emerald Erickson – University of Minnesota - Duluth

Elizabeth Fein – Kent State University

Shelby Frost – Winona State University

Lynn Galston – University of Wisconsin – Eau Claire

Sally Goodman – University of Minnesota - Duluth

Susan Karberg – University of Minnesota - Duluth

Natalie King – Colorado State University

Curtis Williams – Indiana University

**REPORT OF THE CHAIRS OF THE 54TH ANNUAL MEETING
INSTITUTE ON LAKE SUPERIOR GEOLOGY
MARQUETTE, MICHIGAN**

The A.E. Seaman Mineral Museum of Michigan Technological University hosted the 54th Annual Institute on Lake Superior Geology on May 6 – 10, 2008 at the Ramada Inn in Marquette, Michigan. The Marquette/Ishpeming area has been the site of the ILSG annual meeting a total of 5 times out of 54. There were a total of 230 registrants for the meeting. Of these 37 were students and 215 pre-registered. The number of registrants for the meeting exceeded expectations.

The Proceedings Volume 54 was published in two parts. Part 1 – Program and Abstracts, edited by Theodore J. Bornhorst and George W. Robinson. Part 1 contains 45 published abstracts for 29 oral and 16 poster presentations. The cover of Part 1 was highlighted by photos of Lake Superior minerals in the collection of the A.E. Seaman Mineral Museum and was designed by George Robinson. Part 2 – Field Trip Guidebook was edited by Theodore J. Bornhorst and John S. Klasner. Part 2 contains guides of seven field trips. The cover of Part 2 was highlighted by a photo of brecciated banded iron formation from Ishpeming, MI similar to one in Van Hise, Bayley and Smyth, 1897 and was provided by Tom Waggoner.

Field trips were a dominant part of the 54th ILSG, consistent with ILSG tradition. There were four pre-meeting, one “syn-meeting” and three post-meeting trips. Participation in the field trips was excellent. Most were full to capacity and one even had names on a waiting list. This first of the pre-meeting trips, was a two day trip on Tuesday and Wednesday, May 6 and 7. Tom Waggoner led this trip of 27 participants to examine banded iron formation of the Marquette District. In addition to the printed field trip guide in the Proceedings Volume, all registrants received supplemental material related to this field trip on a CD and a colored map of the Marquette District. Cliffs Mining Services Company is thanked for providing financial support to distribute colored maps to all registrants and for access to the operating iron mines. On Wednesday, May 7, there were three concurrent one day field trips. Bill Cannon and Klaus Schulz lead a trip to inspect the Archean-Paleoproterozoic unconformity at Silver Lake and possible seismites from the Sudbury Impact. This was a once in a lifetime opportunity since beginning in 1910 these outcrops have been under the waters of Silver Lake, a natural body of water enhanced for hydroelectric generation. In May 2003 an earthen dam failed and exposed the outcrops making the trip possible for the 25 participants. The reconstruction of the dam will likely be completed in a few years, so once again the outcrops will be underwater. Tom Quigley and Bob Mahin of Aquila Resources Inc. led a field trip focused on the geology of the Back Forty project south of Marquette in Menominee County for 43 participants. Aquila Resources Inc. is thanked for providing this field trip for ILSG and for financial support for color printing of the Field Trip Guidebook. Andrew Ware, Jon Cherry, and Xin Ding led a field trip that concentrated on the geology of the Eagle Project. Kennecott Minerals Company is thanked for generously providing this field trip not just once before the technical sessions, but twice, before and after the technical sessions for a total of 87 participants. Kennecott also provided financial support for color printing of the Field Trip Guidebook. The Sudbury impact layer is a topic of high interest. Since a single locality with outcrops of this layer was available near Marquette, the

organizers sought to have an abbreviated “syn-meeting” field trip. Bill Cannon, graciously agree to lead yet another field trip for the 54th ILSG. Thus, immediately following the technical sessions on Friday May 9 there was a 3 hour field trip to the McClure locality to examine the Sudbury impact layer. This trip was so popular with registrants, that in addition to the 52 participants, there was a waiting list and multiple people were not able to participate. There were three post-meeting field trips on Saturday May 10. One was a repeat of the pre-meeting Eagle trip. Glenn Scott, Helen Lukey, Al Strandlie and CCI/CCMO staff led a trip focused on sustainable recovery of iron from the Marquette District. This environmentally oriented trip had 13 participants. A color version of the printed field trip guide was provided to all participants on CD. Cliffs Mining Services Company is thanked for providing this field trip for the 54th ILSG. Dean Rossell led a trip to study the geology of the Keweenaw BIC intrusion. This trip, like the other trips, was well attended with 38 participants. Kennecott Minerals Company is thanked for making this trip possible for the 54th ILSG participants.

The two days of technical sessions were held at the Ramada Inn of Marquette. The eight session chairs helped keep the presentations on track. There were the normal technical glitches. The student paper committee once again had a difficult job of selecting among 18 student oral and poster presentations. The committee awarded three Best Student Paper awards with a cash prize of \$200 each: Elizabeth Drommerhausen (Minnesota State University) for her poster presentation titled: *Properties of fluid involved in formation of natural ore in the Mesabi Iron Range, Minnesota*, Carissa Isaac (Lakehead University) for her oral presentation titled: *Stable isotope geochemistry of the Musselwhite Au Mine, north Ontario: Implications for mineralization*, and Natalie King (Colorado State University) for her oral presentation titled: *Using mineralization to evaluate small-scale controls on shale permeability in the Nonesuch Formation*.

One hundred and sixty-three participants attended the banquet on Thursday night. The 2008 banquet speaker was Jon Cherry, General Manager of Kennecott Minerals – Eagle Project. Jon brought participants up-to-date on the Kennecott Eagle Project with a well received Powerpoint presentation. A highlight of the banquet for me (Ted Bornhorst, CO-chair) was the presentation of the 2008 Goldich medal. Ted Bornhorst, Michigan Technological University was presented the medal by Jim Miller. Jim cited Ted for his contributions to Lake Superior geology and his service to ILSG.

The Institute’s Board of Directors met on May 8, 2008. A brief overview of the meeting is provided below:

1. Accepted the Report of the Chair for the 53th ILSG from Laurel Woodruff and Jim Miller.
2. Accepted the minutes of last Board meeting from ILSG secretary Pete Hollings.
3. Accepted the 2007-2008 ILSG Financial Summary from ILSG treasurer, Mark Jirsa
4. Accepted the motion to reappoint Pete Hollings as Secretary of the ILSG, and Mark Jirsa as the Treasurer of the ILSG. In keeping the ILSG constitution, the motion by the board to reappoint Hollings and Jirsa was brought forward to the membership of ILSG at the annual banquet. The membership passed the motion unanimously.
5. Ted Bornhorst, agreed to serve as on-going ILSG Board Member.

6. Nominated Al MacTavish of Magma Metals (Canada) Ltd. to replace Doug Duskin as the “industry member” on the Goldich Committee. The Board approved MacTavish as the new Goldich Committee member with a term of 3 years.
7. Received from Mike Mudrey a progress report on scanning initiative.
8. Discussed changes as proposed by Chair Bornhorst to the membership criteria as posted on the web site. A previous Board made email as the only contact to determine membership in ILSG. The proposed revisions returned the criteria to postal address and made “Member for Life” status truly member for life. Motion to accept the changes proposed by Bornhorst by Jim Miller, second by Mark Smyk, passed unanimously.
9. Approved Ely, Minnesota at the site for the 55th annual ILSG meeting with co-chairs Jim Miller, George Hudak, and Dean Peterson of the Precambrian Research Center.
10. The Board once again discussed special awards for contributions to ILSG. The Board agreed that the only award from ILSG will be the Goldich Award. Chairs of individual meetings can consider special awards or recognition of individuals, but only with prior consent of the Board.

The Co-chairs, Ted and John, thank the participants, field trip leaders, and presenters for without you there would be no ILSG. And we also thank others, not already cited above, who played a role in this years meeting: Gretchen Klasner was invaluable to the success of the meeting as she did all of the on-site registration. The staff of Ramada Inn was professional and did an excellent job of responding to last minute requests. Undergraduate geo majors from Michigan Tech were drivers of vans for the field trips: Carla Alonso, Austin Andres, James Julip, Matt Laird, Eric Murray. Darlene Comfort, A.E. Seaman Mineral Museum, did a great job of keeping track of all of the registration details. This was a major effort for her!

John and I hope that you agree that the 54th ILSG was a real success. Attendance in general and for the field trips was above our initial expectations. We are gratified that for all of the positive comments provided by many of you, thanks as it does make a difference. We are both happy to have the 54th annual ILSG in our past. Yes, being Chair of the annual meeting is a lot of work and added stress. But, it is worth it and we encourage others to try it out!! ILSG is a great professional organization with a long and rich history. We look forward to seeing you at the 55th ILSG and many more.

Ted Bornhorst and John Klasner

Co-Chairs, 54th Institute on Lake Superior Geology

2009 BOARD OF DIRECTORS

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

Jim Miller, Co-Chair, 55th Meeting (2010; joined board after 2007 meeting)

University of Minnesota Duluth, MN / PRC, University of Minnesota Duluth, Duluth MN

George J. Hudak, Co-Chair 55th Meeting (will continue on board until 2012)

Univ. of Wisconsin Oshkosh / PRC, University of Minnesota Duluth, MN

Dean M. Peterson, Co-Chair, 55th Meeting

Duluth Metals Limited/ PRC, University of Minnesota Duluth, MN

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2009 ILSG/EISENBRAY FUNDS

Part of the registration costs for the 2009 meeting went toward establishing a fund to provide travel support for students. Eisenbray funds, totalling \$1000, will be specifically distributed to the four recipients of 2009 ILSG Research Grants (* below). Another \$1900 will be distributed to the other students listed below.

Dan Costello*	University of Minnesota Duluth
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Cara Leitheiser	University of Minnesota Duluth
Natalie Pietrzak	University of Western Ontario
Victoria Stinson	Lakehead University

2009 BANQUET SPEAKER

The Deep Underground Sky

Dr. Marvin Marshak

Professor of Physics/Director of Undergraduate
Research at the University of Minnesota

*Founder of the University of Minnesota Underground
Research Laboratory at the Soudan Mine*



PROGRAM

TUESDAY MAY 5, 2009

8:00 a.m. **FIELD TRIP 1: CU-NI DEPOSITS OF THE DULUTH COMPLEX**

Rich Patelke – *Polymet Mining*

Mark Severson – *Natural Resources Research Institute, Univ. of Minnesota Duluth*

Dean Peterson – *Duluth Metals Ltd.*

Tim Jefferson – *Teck American*

Ernie Lehmann – *Franconia Minerals*

6:00 p.m. **RETURN OF FIELD TRIP 1 TO GRAND ELY LODGE**

WEDNESDAY MAY 6, 2009

8:00 a.m. **FIELD TRIP 1 (CONTINUED): CU-NI DEPOSITS OF THE DULUTH COMPLEX**

8:00 a.m. **FIELD TRIP 2: GLACIAL GEOLOGY OF THE VERMILION MORaine**

Phil Larson – *Cliffs Natural Resources*

Howard Mooers – *Department of Geological Sciences, University of Minnesota
Duluth*

6:00 p.m. **RETURN OF FIELD TRIPS 1 AND 2 TO GRAND ELY LODGE**

4:00 p.m. - 10:00 p.m. **REGISTRATION AT GRAND ELY LODGE**

7:00 p.m. - 10:00 p.m. **ICE BREAKER AND POSTER SESSION**

THURSDAY MAY 7, 2009

8:00 a.m. - 12:00 noon **REGISTRATION**

8:45 a.m. **INTRODUCTORY REMARKS**

Jim Miller, George Hudak, and Dean Peterson, 2009 ILSG Co-Chairs

8:55 a.m. **REMEMBRANCE OF JOE MANCUSO (1934-2009)**

TECHNICAL SESSION I

Session Chairs:

Mary Louise Hill, *Lakehead University*
Phillip Larson, *Cliffs Natural Resources*

- 9:00 a.m. **Medaris, L. G., Jr., Jicha, B. S., Dott, R. H. Jr., and Singer, B. S.**
A 1465 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ age for the Seeley Slate: implications for metamorphism and deformation in the Baraboo Range, WI
- 9:20 a.m. **Addison, W. D., Brumpton, G. R., Fralick, P. W., and Kissin, S. A.**
The complex Gunflint-Rove Formations boundary at Thunder Bay, Ontario: Two disconformities and a base surge debrisite
- 9:40 a.m. **Cannon, W. F., and Schulz, K. J.**
Reconstructing the Penokean Foreland Basin using the Timeline of the 1850 Ma Sudbury Impact Layer
- 10:00 a.m. **COFFEE BREAK AND POSTER SESSION**
- 10:40 a.m. **Peitrzak, N. J.*, Duke, N., Scott, G., and Lukey, H.**
Ore Textures and Mineral Chemistry within the Oxide-Carbonate-Silicate Flotation Ores at the Cliffs Natural Resources' Tilden Mine, Michigan
- 11:00 a.m. **Walsh, James F.**
Hydrostratigraphy of the Biwabik Iron Formation – Implications for Current Groundwater Flow Patterns and Past Genesis of Natural Ore Bodies
- 11:20 a.m. **Lunch Break (2009 ILSG Board Meeting - by invitation)**

TECHNICAL SESSION II

Session Chairs:

Dyanna Czeck, *University of Wisconsin Milwaukee*
Greg Stott, *Ontario Geological Survey*

- 1:00 p.m. **Gilbert, H. P.**
Bird River Belt in Southeastern Manitoba – A Nearcean Volcanic Arc in the Western Superior Province
- 1:20 p.m. **Forslund, N. R.*, Hill, M. L., and Middleton, R. S.**
Alteration in the Southern Felsic Volcanics at Marshall Lake, Northwestern Ontario

- 1:40 p.m. **Jirsa, M. A., and Driese, S. G.**
Neoproterozoic Weathering and Atmospheric pO₂ Inferred from Paleosaprolite between Granite-Greenstone and Superjacent Conglomerate in the Boundary Waters Canoe Area, NE Minnesota
- 2:00 p.m. **COFFEE BREAK AND POSTER SESSION**
- 2:40 p.m. **Stinson, V. R.*, Kolb, M. J.*, and Hill, M. L.**
Metamorphism and Deformation at Musselwhite Mine
- 3:00 p.m. **Wendland, C., Fralick, P., and Hollings, P.**
Diamondiferous Mass-Flow and Placer Deposits Forming a Neoproterozoic Fan Delta, Wawa Area, Superior Province
- 3:20 p.m. **Mudrey, M. G.**
Goldich Award Winners Who Have Passed On
-
- 6:00 p.m. **ICE BREAKER – MIXER – CASH BAR**
- 7:00 p.m. **ANNUAL BANQUET AND AWARD PRESENTATION**
- **Announcement of 56th Annual Meeting Location**
 - **2009 Goldich Award Presentation to L. Gordon Medaris, Jr.**
 - **2009 Banquet Address by Dr. Marvin Marshak, University of Minnesota**
All registered participants are welcome to the banquet address
-
-

FRIDAY MAY 8, 2009

- 8:30 a.m. **INTRODUCTORY REMARKS**
Jim Miller, George Hudak, and Dean Peterson, Co-Chairs, 2008 ILSG

TECHNICAL SESSION III

Session Chairs:

Allan MacTavish, Magma Metals (Canada) Limited
Dave Dahl, Minnesota Department of Natural Resources

- 8:40 a.m. **Hansen, E., Reimink, J., and Harlov, D.**
Titanite, Pseudorutile, and REE-Minerals in the Allouez Conglomerate, Keweenaw Peninsula, Michigan
- 9:00 a.m. **Hollings, P., Smyk, M. C., Halls, H., and Heaman, L.**
Mesoproterozoic Midcontinent Rift-Related mafic intrusions in Northwestern Ontario: continuing geochemical, paleomagnetic, petrographic, and geochronological studies

- 9:20 a.m. **Chandler, V. W.**
Magnetic Anomalies from Pleistocene Sources in the Western Lake Superior Region: The Edge of Insanity or a Promising Threshold?
- 9:40 a.m. **Verburg, R., and Dunlavy, P.**
Mine Water Quality Prediction and Environmentally-Responsible Mining -Yes We Can!
- 10:00 a.m. **COFFEE BREAK AND LAST POSTER SESSION**
- 10:40 a.m. **Schulz, K. J., and Nicholson, S. W.**
Geochemistry of Midcontinent Rift-related Dikes and Mafic-Ultramafic Intrusions in the Baraga Basin, northern Michigan: Implications for the Nature of Rift Magmatism and Ni-Cu-PGE Mineralization
- 11:00 a.m. **Watkins, K. P.**
Magma Conduit Hosted Platinum-Palladium-Copper-Nickel Mineralization at the Thunder Bay North Project, Northwest Ontario: Discovery, Exploration, Geology, and Resource Potential
- 11:20 a.m. **Gál, B.*, Peterson, D. M., and Molnár, F.**
Magmatic vs. Hydrothermal Processes in the South Filson Creek Mineralization, South Kawishiwi Intrusion, Duluth Complex
- 11:40 a.m. **Peterson, D. M.**
The Nokomis Cu-Ni-PGE Deposit, Duluth Complex, Minnesota
- 12:00 p.m. **LUNCH BREAK AND MEETING OF THE STUDENT PAPER COMMITTEE**

TECHNICAL SESSION IV

Session Chairs:

**Mehgan Blair, Barr Engineering Co.
 Dan England, Eveleth Fee Office, Inc.**

- 1:00 p.m. **PRESENTATION OF THE STUDENT TRAVEL AND BEST PAPER AWARDS**
- 1:20 p.m. **Thorleifson, H.**
Options for Geologic Sequestration of Carbon in the Upper Midwest: Mineral Carbonation and Deep Injection
- 1:40 p.m. **Arends, H., Johnson, R., Hanson, K., Friedrich, H., and Kostka, S.**
Structuring, Gathering, and Distributing Geological Data for Public Use
- 2:00 p.m. **Miller, J. D., Carranza-Torres, C., Davis, R., and Hendrickson, D.**
New Educational Initiatives at the University of Minnesota Duluth: Preparing Students for Future Jobs in the Mining and Minerals Exploration Industries

2:20 p.m. **COMPLETION OF 2009 ILSG TECHNICAL SESSIONS AND FINAL STATEMENTS BY THE 2009 ILSG CO-CHAIRS**

3:00 p.m. **FIELD TRIP 3: TOUR OF THE SOUDAN IRON MINE AND PHYSICS LAB**

Dean Peterson – *Duluth Metals Ltd.*

James Pointer – *Minnesota Department of Natural Resources, Parks and Recreation*

Marvin Marshak – *Department of Physics, University of Minnesota*

3:00 p.m. **FIELD TRIP 4: PIONEER MINE CANOE EXCURSION**

Mark Jirsa – *Minnesota Geological Survey*

6:30 p.m. **RETURN OF FIELD TRIPS 3 AND 4 TO GRAND ELY LODGE**

SATURDAY MAY 9, 2009

8:00 a.m. **FIELD TRIP 5: GEOLOGY AND METAMORPHISM OF THE EASTERN MESABI RANGE**

Dick Ojakangas – *Department of Geological Sciences, Univ. of Minnesota Duluth*

Mark Severson – *Natural Resources Research Institute, Univ. of Minnesota Duluth*

Doug Halverson, Jeff Bird, Tom Campbell, Jarred Lubben, and Peter Jongewaard
– *Cliffs Natural Resources*

William Everett – *Mesabi Nugget*

8:00 a.m. **FIELD TRIP 6: GEOLOGY OF THE LAKE ONE TROCTOLITE BY CANOE**

Jim Miller – *Department of Geological Sciences, University of Minnesota Duluth*

8:00 a.m. **FIELD TRIP 7: ARCHITECTURE OF AN ARCHEAN GREENSTONE BELT**

Dean Peterson – *Duluth Metals Ltd.*

Mark Jirsa – *Minnesota Geological Survey*

George Hudak – *Department of Geology, University of Wisconsin Oshkosh*

6:00 p.m. **RETURN OF TRIPS 5 AND 7 TO GRAND ELY LODGE**

SUNDAY, MAY 10, 2009

8:00 a.m. **FIELD TRIP 6: GEOLOGY OF THE LAKE ONE TROCTOLITE BY CANOE (CONTINUED)**

8:00 a.m. **FIELD TRIP 7: ARCHITECTURE OF AN ARCHEAN GREENSTONE BELT (CONTINUED)**

4:00 p.m. **RETURN OF TRIPS 6 AND 7 TO GRAND ELY LODGE**

55TH ANNUAL INSTITUTE ON LAKE SUPERIOR GEOLOGY ENDS

POSTER PRESENTATIONS

Boerboom, T. J. and Green, J. C.

Bedrock Geologic Map of the Deer Yard Lake and Good Harbor Bay Quadrangles, North Shore of Lake Superior, Minnesota

Bruesewitz, J.* and Cameron, B.

Geochemical and New SHRIMP-RG Zircon Age Constraints of the Cary Mound Granite, Wood County, Wisconsin

Coleman, J., and Chiriboga, E.

Methods for Estimation of Indirect Hydrologic Impacts on Wetland Plant Communities at Potential Hard Rock Mine Sites

Costello, D. E.*, Miller, J. D. Jr., and Jirsa, M.A.

Geology of the Tuscarora Intrusion, Northeastern Minnesota and its Relationship to the Anorthositic Series of the Duluth Complex

Dayton, R. N.*, Miller, J. D. Jr., and Vervoort, J. D.

Quantifying Assimilation vs. Fractional Crystallization using Sm-Nd, Lu-Hf and Pb Isotope Systems: The Geochemical Evolution of the Sonju Lake Intrusion, Finland, MN

Diedrich, T., Brecke, D., Schreiber, M., and Zanko, L.

Taconite-Derived Mineral Dust in Population Centers on the Mesabi Iron Range: Tracking Mineral Fibers from Ore to Air

Fage, A.* and Hollings, P.

Geology and Geochemistry of the Fearless-Python Property, Schreiber-Hemlo Greenstone Belt, Ontario

Frey, B. A.

Vermilion Greenstone Gold – New Data, Northeastern Minnesota

Gary, J. L.*, Wattrus, N. J., Colman, S. M., and Voytek, E. B.

Characterizing the Discharge Features of Glacial Lake Agassiz During the Post-Marquette Period Using Marine Seismic-Reflection Methods

Gere, M. A., and Hoane, T. B.

2009 Update: Leasing State of Michigan Lands for Metallic and Nonmetallic Minerals

Hage, M. M.*, and Fedo, C. M.

Geochemistry and Petrology of Gunflint Iron Formation, Gunflint Trail, Minnesota

Hauck, S. A., Heine, J. J., and Thorleifson, L. H.

A Follow-up Glacial Till Indicator Mineral Survey in Minnesota: What Does It Indicate About Exploration for Diamonds And Other Mineral Deposits

Hefferan, K. P., and Heywood, N. C.

Developing a 21st Century Geoscience Major: Melding the Old with the New

Hiller, J. A.* and Shapiro, R. S.

Detailed Petrographic Analysis of Anthraxolite Morphology in the Biwabik Iron-Formation, Northern Minnesota

Hull, A.*, Holm, D., and Schneider, D.

Preliminary Results of ⁴⁰Ar/³⁹Ar Thermochronology from the Central Yavapai Province, U. S. Midcontinent

Jansen, A.C.*, Hudak, G. J., Heine, J. J., and Peterson, D. M.

Lithogeochemical Evaluation of Neoproterozoic Mafic Volcanic Rocks Comprising the Footwall of the Soudan Member of the Ely Greenstone Formation, Northeastern Minnesota

Jirsa, M., Cowan, H.*, Kowalik, J.*, and Niedermiller, J.*

Geologic Mapping of Neoproterozoic Rocks Near Paulsen Lake, Boundary Waters Canoe Area Wilderness, by Students of the Precambrian Research Center's 2008 Field Camp

Johnson, T. K.*, Hansen, V. L., Hudak, G. J., and Peterson, D. M.

Structural, Kinematic, and Lithogeochemical Investigation of the Murray Shear Zone, Northeast Minnesota

Makovsky, K.*, and Losh, S.

Fluid Movement through the Mesabi Iron Range, Minnesota

Markwood, L. W.*, and Zieg, M. J.

Interpretations of the Emplacement and Cooling History of a Thin Diabase Sill, Nipigon, Ontario

Medaris, L. G. Jr., and Fournelle, J. H.

Metamorphic Pseudomorphs in the Seeley Slate, Baraboo Range, Wisconsin

Meineke, D. G., and Djerlev, H.

Geology and Magnetic Taconite Resources of Western Gogebic Iron Range, Wisconsin

Shapiro, R.S.

Alteration of Stromatolite Biosignatures in the Biwabik Iron-formation: Relevance to Astrobiology

Stifter, E.*, Wartman, J.*, Gibbons, J.*, Kane, K.*, Murphy, L.*, Carlson, A.*, Mason, T.*, Hudak, G. and Peterson, D.

Bedrock Geologic Map of the Disappointment and Ima Lakes Area, Lake County, Northeastern Minnesota



ABSTRACTS

THE COMPLEX GUNFLINT-ROVE FORMATIONS BOUNDARY AT THUNDER BAY, ONTARIO: TWO DISCONFORMITIES AND A BASE SURGE DEBRISITE

William D. Addison, Gregory R. Brumpton,² Philip W. Fralick,³ Stephen A. Kissin³

1 R.R. 2, Kakabeka Falls, P0T 1W0, Canada (baddison@tbaytel.net). 2 211 Henry St., Thunder Bay, P7E 4Y7, Canada. 3 Department of Geology, Lakehead University, Thunder Bay, P7B 5E1, Canada.

Eight subaerially exposed chaotic debrisites containing ejecta from the 1850 Ma (Krogh et al., 1984) Sudbury impact event have been discovered in and near the City of Thunder Bay, Ontario. Ejecta features include planar deformation features (PDF) in quartz grains, vesicular devitrified glass clasts (DVG) and accretionary lapilli (Addison et al., 2005). Megascopic to microscopic Gunflint breccia clasts and ejecta are minor components embedded in an often recrystallized dominantly carbonate matrix. Seven sites are erosionally truncated. Only the Terry Fox site shows a complete profile extending from the Gunflint Formation up through the debrisite and into the overlying Rove Formation.

The study area has had a complex history, summarized as follows.

The Upper Gunflint Formation exhibits an ocean regression assemblage, terminating in stromatolites at most study localities, disconformably overlain by the debrisites. We postulate that the regression was completed at some unknown time before the 1850 Ma Sudbury impact event, leaving a subaerially exposed carbonate landscape.

A sporadic, 0.3-1.2 m thick, iron-rich alteration profile found 0-1 m below the debrisite base at most sites may be evidence of a paleosol. If further work supports this hypothesis, it would confirm that the study area was subaerial prior to impact.

Approximately two minutes after the Sudbury impact began, violent earthquakes fractured and delaminated lithified portions of the Upper Gunflint Formation, as evidenced by still in situ fractured rock at the Hwy 588 and GTP sites and by numerous mostly sharply angular sub-millimeter to meter size Gunflint clasts within the debrisite.

The earthquakes were followed by massive base surges which stripped all unlithified material down to bedrock and ripped up and entrained most of the earthquake fractured Upper Gunflint Formation rock. The base surges then contained the following mixture of features in order of volume percent: 1) clasts of fractured carbonate in the silt to coarse sand size range; 2) ripped up clasts of Gunflint fractured chert, chert-carbonate and stromatolites; 3) ejecta consisting primarily of DVG, and much lesser volumes of accretionary lapilli, tektites and microtektites, quartz and feldspar grains, some of which show planar features and PDFs; and 4) small clasts of uncertain origin.

The travel distance for most Gunflint chert and chert-carbonate clasts was relatively short as most are very angular. Slightly rounded chert-carbonate clasts are less common and probably travelled only slightly further from their source than the angular ones. No clasts show weathering rinds.

The base surges contained sufficient water vapor that accretionary lapilli were able to form. Some accretionary lapilli passed through zones with varying water vapor concentrations allowing them to accumulate alternating coarser-grained layers and finer-grained layers.

The debrisites deposited by these base surges are chaotic and show significant changes in clast sizes and composition over meter scale and even centimeter scale distance within the deposits. The one exception to this chaos is a clear upward fining of Gunflint clasts within the debrisite, which can probably be attributed to the limited lifting and transporting power of a gas-supported fluidized flow like a base surge. These observations are consistent with base surge deposits described from the Chicxulub, Houghton and Ries impact events.

The DVG shows varying degree of vesicle collapse ranging from none (round vesicles) to partial collapse (ovoid vesicles) to totally flattened vesicles. This suggests that DVG clasts arrived at varying temperatures and plasticities and had time to deform before cooling was complete. Had DVG landed in water, quenching would have been nearly instantaneous and all vesicles would have been round.

We initially interpreted these debrisites as tsunami deposits. If tsunamis were ever involved, we would expect some sorting of DVG, with more of the least dense clasts (most vesicles) being deposited towards the top of the debrisites and with denser DVG clasts (few or no vesicles) being more common towards the base of the debrisite. That is not the case.

The debrisites were then subaerially exposed for 15-18 Ma (Addison et al, 2005). It is improbable that an unlithified deposit could survive exposed for this long. The underlying Upper Gunflint Formation and overlying Rove Formation hint at a possible preservation mechanism. Volcanic tuffs are common in both the Upper Gunflint Formation and especially in the lower Rove Formation where there are seven tuff layers per meter on top of the debrisite. If similar tuffs were deposited on top of the debrisite during the period of subaerial exposure they may have provided sufficient protection to allow survival of some of the debrisite. Anastomosing chert and agate within the debrisite and centimeter-scale agate stalactites in debrisite vugs suggest that silica was leached from such tuffs and was redeposited within the debrisite until ocean transgression and deposition of the Rove Formation protected it until today.

Subsequently ocean transgression deposited about one meter of carbonate before deposition of the lower Rove Formation organic-rich muds and interlayered volcanic ash. This abrupt transgression marks a disconformity at the debrisite-Rove Formation boundary.

Large scale carbonate replacement and recrystallization during diagenesis destroyed or partially obscured many ejecta and non-ejecta features in the debrisite. Silica replacement did the same to a lesser extent.

These observations and interpretations add heretofore unknown detail to what happened at the Gunflint-Rove boundary. Will similar sequences be discovered elsewhere in the Lake Superior region?

References

Addison, W.D., Brumpton, G.R., Vallini, D.A., McNaughton, N.J., Davis, D.W., Kissin, S.A., Fralick, P.W., and Hammond, A.L., 2005, Discovery of distal ejecta from the 1850 Ma Sudbury impact event: *Geology*, v. 33, p. 193-196.

Krogh, T. E., Davis, D. W., and Corfu, F., 1984, Precise U-Pb zircon and baddeleyite ages for the Sudbury area in Pye et al., eds., *The Geology and Ore Deposits of the Sudbury Structure: Ontario Geological Survey Special Volume 1*, p. 431-446.

STRUCTURING, GATHERING AND DISTRIBUTING GEOLOGIC DATA FOR PUBLIC USE

Heather Arends, *Minnesota Department of Natural Resources, Aggregate Resource Mapping Program, St. Paul MN, USA. E-mail: Heather.Arends@dnr.state.mn.us, Tel: 1 651 259-5376; Fax: 1 651 259-5939*

Renee Johnson, Kevin Hanson, Hannah Friedrich, and Steven Kostka, *Minnesota Department of Natural Resources, Aggregate Resource Mapping Program, St. Paul MN, USA*

The primary audience using aggregate resource maps and data are non-geologists, local units of government, and the general public. With increasing use of geospatial information and web-based mapping software, like Google Earth®, users expect information that is Internet accessible, interactive, easily compiled, and well documented. In addition, toolsets available for geologic mapping are evolving with the advancement of GIS (Geographic Information Systems) and GPS (Global Positioning Systems). With this evolution, governments and publicly financed institutions have a new responsibility to produce geospatial information. Over the past two years, the Aggregate Mapping Resource Program modified aspects of their data management, mapping methodology, and distribution of data to meet the growing demand of digital data. Internally, benefits of these changes include eliminating data entry redundancies, streamlining documentation, and an overall accelerated rate of mapping.

Currently three geologists in our DNR program gather, enter, and produce geologic data. Databases are needed to ensure standards between geologists while accommodating different mapping styles and geologic settings. Standardization includes determined attribute widths and names, field order, information stored as text or numbers, and how people look at data versus how data is queried. Considering the pros and cons of database software, we prefer Microsoft Access® to ESRI® geodatabases for several reasons: the ability to develop one to many relationships, create new attributes on the fly, and programming flexibility. Data standardization expedites writing metadata and allows for the compilation of different project data with no additional processing for the user.

Advancements in our methods of data collection include using a tablet computer with GIS software in conjunction with GPS in the field. Previous mapping methods consist of recording observations on a USGS (United States Geologic Survey) 24K quadrangle maps and/or within a fieldbook. Geologists then digitize location information and re-enter field descriptions into a database. Consequently, the same data is recorded twice and transcriptional error is potentially introduced into the dataset. Using a field computer and GPS provides better location accuracy, tracking capabilities, and eliminates redundant data entry processes. Furthermore, consulting data sets, such as aerial photography, parcel and ownership data, high-resolution elevation models, historical maps, and water well stratigraphy, in the field while simultaneously making observations provide additional benefits to the geologists. Various GIS software packages were tested. In our determination, the most stable configuration combines ArcGIS 9.3® with the GPS tacking toolbar for ArcGIS 9.2/9.3®.

To improve distributing data, a DNR developed, web-based map server geospatially displays information used to map aggregate resources, aggregate resource data, base maps, and links to data documentation. The map server allows users to interact with GIS data without the having to download, install, and learn a new software program. By interacting with the data, a greater level of transparency exists on how different geologic units are delineated and classified given the available information at a single time, which reinforces the relationship between geology and distribution of mineral resources.

BEDROCK GEOLOGIC MAP OF THE DEER YARD LAKE AND GOOD HARBOR BAY QUADRANGLES, NORTH SHORE OF LAKE SUPERIOR, MINNESOTA

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

GREEN, John C., University of Minnesota-Duluth, jgreen@d.umn.edu

The Minnesota Geological Survey is continuing to map the bedrock geology of 7.5' quadrangles near Lake Superior as part of the USGS STATEMAP program, resulting to date in thirteen published 1:24,000 scale maps from Duluth to Grand Marais, in addition to 10 quadrangles already published under the former USGS COGEOMAP program. The Deer Yard Lake and Good Harbor Bay quadrangles are the most recent of these geologic maps (Fig. 1A). All maps in this series are available as printed maps, or as PDF and Arcview export files at the MGS website (<http://www.geo.umn.edu/mgs/>).

Outcrop mapping was augmented by some 50 sets of water well cutting samples, collected at 10 foot intervals by McKeever Well Drilling of Little Marais, Minnesota. These provided a crucial glimpse of the volcanic stratigraphy in the third dimension as well as information where the bedrock is poorly exposed.

The area of this map lies near the top of the 7-10 km thick North Shore Volcanic Group (NSVG), and crosses the boundary between the upper portion of the Northeast sequence and the slightly discordant overlying Schroeder-Lutsen sequence (Fig. 1B). In addition there are several thick sandstone units, as well as components of the Beaver Bay Complex (Leveaux ferrodiorite, Murphy Mountain diabase, and Beaver River diabase) present in the map area.

In keeping with prior work, the NSVG is subdivided into informal lithostratigraphic packages separated by major compositional changes, by intrusions or faults across which correlation is tenuous, or where thick flows or flow sequences form mappable units. The informal lithostratigraphic packages shown on this map include the Lutsen basalts, the Good Harbor Bay lavas (which include the Good Harbor Bay andesites, the Cutface Creek sandstone, and the Terrace Point basalt flow of Green, 2002), the Breakwater basalt, the Grand Marais felsites (rhyolite and icelandite), the Cascade River basalt, and the Croftville lavas (which includes the Pincushion Mountain trachybasalt of Green, 2002). The volcanic units immediately overlying (southeast of) the Leveaux ferrodiorite are poorly exposed and not named.

The new mapping has refined the volcanic stratigraphy of the NSVG in this area and has continued previously mapped units, in particular thick interflow sandstone units, for several kilometers along strike from where mapped prior to the west (Boerboom and Green, 2007). Four thick sandstone units were identified, one within the Lutsen basalts (Indian Camp Sandstone), one below the Terrace Point flow (Cut Face Creek sandstone), and two other unnamed units identified mainly in water well samples. The Indian Camp and Cut Face Creek sandstones were already well known from exposures near the shore. Examinations of water well samples show that the Indian Camp sandstone is up to 170 feet thick and the Cut Face Creek sandstone more than 250 feet thick. The northern-most sandstone units were identified only in scattered water well cutting samples, but they correspond well with linear topographic depressions and coincident linear negative aeromagnetic anomalies, and can be confidently extended for some distance beyond the well intercepts (Boerboom, 2007).

The Terrace Point basalt is a thick ophitic flow with scattered tabular phenocrysts and rare large megacrysts of glassy plagioclase, and contains rare but locally abundant xenoliths of granite, anorthosite, porphyritic ferrodiorite, rhyolite, conglomerate, andesite, and basalt, most of which are only tens of centimeters in size. However, near the base of the flow in the Cascade River the basalt contains a 60 m-diameter xenolith of coarse-grained biotite granite which yields a U-Pb zircon age of 1096.7 ± 0.8 Ma (Green and others, 2001) as well as xenoliths of thermally metamorphosed sedimentary rocks, porphyritic ferrodiorite that matches the distinct texture of the Leveaux porphyry, and other volcanic rock types. The basalt here contains local hybrid pods contaminated by felsic material melted from the xenoliths, and exhibits a strong vertical to irregular flow banding. Overall, these features indicate this may be a feeder zone to the overlying Terrace Point basalt flow, a unique feature rarely found in the NSVG. The types of xenoliths and the plagioclase phenocrysts in the ophitic Terrace Point basalt are similar to those in the Beaver River diabase, leading to the speculation that it may be the extrusive equivalent to the diabase, which is also known from mapping to the southeast to intrude the Leveaux porphyry.

Intrusive rocks of the Beaver Bay Complex in this map area consist of the Beaver River and Murphy Mountain diabase, and the eastern-most occurrence of the porphyritic Leveaux ferrodiorite. The latter is

inferred from map distribution and measurements of aligned feldspar phenocrysts to form a southeast-dipping, funnel-shaped, subvolcanic sill-like intrusion.

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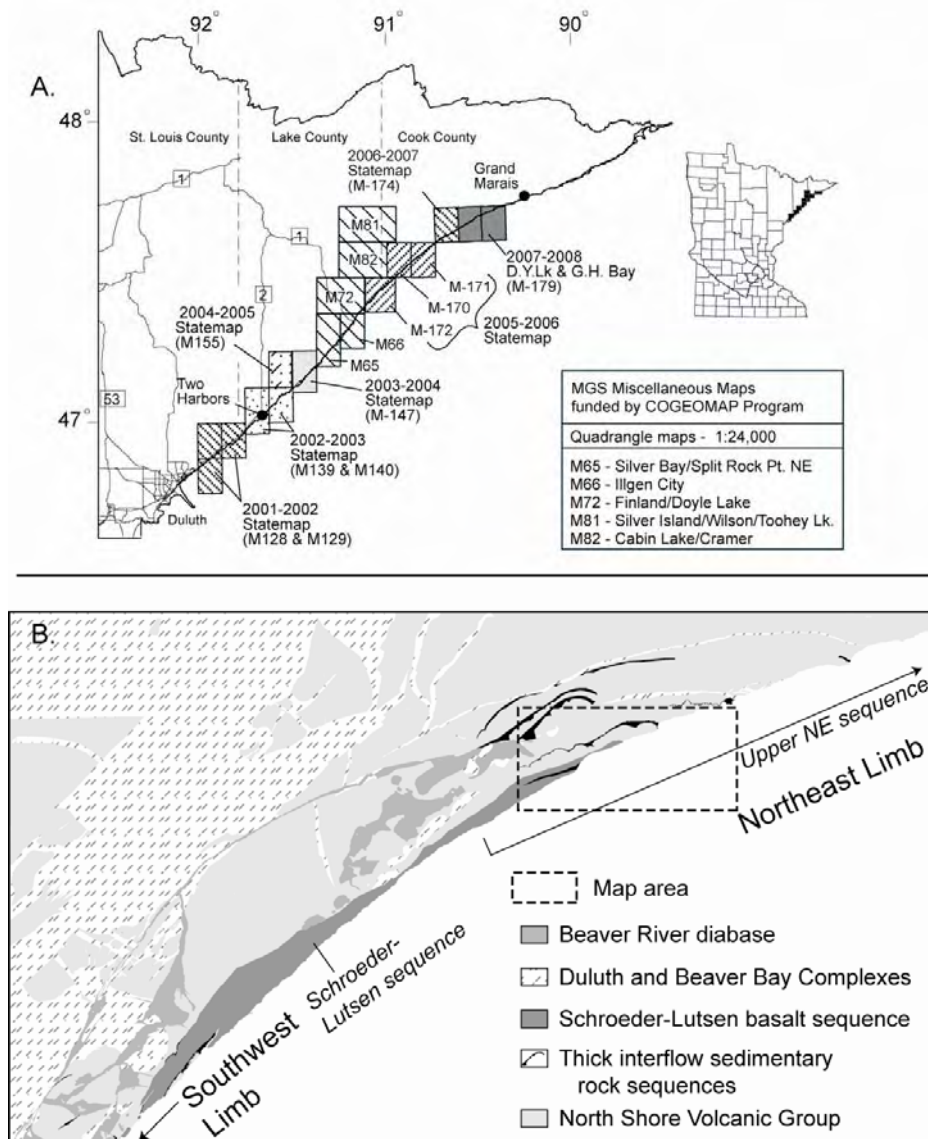


Figure 1. A. Index map showing the location of mapped 7.5' quadrangles along the North Shore of Lake Superior. M numbers refer to MGS Miscellaneous maps. B. Index map showing the locations of the major intrusions and volcanic sequences in part of northeastern Minnesota.

GEOCHEMICAL AND NEW SHRIMP-RG ZIRCON AGE CONSTRAINTS ON THE CARY MOUND GRANITE, WOOD COUNTY, WISCONSIN

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The Cary Mound granite is a late to post Penokean granite suite approximately 10 miles south of Marshfield, WI, and would be included with the 1835 Ma alkali-feldspar granite suite of Sims et al. (1989). Included within the suite are the alkali-feldspar granophyric granite, coeval rhyolite, diorite and mafic enclaves assumed coeval with the granite/rhyolite, and lamprophyre of uncertain younger age based on crosscutting relationships.

Updated SHRIMP-RG zircon dates from USGS-Menlo Park have been obtained. The Cary Mound samples are characterized by euhedral zircon with homogenous cores with textural evidence for minor recrystallization surrounded by oscillatory zoned rims (Fig. 1). There is no difference in ages obtained for core versus rim domains. Using ten analyses from sample CMG-04 (county highway department quarry) give a concordia age of 1826 ± 9 Ma. Twelve analyses from sample CMG-15 (Haske quarry) give a Concordia age of 1827 ± 5 Ma (Fig. 2). These ages are statistically the same as the 1833 ± 4 Ma date reported by Sims et al. (1989).

Previous interpretations of the 1835 Ma alkali feldspar granite indicate that it is most likely the result of crustal melting of a thickened post Penokean crust. The presence of significant amounts of diorite crosscutting and intermingled with the granite and mafic enclaves of basaltic nature that are related to the diorite indicate melting was more complex than a simple batch melt of thickened crust. The granite/rhyolite is likely a product of partial melting from a feldspar-rich continental crust as indicated by the strong depletions in Sr and Ti. The high concentrations of MgO, Ni, Cr, Zn, and V would be indicative of a mantle source for the mafic enclave with the diorite forming by fractionation from the parent basalt.

The lamprophyre is characterized by an orthoclase and anorthoclase groundmass with abundant phlogopite phenocrysts and euhedral pseudomorphs of amphibole that have been replaced by montmorillonite. Using the classification of Rock (1991) the lamprophyre best falls into the calc-alkaline field and is termed a minette. It is enriched in Ba and Sr as is typical for lamprophyres. The lamprophyre is also enriched in the rare earth elements (REE's), especially the LightREE's.

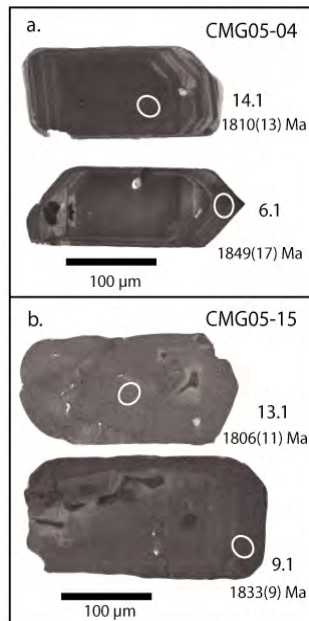


Figure 1. Representative cathodoluminescence images of zircons from samples (A) CMG05-04 and (B) CMG05-15. Ellipses indicate individual analysis spots for the sensitive high-resolution ion microprobe - reverse geometry (SHRIMP-RG). Each spot is labeled by grain number, alysis number (e.g. 4.1) and the corresponding $^{207}\text{Pb}/^{206}\text{Pb}$ age ($\pm 1 \sigma$ Ma).

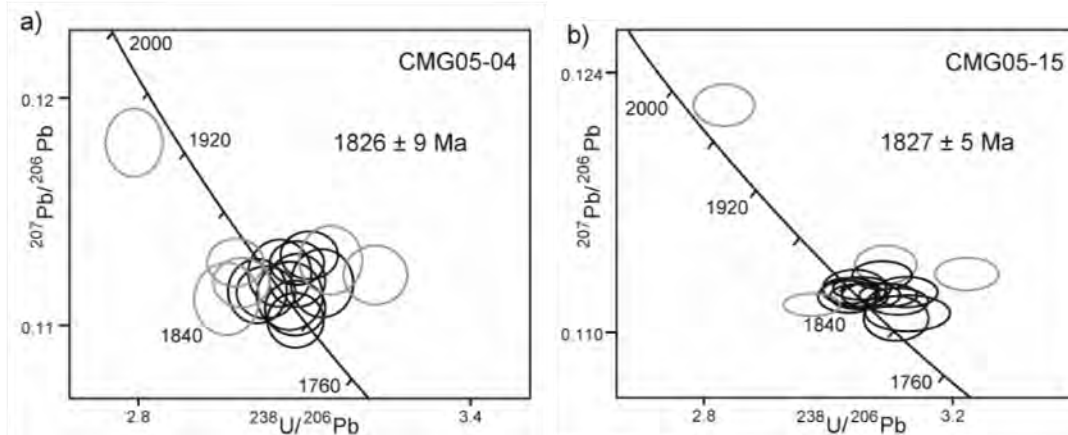


Figure 2. Tera-Wasserburg plots of sensitive high-resolution ion microprobe – reverse geometry (SHRIMP-RG) U-Pb data of zircon for samples (A) CMG-05-04 and (B) CMG-05-15. The data are presented as 1σ error ellipses uncorrected for common Pb.

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RECONSTRUCTING THE PENOKEAN FORELAND BASIN USING THE TIMELINE OF THE 1850 MA SUDBURY IMPACT LAYER

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The evolution of foreland basins, which are linear sedimentary basins formed on continental margins during terrane accretion, is highly variable both in time and space. Where terranes override thinned continental margins, a deep basin or foredeep forms near the margin and passes landward successively to a shallower outer slope, forebulge, and shelf. As accretion proceeds, these zones migrate toward the continent and are superimposed on previous sedimentary successions. Geologic and geochronologic studies (see Schulz and Cannon, 2007, for a review) have confirmed that the Paleoproterozoic Animikie Group and Marquette Range Supergroup in the Lake Superior region record the complex history of such a basin, the Penokean foreland.

Unraveling the history of this complex basin is hampered by paucity of precise time lines. Only a few volcanic layers have been precisely dated and these are insufficient to reconstruct the basin history in more than a general manner. However, recently a bed of ejecta-bearing breccia that was deposited instantaneously across the Lake Superior region has been recognized as being related to the 1850 Ma meteorite impact at Sudbury, Ontario (Addison et al., 2005; Jirsa et al., 2008; Cannon et al., 2009). The Sudbury impact layer (SIL) can be traced regionally and provides a unique opportunity to reconstruct the Penokean foreland basin when the Penokean orogen was in a transformative state from a period of mild extension to the earliest stages of thrusting of volcanic arcs onto the continental margin (Schulz and Cannon, 2007).

At the time of deposition of the SIL, the northern part of the Penokean basin near Thunder Bay was very shallow to subaerial as indicated by the occurrence of algal stromatolites beneath the SIL and local evidence of subaerial weathering. This shoaling of the basin probably accompanied the arrival of the forebulge. To the southwest conditions were different. At Gunflint Lake and along the Mesabi Range, the SIL lies conformably on the Gunflint and Biwabik Iron Formations for 250 km along strike. In this area, the stratigraphic succession records a progressively deepening basin with the upper cherty member of the Biwabik, a shallow-water, partly stromatolitic unit, overlain by deeper-water carbonate and silicate iron-formation of the upper slatey member. The SIL was deposited on the upper slatey member and was succeeded by black shale of the Virginia and Rove Formations. The shallow-water deposits of the upper cherty member may record the passage of the forebulge slightly before it arrived at Thunder Bay; the upper slatey member may mark the ensuing submergence on the outer slope prior to 1850 Ma.

Farther south, deposition of the major iron-formations of the Gogebic and Marquette Ranges ended well before 1850 Ma. By then, both ranges had been uplifted, eroded, and resubmerged, recording passage of the forebulge (outer arch) and submergence onto the outer slope. As much as 500 m of clastic sediments, largely reduced-facies black shale, that represent temporal equivalents of the iron-formations of the Gunflint and Mesabi Ranges, covered the iron-formations of the Gogebic and Marquette Ranges by 1850 Ma. Just north of the Marquette Range, the SIL lies on a chert-carbonate unit of the Michigamme Formation, which is the southern temporal equivalent of the Gunflint Formation. Thus, at 1850 Ma iron-

formations were being deposited on distal (shoreward) parts of the outer slope while black shales were being deposited on more proximal, deeper parts of the slope.

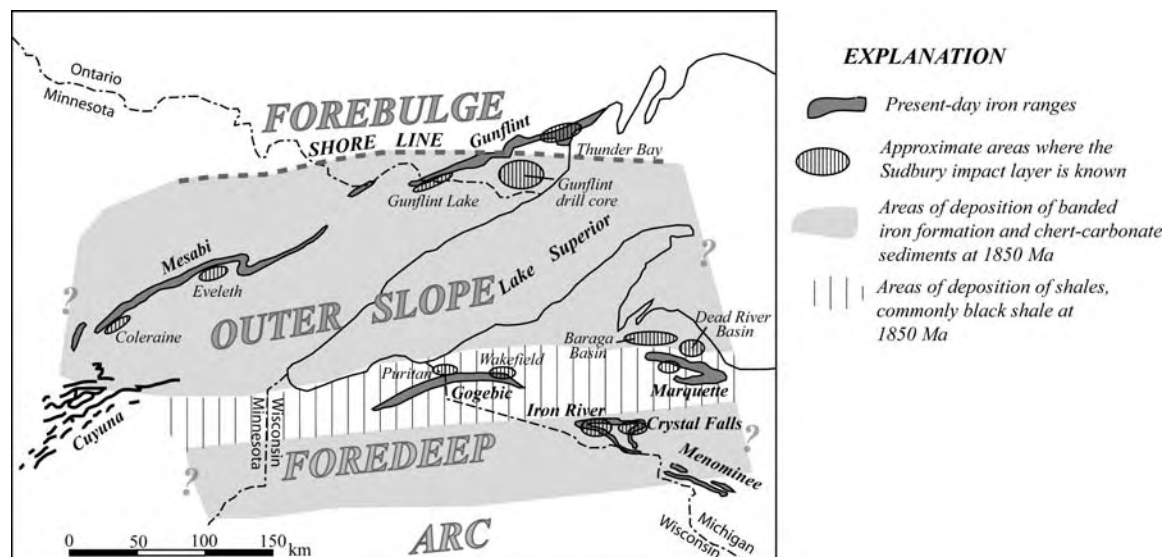


Figure 1. Reconstruction of the Lake Superior region at 1850 Ma based on lithofacies immediately below the Sudbury impact layer. Area as shown has been foreshortened by 30 km across the Midcontinent Rift to restore relations prior to Mesoproterozoic extension.

In the southernmost part of the basin, deep-water iron-formations of the Iron River-Crystal Falls district occur directly beneath the SIL indicating that an additional iron-formation facies was deposited deep within the axial zone of the basin near the advancing overthrusting arc terrane. Thus, the reduced shale facies deposited on the deeper portions of the outer slope passed southward to at least a brief period of ferruginous chemical sedimentation in the sediment-starved axial zone of the foreland basin.

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MAGNETIC ANOMALIES FROM PLEISTOCENE SOURCES IN THE WESTERN LAKE SUPERIOR REGION: THE EDGE OF INSANITY OR A PROMISING THRESHOLD?

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Over the last few decades high-quality aeromagnetic data in Minnesota, Wisconsin and Lake Superior has been crucial to interpreting the geology of the Precambrian bedrock, which lies concealed beneath a nearly continuous cover of Pleistocene glacial deposits. It has been generally assumed that Pleistocene deposits are non-magnetic, and thereby “transparent” to the magnetic data, but it is now appears that weak anomalies, generally on the order a few nanoTeslas to a few 10’s of nanoTeslas, are associated with the Pleistocene deposits themselves. Detection of these weak magnetic anomalies, which is usually most effective using derivative-enhanced data, requires that the underlying bedrock be non-magnetic, thereby providing a sufficiently quiet magnetic anomaly background. These quiet background conditions are best developed over thick basins of non-magnetic sedimentary rocks, such as the Keweenaw sandstone sequences of the Mesoproterozoic Midcontinent Rift System and the slate-greywacke sequences of the Paleoproterozoic Animikie basin and associated outliers. The outlines of these basins are shown in Figure 1, along with the interpreted traces of Pleistocene-related anomalies.

These weak anomalies have straight to wandering forms that are reminiscent of stream channels, and they appear to be most closely associated with glacial deposits of the Rainy and Superior Lobes, both of which passed over magnetite-enriched bedrock at short distances up-ice. Magnetic susceptibility determinations of the glacial deposits, based either on model studies or on direct measurements of till and outwash samples, indicate that moderate values, generally in the 0.0025-0.0050 SI range, are common. Some of these weak anomalies can be directly related to topographic features, such as the Toimi drumlins of northeastern Minnesota and the Wadena drumlins of west-central Minnesota (Figure 1), but most show little or no correspondence to surface features.

The causes of many of these weak anomalies remain unknown, but recent investigations indicate that at least some are related to bedrock valleys that are filled with relatively magnetic glacial materials. In east-central Minnesota these anomalies have been particularly useful in tracing buried valleys in areas with sparse drill-hole control. Weak anomalies in western Lake Superior have been used to trace several deep bedrock channels that may have developed as tunnel valleys beneath Superior Lobe ice. Although little geologic control exists in the Animikie basin, many stream-like anomalies parallel the expected east-west structural grain for the bedrock, and could therefore reflect bedrock-controlled valleys.

Although these channel-like anomalies are geophysical oddities that are somewhat restricted in their occurrence, they have proven to be pertinent to hydrogeologic and Pleistocene studies in the region, and further investigations are warranted.

Aeromagnetic data used in this study were acquired with support from the U. S. Geological Survey, the Geological Survey of Canada, and the Minnesota Legislature through the Legislative Commission on Minnesota Resources. Ship-borne magnetic data from Lake Superior were acquired by the Minnesota Geological Survey, in cooperation with the Large Lakes Observatory. Interpretive work supported by the Minnesota Geological Survey through the State Special Appropriation, the County Geologic Atlas Program, and appropriations from the Minnesota Minerals Coordinating Committee.

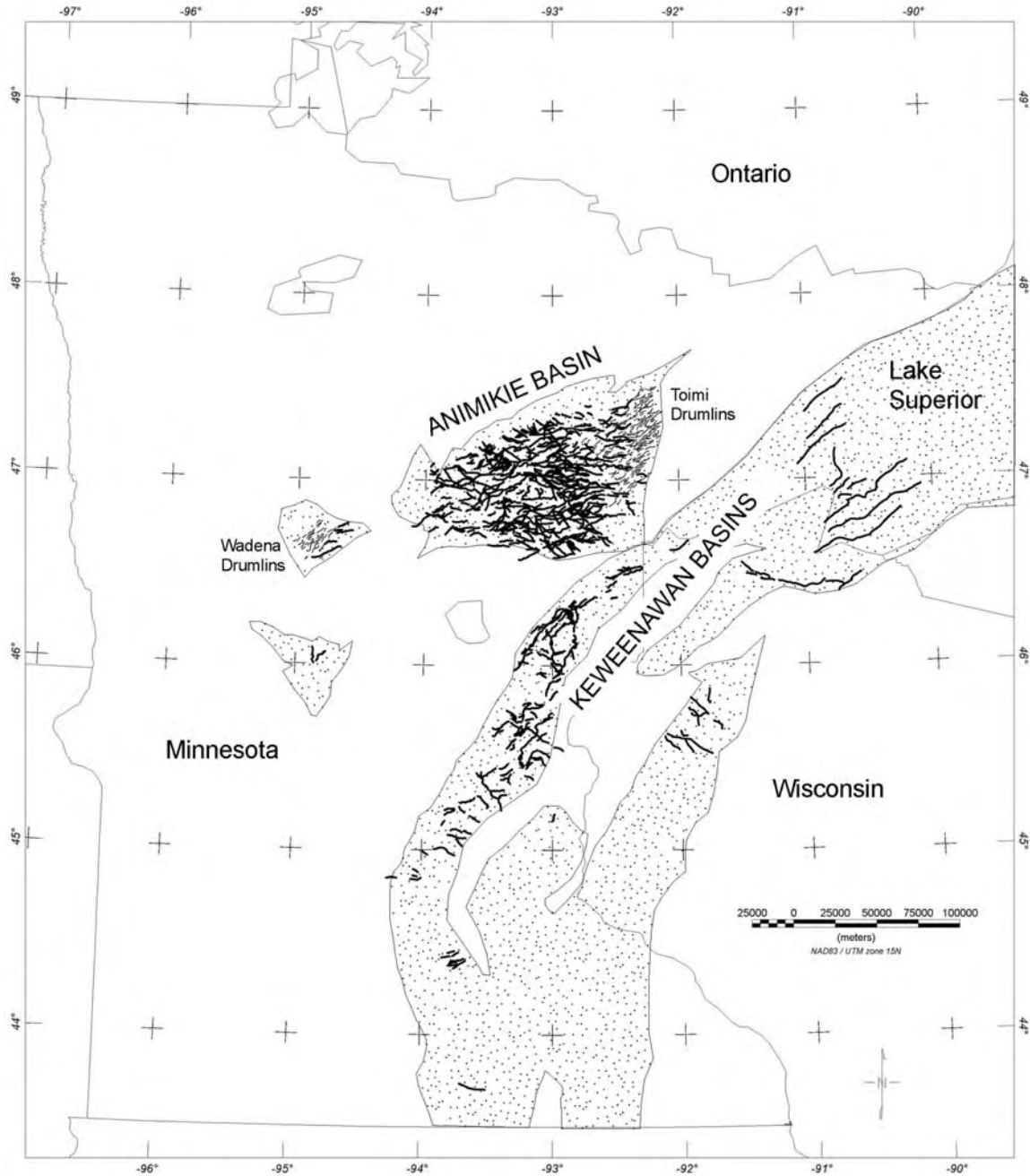


Figure 1. Map showing the traces of magnetic anomalies that are interpreted to reflect Pleistocene deposits. Lighter lines designate anomalies that are related to drumlin fields. Stippled areas outline basins of Paleoproterozoic and Mesoproterozoic sedimentary rocks described in text.

METHODS FOR ESTIMATION OF INDIRECT HYDROLOGIC IMPACTS ON WETLAND PLANT COMMUNITIES AT POTENTIAL HARD ROCK MINE SITES

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In areas of mineral development where wetlands are common it is frequently necessary to predict how mine development may affect wetlands through direct and indirect impacts. Direct impacts to wetlands are usually identified as filling or removal of wetlands during mine development, facilities construction, and waste storage or disposal. Indirect impacts to wetlands are less clearly defined but can result from, among other factors, modifications in physical hydrology. Developments in modeling of physical hydrology of ground and surface waters and a better understanding of how wetland communities are tied to physical hydrology allow for estimation of the indirect impacts of mineral development on wetland communities.

As part of evaluation of several proposed mine projects, tools for evaluation of mine induced changes to surface and groundwater have been explored. These tools, primarily various surface and ground water models, integrate site specific geologic and hydraulic data into a framework that is based on the current understanding of how waters interact with the land surface and shallow and deep geology. Given an adequate understanding of a site's soils and geology these modeling tools can predict how modifications to the landscape through mining, facilities construction, or waste disposal may effect the level and rate of flow of waters in wetlands. Although these modeling approaches are fairly mature, their success depends on the type and quality of data available on which to base the analysis. Some of the most critical pieces of information for such modeling are the character of bedrock fracturing, the character of surficial materials, and hydraulic links between bedrock fractures and surficial materials. Existing drilling programs for mineral exploration can be adapted to provide some of this information by the analysis of fracture patterns and orientation in core and the retention of data on surficial materials that are penetrated prior to bedrock entry.

The methods for integrating geologic and hydrologic information into ground and surface water models have been in use for many years. On the other hand, methods to predict the effect that a change in physical hydrology has on wetland plant communities has, up to this point, been less clearly defined. As part of the effort to evaluate the potential impacts of the proposed Crandon Mine in Wisconsin, methods were developed for identifying the sensitivity of plant communities to water level changes. These methods, while still being refined, present an opportunity to bridge the gap between expected changes in physical hydrology and effects on wetland plant communities.

GEOLOGY OF THE TUSCARORA INTRUSION, NORTHEASTERN MINNESOTA AND ITS RELATIONSHIP TO THE ANORTHOSITIC SERIES OF THE DULUTH COMPLEX

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The petrogenetic relationship between the layered series and anorthositic series of the Duluth Complex is not well understood. The Tuscarora Intrusion, located in the northeastern portion of the complex, is one of the best examples of this ambiguous relationship. Previous work in the Tuscarora within the Long Island Lake quadrangle (Morey et al. 1981) has described the troctolitic and anorthositic lithologies as interlayered on the scale of centimeters to meters. This observation is unique among the layered series of the Duluth Complex. This project seeks to take advantage of recent wildfires within the area to study the relationship between the Tuscarora Intrusion and the Anorthositic Series within the Gillis Lake quadrangle, through field mapping, petrographic observations, and geochemical analyses.

The layered series occurs as a number of discrete mafic layered intrusions at the base and mid-levels of the complex, all of which are overlain by a structurally complex cap of anorthositic gabbros of the anorthositic series and granophyric rocks of the felsic series. Field relationships observed over many decades of study throughout the Duluth Complex typically show anorthositic series rock types as inclusions within layered series rocks or show layered series rock intrusive into anorthositic rocks. These observations, along with the very distinctive lithologies and internal structures of the two series, had long been interpreted to suggest that the anorthositic series was significantly older than the layered series (Miller and Weiblen 1990). However, U-Pb zircon ages show that the two units are essentially the same age (1099 Ma $\pm$ 0.5 Ma; Paces and Miller 1993). These age data imply not only that the two main stage rock series of the Duluth are approximately the same age, but also that they may be comagmatic or at least part of the same magmatic event. This possibility of a closer genetic relationship between the two series is actually supported by many gradational to ambiguous relationships between the two series, which in the past had been largely ignored as inconsequential anomalies (Paces and Miller, 1993). The Tuscarora Intrusion is one of the best examples of this ambiguous relationship, as described by Morey et al. (1981).

This study found no direct evidence for interlayering between the troctolitic and anorthositic lithologies. Rather, the anorthositic series were found to be elongate inclusions within the troctolitic rocks of the Tuscarora Intrusion. The anorthositic inclusions are concentrated in the upper portion of the Tuscarora, as described below. Geochemical analyses of samples collected from both series show similar mineral chemistries and trace element behavior trends. This is interpreted to suggest that the two lithologies are closely related and may be part of the same magmatic event, even though they are not interlayered. These results agree with other studies where anorthositic rocks have been found as inclusions within the layered series.

An unexpected discovery of this project is that the Tuscarora Intrusion can be divided into two distinct lithologic zones, based on modal mineralogy, textural patterns, internal structure, and inclusion type and amount (Fig. 1). Moreover, each zone can be divided into a couple of distinctive units. The lower zone (LZ) is somewhat heterogeneous, with compositions ranging from olivine gabbro to augite troctolite. A thin basal unit (Tbh) is very taxitic, with local biotite and orthopyroxene suggestive of footwall contamination. The augite troctolite unit (Tat) contains well-developed but variably oriented foliation and modal layering. Some of this structural variability may be due in part to the presence of very large (up to 100s of meters across) mafic hornfels inclusions (unit Thf, fig. 1), which occur throughout the Tat unit. These inclusions are interpreted to have been

derived from the North Shore Volcanic Group, into which the Tuscarora and other Duluth Complex intrusions were emplaced.

In contrast, the upper zone (UZ) is much more homogenous and consistently troctolitic. It can be subdivided into a thin melatroctolite basal unit (Tmt or Tum) that grades upwards into a fine-grained, well-foliated troctolite to leucotroctolite (unit Ttr or Tut). This unit contains an abundance of anorthositic-type inclusions as described above, presumed to have been derived from the overlying anorthositic series (unit Aau). In addition, a large inclusion of the adjacent Poplar Lake inclusion (unit Pgb) has been identified by previous mapping (Morey 1981). A troctolitic dike (unit Ttd) has been mapped in the western portion of the map area extending from the upper zone, through the lower zone and into the footwall sedimentary rocks. This dike is approximately 80 meters across and contains several small inclusions of poikilitic troctolitic anorthosite.

Based on results from field mapping, petrographic observations, and geochemical studies, the two zones of the Tuscarora Intrusion are interpreted to represent successive injections of melt within a single magma chamber. The Lower Zone was emplaced first, and encountered NSVG lithologies located between the recently formed Anorthositic Series and footwall rocks. This unit began to crystallize, followed by the introduction of a replenished melt to the chamber. The Anorthositic Series served as a hanging wall to this newly emplaced magma, and was incorporated as elongate inclusions in the roof portion of the crystallizing Upper Zone.

This poster presentation focuses on the geologic map produced as part of this study. Support for mapping was provided by the Educational Component of the National Cooperative Geologic Mapping Program (EDMAP) of the United States Geological Survey. Geochemical studies were supported by grants from the Institute of Lake Superior Geology and from the Dept. of Geological Sciences and the Precambrian Research Center at UMD.

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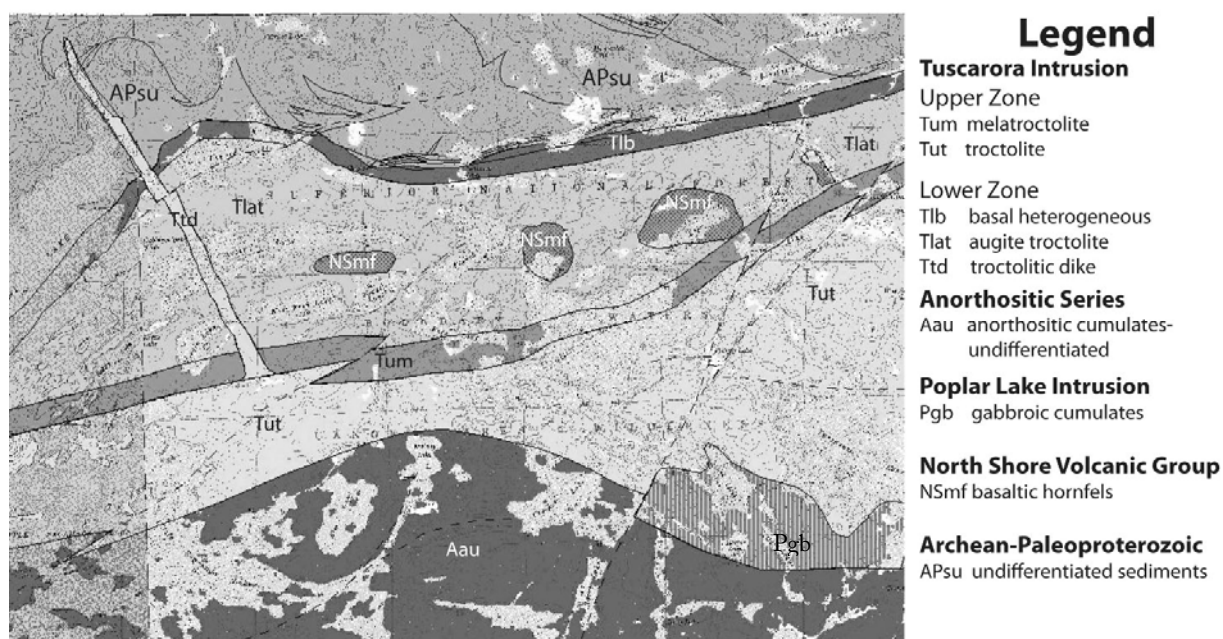


Figure 1: Generalized bedrock geologic map of the Tuscarora Intrusion and related rocks within the Gabimichigami and Gillis Lake quadrangles. Unit descriptions are provided in text.

QUANTIFYING ASSIMILATION VS. FRACTIONAL CRYSTALLIZATION USING Sm-Nd, Lu-Hf AND Pb ISOTOPE SYSTEMS: THE GEOCHEMICAL EVOLUTION OF THE SONJU LAKE INTRUSION, FINLAND, MN

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The Sonju Lake Intrusion (SLI), located within the Beaver Bay Complex near Finland, MN, is the most completely differentiated intrusion related to the 1.1Ga Midcontinent Rift System (Miller and Ripley, 1996). The Finland granite, which is composed of micrographically-textured leucogranite to ferromonzonite, forms the hanging wall of the SLI. The SLI exhibits a cumulate stratigraphy consistent with closed system differentiation of tholeiitic magma by fractional crystallization (Stevenson, 1974; Miller and Ripley, 1996). Field relationships from outcrop and drill core through the SLI and the overlying Finland granite show a cyclic to irregularly gradational contact between the two bodies. This relationship, the smooth compositional variations across the contact and the parallel zonation of the two subunits of the Finland granite with the strike of the mafic cumulates of the SLI are consistent with the Finland granite being a late stage felsic differentiate of the SLI (Miller and Ripley, 1996). However, geophysical modeling of gravity and aeromagnetic data implies a volume of granite that approaches that of the SLI and therefore exceeds the volume of felsic material that could be accounted for by differentiation of a mafic body the size of the SLI (Miller et al., 1990). Miller and Ripley (1996) suggested that the earlier emplacement of the Finland granite acted as a density barrier to the upward movement of the mafic SLI magma. Underplating of the hot mafic SLI magma would be expected to lead to melting in the lower portions of the Finland granite. This poses a fundamental question of what portion of the apparent differentiation of the SLI is related to fractional crystallization, and how much is related to assimilation of a felsic partial melt from the granite. Major and minor element whole rock data are inadequate to the task of distinguishing these processes because the Finland Granite geochemically resembles an upper differentiate of the SLI. However, a radiogenic isotope study of these two systems has the potential to address the question, as reconnaissance isotopic data show that the granite has a radiogenic isotope signature that is distinct from the mafic rocks of the SLI (Vervoort, Unpublished data).

To evaluate the roles of fractional crystallization and assimilation in the crystallization of the SLI, a total of 21 samples were collected from outcrop and drill core for analysis for Sm-Nd, Hf-Lu, and Pb isotopes. The analyses were conducted at the radiogenic isotope facility at Washington State University using a Finnegan Neptune MC-ICPMS. Pb isotope compositions were analyzed for all 21 samples and 16 samples were chosen to measure Sm-Nd and Lu-Hf isotope compositions. These data were combined with Nd data from 8 samples in a previous reconnaissance study (Vervoort, 1996, unpublished data) to profile of the isotopic variation through the Sonju Lake intrusion and up into the overlying Finland Granite. The sample locations are shown on Figure 1.

All of the samples collected from the exposed eastern area of the SLI and Finland Granite (Fig. 1) show initial epsilon Nd values for the SLI that are consistent with other uncontaminated, mantle-derived mafic volcanic rocks of the rift (epsilon Nd 0 ± 2 , Vervoort et al., 2007). Samples from the Finland Granite yield moderately radiogenic initial epsilon Nd values of ≈ -3.5 . Only minor contamination effects are evident in the uppermost SLI cumulates. However, a surprising result came from six samples collected from a drill core (SLI-1) that penetrates the transition zone between the SLI and the granite about 7 km to the west of the exposure area (Fig. 1). These samples, taken mostly from the well-foliated apatite ferrodiorite cumulates of the slat unit (Fig. 1), yield the most radiogenic initial epsilon Nd values, ranging from -4.1 to -5.2. This may imply that the Finland granite has isotopic heterogeneities, which has been shown by Beard (2008) to be possible in magmatic systems formed by partial melting. Several follow up samples were submitted to better

understand this discrepancy. We hope to have these results and our best interpretation of these data available at the time of our presentation.

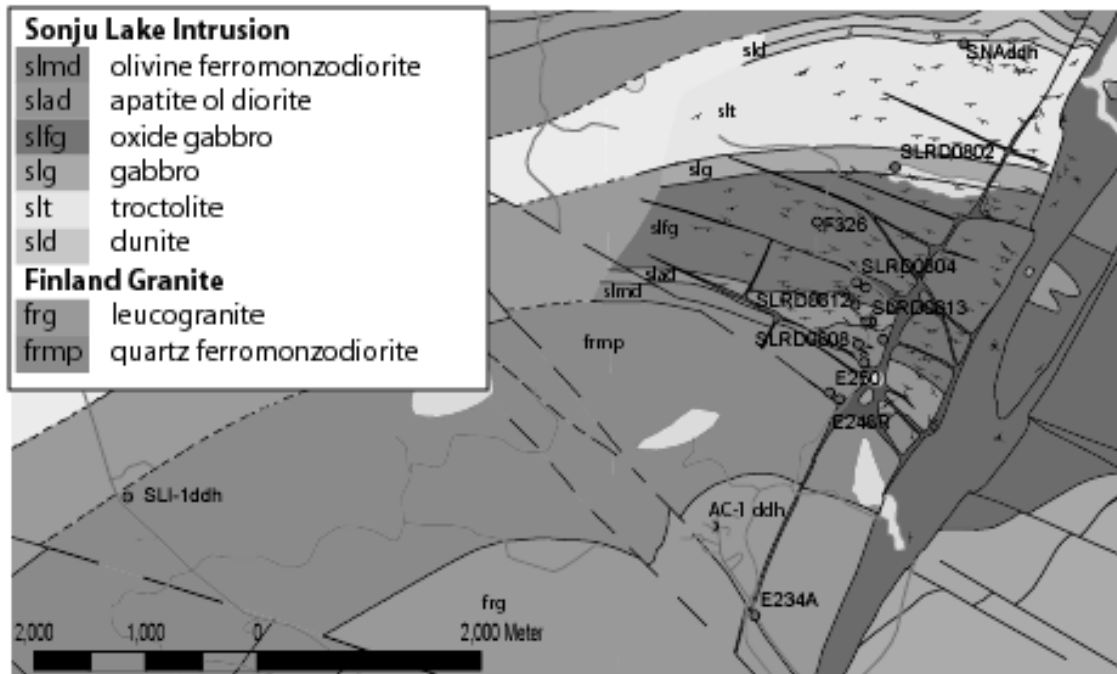


Figure 1. Geologic units of the Sonju Lake intrusion and Finland Granite, showing sample and drill core locations. Modified from Miller et al., 1993

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TACONITE-DERIVED MINERAL DUST IN POPULATION CENTERS ON MESABI IRON RANGE: TRACKING MINERAL FIBERS FROM ORE TO AIR

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In an effort to address long-standing questions regarding the impact of dust derived from mining taconite on human health, the University of Minnesota is conducting multiple complementary health-related studies, including an exposure assessment, epidemiology studies, and exposure characterization research. As one of these studies, NRRI performing a detailed characterization of the dust that is produced from mining and processing Biwabik Iron Formation ore, with emphasis on any mineral fibers present and the elongated mineral particles that are produced from mining and processing activities.

The characterization of mineral fibers and elongated particles begins with the examination of fibrous minerals *in situ* from thin sections of metamorphosed and unmetamorphosed iron-formation (fig.). We are also looking at the crushed material corresponding to these thin sections (fig.), and the particulate matter present in the air of the taconite operations where it is mined and processed. Finally, we are conducting a three-year long, field-based study of taconite-derived mineral dust present in the air of communities directly surrounding the taconite operations of the Mesabi Iron Range. The community air sampling will result in long-term average mineral fiber concentrations in ambient air at these locations; characterization of any mineral fibers that are found using metrics relevant to their impact on human health (aerodynamic diameter, dimension, mineralogy, and chemistry); and average total particulate matter and its size distribution at these locations. Retrospective observations will be made using dated lake sediment cores from the region.

Particulate matter (in ambient community air, within taconite operations, and aerosolized crushed material) is being collected using a Micro-Orifice Uniform-Deposit Impactor and on a total filter. These samples are then analyzed by a gravimetric method, scanning electron microscopy, energy-dispersive X-ray spectroscopy, and X-ray diffraction.

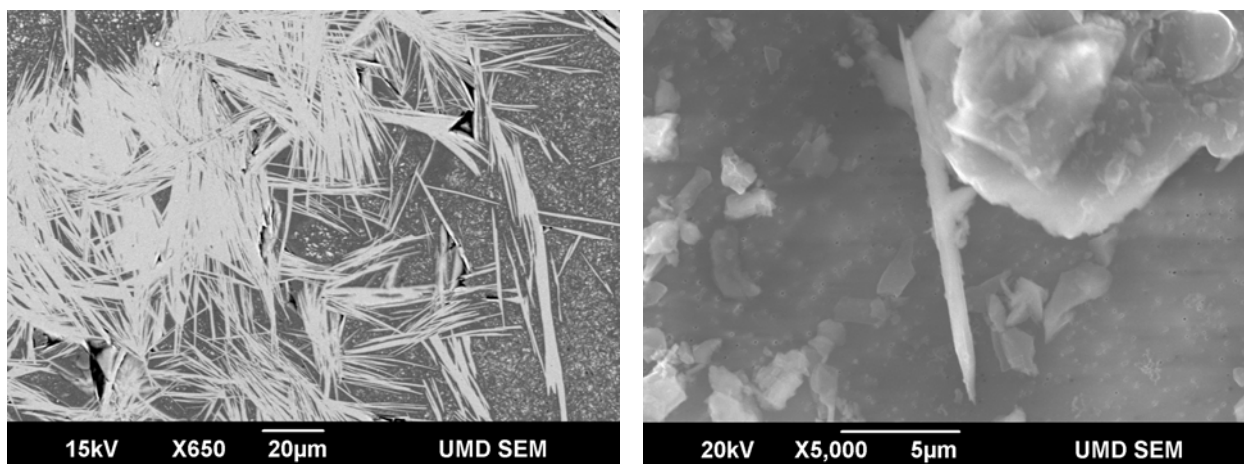


Figure: BSE SEM image of Minnesotaite needles in thin section of unmetamorphosed Biwabik Iron Formation (left); SEI SEM image of Minnesotaite particle liberated from crushing that same rock (right).

GEOLOGY AND GEOCHEMISTRY OF THE FEARLESS-PYTHON PROPERTY, SCHREIBER-HEMLO GREENSTONE BELT, ONTARIO

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The Fearless-Python property, owned by Metacorp Limited, is located approximately 50 kilometres east of the town of Marathon, Ontario and is situated within the Schreiber-Hemlo greenstone belt of the Wawa subprovince of the Archean Superior Province. Fearless-Python has been extensively explored over the past 40 years, mainly being examined for Hemlo-type gold deposits. The property is sandwiched between the Cedar Lake Pluton (2688 – 2687 Ma, Corfu and Muir, 1989) to the north and the Pukaskwa Batholith (2719 and 2688 Ma, Corfu and Muir, 1989) to the south. The geology is dominated by generally east-west trending and northerly dipping metasedimentary rocks with mafic to intermediate metavolcanic rocks and minor felsic metavolcanic rocks. High level intrusive dykes and Proterozoic diabase dykes crosscut all lithologies (Thompson and Paakki, 2001). The entire Schreiber-Hemlo Greenstone belt has been affected by lower to mid amphibolite facies metamorphism (Pan and Fleet, 1993).

The geology of the property is favorable for several deposit types, including; **1)** the Gouda shear zone which hosts gold mineralization lies within the southern portion of the property and the major structural trend which is host to the Hemlo gold deposit, directly to the east, is also present within the property. The highest gold values are located within the Gouda Lake Horizon which occurs at the base of a well-developed, potassically altered quartz eye sericite schist hosting gold as well as disseminated and semi-massive to massive sulphides consisting of pyrite, pyrrhotite, sphalerite and lesser galena **2)** VMS mineralization has been recognised at a number of locations within the property. Significant occurrences of massive sulphides are present at two locations on the property, as well as several smaller zones of anomalous Zn, Cu, Pb values. **3)** Molybdenite occurs as coarse aggregates in crowded feldspar porphyry and granite pegmatite dykes in the Duck Lake area north of the Gouda shear zone. **4)** Possible Outokumpu-type Ni-Co-Zn-Cu mineralization has also been reported at two locations on the property.

Preliminary analysis of trace element geochemistry shows that the metavolcanic rocks range from calc-alkaline to tholeiitic in composition. Primitive mantle normalized plots shown in Figure 1 indicate island arc and MORB-like affinities for the metavolcanic rocks. Felsic metavolcanic rocks have MgO contents of 0.2-1.4 weight percent, SiO₂ of 68.3 weight percent and La/Sm, Gd/Yb ratios of 2.11-5.17 and 2.19-5.33 respectively. Intermediate and mafic metavolcanic rocks have MgO contents of 3.5-8.9 weight percent, SiO₂ of 47.4-58.2 weight percent and La/Sm, Gd/Yb ratios of 0.64-3.31 and 1.04-4.72 respectively.

Spatial relationships suggest that there may be a genetic relationship between the different deposit types at the Fearless-Python property. Hemlo-type gold and VMS mineralization occur together in the Gouda Lake Horizon. Molybdenite occurs in close proximity to the north of the Gouda shear zone. The CADI zone, which is a nickel prospect, occurs along strike to the west of the Gouda shear zone. Additional work in the summer of 2009 will

utilise drill core and surface mapping to explore these relationships and test the model that the multiple mineralization events are genetically related.

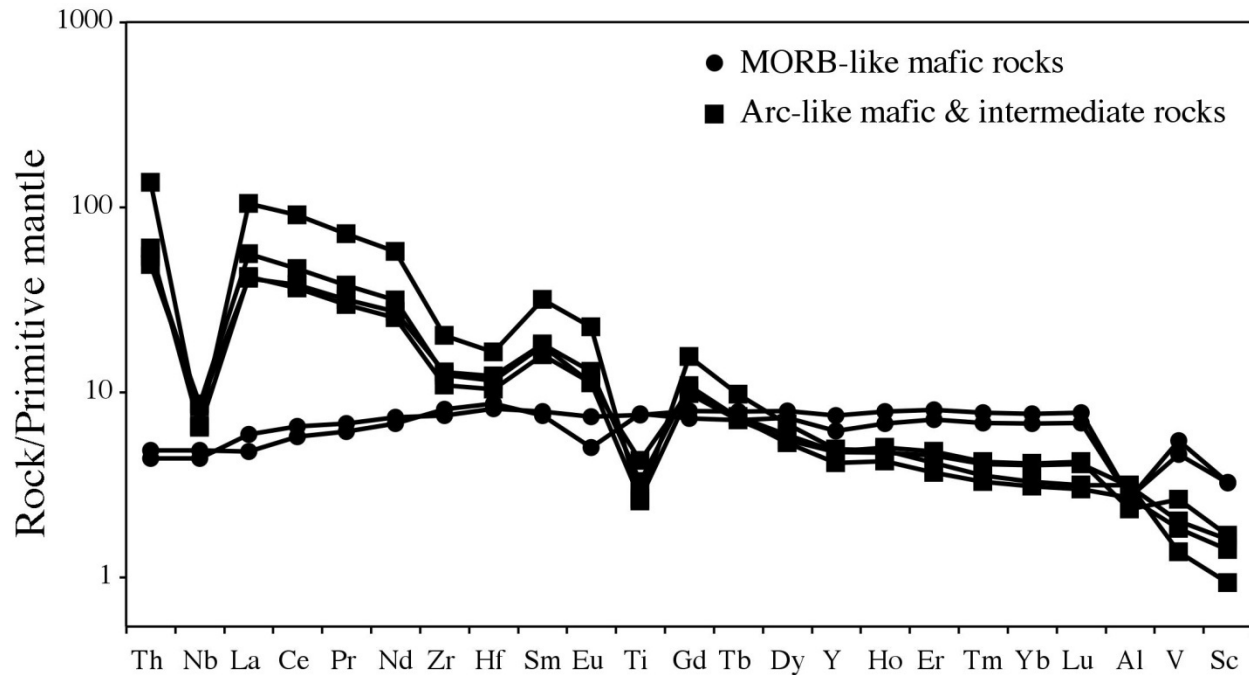


Figure 1. Representative primitive mantle normalised diagram for volcanic rocks of the Fearless-Python property (normalising values from Sun and McDonough, 1989).

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ALTERATION IN THE SOUTHERN FELSIC VOLCANICS AT MARSHALL LAKE, NORTHWESTERN ONTARIO

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The Marshall Lake property is a copper-zinc-rich volcanic-hosted massive sulfide (VHMS) deposit located approximately 255km northeast of the city of Thunder Bay, Ontario. The study area consists of a series of Archean rocks including metavolcanics that range in composition from mafic to felsic, and metasedimentary units, both clastic and chemical. The Summit Lake pluton is another significant lithology that may have played a role in driving the ore-bearing fluids, since it is penecontemporaneous with the surrounding metavolcanics.

In the past, most work in the area has concentrated on the northern part of the sequence where most of the mineralization is known to occur. In 2006, East West Resource Corporation acquired the property, and since this time there has been an increased effort to understand the deposit as a whole; not only the area proximal to the mineralization, but also the distal rocks to the south.

The alteration and subsequent metamorphism at Marshall Lake are typical for a bimodal mafic VHMS type deposit. The metamorphic assemblages present in the southern felsic metavolcanics represent depletion in sodium and silica and enrichment in magnesium and potassium when compared with an unaltered rock of similar composition. Most of the mapped area, especially along the contact between the metavolcanics and metasedimentary rocks, are dominated by the metamorphic assemblage garnet-amphibole. The intensity of this alteration decreases with distance from this contact.

In the genesis of a VHMS deposit two types of fluids can contribute to the alteration geochemistry: the ore-bearing fluids that penetrate the siliceous cap rock underneath the precipitation site, and the convecting seawater that enters through fractures in the seafloor. The latter fluid type would result in the enrichment in potassium and magnesium that is seen. The evidence seen in the field, through petrography, and in the geochemistry is suggestive that seawater had more effect on the alteration of the southern volcanics than the ore-bearing fluids, however a background signature from the ore-bearing fluids is still present as can be seen with the depletion of sodium and silica.

If this is indeed the case then it would indicate that the metasedimentary units to the south of the metavolcanics, consisting of banded iron formation within clastic sediments, may have been the paleoseafloor during the genesis of the deposit, and the volcanics to the north would have underlain these sediments. The sequence would then be regionally topping to the northeast, which agrees with the few structural measurements that are available.

This would have some economic significance as well, since it may warrant exploration for the presence of a lead-zinc-rich horizon within (or in close proximity to) the banded iron

formation, since lead and zinc would precipitate out at the top of the stratigraphic pile. Geophysical surveys used in the past to identify targets would have been difficult to interpret, since the iron formation itself is such a strong conductor and has such a high magnetic susceptibility.

VERMILION GREENSTONE GOLD - NEW DATA, NORTHEASTERN MINNESOTA

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A petrologic and geochemical reexamination of thirty archived sets of drill samples from the Vermilion Greenstone Belt in Northeastern Minnesota has revealed previously unrecognized gold-bearing intervals and mineral associations supporting new or additional gold mineralization models with individual prospects. Gold concentrations as high as 148ppm were observed during the collection of 3,772 semi-quantitative XRF analyses. The presence of acicular sodic-rich amphiboles in a sequence with gold-bearing chert-graphite-sulfide layers suggests that gold mineralization may be associated with sodic metasomatism.

The Vermilion Greenstone Belt has long been associated with gold. In 1865, a “gold rush” occurred in the area around Lake Vermilion. Appreciable gold was not found at the time, but it did lead to the discovery of direct shipping iron ore at Soudan, Minnesota and eventually Ely, Minnesota. The Soudan Mine and the five major mines in Ely produced about 100 million tons of ore. Exploration also led to the developing of numerous smaller mines in the greenstone. Many of these did not even warrant a rail spur, but the ensuing exploration activities and relatively good outcrop exposure encouraged future work for other metals, including gold.

Most Vermilion greenstone rocks have been subjected to greenschist facies metamorphism. Outcrop exposure is variable, but good compared with most of Minnesota. Past sampling, maps, and reports have been produced by the Minnesota Geological Survey, the Natural Resource Research Institute, and the Minnesota DNR. Exploration by at least fifteen exploration companies have produced historic drill hole samples, geochemistry, geophysical work and other data. A known, widespread presence of anomalous gold within the Vermilion “greenstone” is one fruit of these efforts.

Our work has included drill sample logging; semi-quantitative, real-time “hand-held” XRF chemistry; and limited assay and microprobe work in order to better elucidate the varied gold occurrences. The .76 cm² XRF sample size complements the visual descriptions, and the grain size of most rocks. The sample size provides direct elemental associations with gold associated with discrete mineral grains. XRF traverses are also useful for zoning associated with veins and alteration fronts. The context of the sampling size, however, must be maintained when examining this data.

Besides providing more detailed element associations with each prospect and encountered mineralization type, the XRF has also allowed for better physical placement of gold mineralization found within anomalous previous assays. Visible clues may be established since gold mineralization may be otherwise hidden. XRF element associations have been found with a summary in Table 1. Several gold mineralization types occur. Note, however, that the values for Foss Lake and Eagles Nest Prospects are based on a smaller number of semi-quantitative XRF readings with anomalous measurable gold. Also, the rutile association of the “Raspberry” is from visible logging. The rutile is found in close proximity to XRF

anomalous gold, but not as intimately as with galena. All the prospects probably have several geochemical processes involved in determining the final gold locations and associations.

Table1 - XRF Element Associations

Prospect	Au Mineralization Type	Semi-quantitative XRF Value	Au Association
Raspberry	Intrusion hosted	To 101 ppm Au	Pb (galena), Quartz veins, Rutile(?); Fe, As, Mn, Cr, Se, Sn
Raspberry	Shear zone related (remobilization?)	To 67 ppm Au	Pb (galena), Quartz veins, Rutile?; Pb, Ag, Se
Foss Lake	Algoma BIF related Au	To 28 ppm Au	Fe oxide to Sulfide-graphite transition; As, Ba, Pb
Eagles Nest Shear	Shear zone related	To 4 ppm Au	Pyrite; Mn, Sr, Ba, Mo?, Cu?
Murray Shear	Volcanic Hosted Massive Sulfide?	To 148 ppm Au	Sphalerite, Cr, Zn, Sb, Cd, Hg

Foss Lake Prospect drill core. The first Foss Lake Prospect drill core examined (DDH# 6314-36-1) contained a sequence of iron formation within basalts. Previously unknown gold was found within disturbed chert and graphite interlamination at the broad transition from oxide-silicate-carbonate BIF to sulfide-graphite BIF. Away from the transition, the sulfide iron formation was heavily assayed with minimal Au. The elevated XRF gold was associated with elevated As, Cu, Co, Pb, and Mo.

Chert layers within the sequence were locally noticeable because of a slight bluish cast exhibited in their appearance. Hand lens examination showed the presence of pale acicular fibers in and on the margins chert. Microscope examination indicated the minerals were amphiboles. Very fine grains were also scattered throughout the chert. The bluish minerals appear to be sodic amphiboles, probably crossite, and indicate probable sodic metasomatism. The nature of the association with the gold mineralization is unknown.

A “dacitic” volcaniclast also had elevated gold. Minor dolostone and ultramafics also occurred within this drill core.

**MAGMATIC VS. HYDROTHERMAL PROCESSES IN THE SOUTH FILSON
CREEK MINERALIZATION, SOUTH KAWISHIWI INTRUSION,
DULUTH, COMPLEX**

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The South Filson Creek (SFC) deposit (located in Sections 25 and 36, Township 62 North, Range 11 West) occurs above the basal units of the South Kawishiwi Intrusion (SKI), and represents a unique geological setting of Cu-Ni-PGE mineralization within the Duluth Complex (DC). It is located in an approximate stratigraphic high of 1000 m above the basal contact unlike all other known ore occurrences in the DC. Researchers have traditionally referred to this area as location of „structurally controlled” mineralization as signs of hydrothermal alteration has been described in previous papers (Kuhns et al. 1990, Severson & Hauck, 2003), however this attribute has to be revised in some points. The nature of hydrothermal processes overprinting the primary magmatic features and their significance in ore-genesis have been characterized in details during our current studies.

Extensive field mapping has revealed mineralization both in the Layered Series troctolites and in the Anorthositic Series in the SFC. Sulfides in the Layered series appear as disseminated fine-grained patches and pockets in an area of approx. ¼ square kilometer only. This type of mineralization was in the main focus of exploration so far. Pyrrhotite, chalcopyrite, pentlandite and cubanite are the main ore-forming sulfide minerals with subordinate amount of other copper-bearing sulfides, presumably secondary in origin (bornite, covellite, talnakhite). Sulfides form interstitial blobs between cumulus silicates, fine-grained disseminations and microscopic veinlets. At least 5 different platinum group minerals have been distinguished in the samples, associated both with magmatic sulfides and secondary hydrothermal alteration products. Highest metal values for this type of mineralization were 1.25 wt% Cu and 0.2 wt% Ni and 2.4 ppm Pd, 1.2 ppm Pt and 0.4 ppm Au. Brittle lineaments in the area do not affect the distribution of sulfides. The magmatic mineralization in the troctolites of the SFC area are similar to the „confined”- style of mineralization (Peterson 2001, 2002).

Mineralization in the Anorthositic Series is most likely hydrothermal in origin as its occurrence shows strong correlation to brittle structures and associated secondary alteration products. It shows only elevated copper-values (but still not as high as in Layered Series) up to 0.2 wt% Cu and some silver enrichment (up to 3 ppm Ag) but no PGE or Ni showings.

Based on petrographic work, three types of hydrothermal alteration were possible to distinguish in the SFC area:

- Alteration products of the first event can only be found in the Layered Series rocks. Serpentinization of olivine, chloritization of mafic minerals, albitization of plagioclase and several secondary sulfide minerals (bornite, covellite, talnakhite) are the product of this alteration event. Redistribution of PGEs have likely occurred due to the elevated Cl-content and salinity of the migrating fluids, however transportation of PGEs on bigger distances did not happen. Magmatic fluids containing high chlorine concentrations most likely were segregated from

- the crystallizing troctolitic melt, which process was documented in the F-enrichment and Cl-depletion trend of apatite in pegmatoidal samples and the presence of highly saline fluid inclusions in apatite.
- The second hydrothermal event can be observed both in the Layered Series and in the anorthosites and was most likely responsible for the formation of the mineralization in the Anorthositic Series rocks. Alteration products are chlorite, fibrous green amphiboles, sericite, prehnite, pumpellyite, carbonate and pyrite. Temperature of the fluids (based on chlorite thermometry and paragenesis) was between 250 and 350°C, pH was near neutral. The fluid was not capable of mobilizing precious metals.
 - The third event is marked by rusty joints throughout the whole area. The joints are filled with rusty, serpentine-like material but alteration is not extensive around them and they do not have any significance regarding mineralization.

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CHARACTERIZING THE DISCHARGE FEATURES OF GLACIAL LAKE AGASSIZ DURING THE POST-MARQUETTE PERIOD USING MARINE SEISMIC-REFLECTION METHODS

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Glacial Lake Agassiz was the largest of the North American glacial margin lakes. Over its 4,000 year existence, Lake Agassiz varied substantially in aerial extent and volume. This variability was a function of the fluctuating retreat pattern of the Laurentide Ice Sheet's southwestern margin, differential isostatic rebound of the North American crust, the topography of the land exposed by the retreating ice, and erosion of the various outlet channels draining the lake. These factors combined to form a history of Lake Agassiz punctuated by sudden and sometimes catastrophic rerouting of its drainage from one outlet channel to another (Teller, 2001). The amount and routing of Lake Agassiz discharge has become controversial. However, extensive onshore observations of Glacial Lake Agassiz discharge features have firmly established that northwestern Lake Superior was a major drainage route following the retreat of the Marquette glacial advance ca. 9,500 years 14C BP (Clark et al, 2001; Teller et al, 2002).

We describe a high-resolution single channel seismic reflection dataset collected with a small airgun that we acquired to test our hypothesis that this drainage event (corresponding to the Nipigon Phase of Lake Agassiz) left diagnostic stratigraphic and geomorphic signatures beneath Lake Superior. The unique bathymetry of northwestern Lake Superior, where water depth plunges off Nipigon and Black Bays, makes this location ideal for the identification and characterization of the Post-Marquette depositional features. The steep and sudden drop-off from the shallow water bays into the deep offshore waters of the lake would have caused the high-velocity floods to slow and drop much of the sediment they were carrying.

Our results confirm the existence of these sediment packages, which are now buried below a thin blanket of Holocene sediment. They form wedges of sediment that are thickest (some over 70 m thick) in the deep water area adjacent to the flood outlet. The apron of sediment thins lakeward and shore-parallel away from the outlet. The seismic character of the basal units of the apron, proximal to the outlet, is chaotic and only very weakly stratified suggesting that these deposits represent coarse sediment laid down during the initial stages of the flood when flow was presumably at its peak. These sediments are overlain and draped by a weakly stratified package that is more widely developed (extending lakeward beyond the bounds of our survey). We interpret this unit, which becomes more stratified and thinner lakeward, to represent the fine grained sediment associated with the latter stages of the flood when flow had eased.

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2009 Update: Leasing State of Michigan Lands for Metallic and Nonmetallic Minerals

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The Department of Natural Resources offers leasing programs for state-owned mineral lands for the exploration and development of oil and gas, underground gas storage and metallic and nonmetallic minerals.

2009 Information on State of Michigan Metallic and Nonmetallic Mineral Leasing Programs:

State Ownerships - Three major categories

Fee - own both surface and mineral rights (4.0 million acres)

Surface - own surface rights only (547,458 acres)

Minerals - own severed mineral rights only (2.3 million acres)

The state also owns 25 million acres of Great Lakes Bottomlands, which includes the mineral rights; however these are not open to exploration or development.

Leases for Metallic and Nonmetallic Minerals – There were 45,240 acres under 200 State Metallic Mineral Leases and 3,688 acres under 48 State Nonmetallic Minerals Leases at the end of FY 2008.

Leasing Process - Nominations – Sealed-bid Auctions - Direct Leases – Fees, other requirements:

Lands nominated for leasing are field reviewed by Department of Natural Resources (DNR) foresters, wildlife biologists and fisheries biologists. Input is requested from other specialists. Lands are classified in four categories: 1) Leaseable; 2) Leaseable with Restrictions, 3) Leaseable, nondevelopment, and 4) Nonleaseable. Public notice is given, public input is requested, and any private surface owners are notified. Before classified lands are leased, final approval must be received from the DNR, and two state approval boards. Performance bonds and insurances are required.

A mining permit and other permits, such as air quality, water discharge, and others, may be required by the Michigan Department of Environmental Quality (DEQ) and possibly other agencies prior to mining.

Metallic Mineral Leases - Exploration and potential development - for any metallic mineral commodity found. Nomination fee is \$300.00 for up to 640 acres within four contiguous sections. Lease terms are 10 years, with possible extension, or held while producing. The **Direct Lease** process is currently used.

Upon leasing - Bonus fee (one-time) \$3 per acre. Annual rental of \$3 per acre increases to \$6 on sixth year. (February 2009 rates, subject to revision) Approved exploration plans and surface use permits required for intrusive exploration. Approval to produce and approved mining and reclamation plan required. Production royalty rate is a percentage of selling price, by commodity as listed in the lease. Royalty may be renegotiated at a later date. See lease document on website for details.

Nonmetallic Mineral Leases -- May be nominated by state or individual, currently there is no nomination fee.

- A. Production of a known nonmetallic commodity from a known location.
 1. **Sealed Bid Lease Auction** - Usually on commodity-specific lease document. Fixed Annual Minimum Royalty. Bid on Royalty Rate per ton, subject to revision every three years based on U.S. Producers Price Index changes. Lease time terms vary, subject to possible extension.
 2. **Direct Leases** ---
 - a. To County Road Commissions for sand and gravel from known locations at fixed CRC Royalty Rates, subject to revision every 3 years based on U.S. Producers Price Index
 - b. To adjacent operations or private surface owners, in some cases. Commodity, Royalty rate and other terms negotiated.
- B. Exploration and potential development for any nonmetallic mineral commodity found, nominations may be for up to 640 acres within four contiguous sections.

Sealed Bid Lease Auction --- Bid on the one-time Bonus rate per acre. Royalty rate fixed

by percentage of selling price of commodity(s) produced, as listed in the Lease. Rate percentage may be renegotiated at a later date.

C. Specific Commodity Exploration Lease ..Will vary with item.

A lease for **Potash** is currently being developed and a sealed bid lease sale is expected to be held in late spring/early summer, 2009

Note --Leases may also require various Surface Use Permits and Fees. Any Intrusive Exploration Activities require an approved Exploration Plan. Various State, local and Federal regulations may apply.

Website Information - Go to the DNR Website --- www.michigan.gov/dnr

Choose Doing Business with DNR - (on Left side)

Open and scroll down to Minerals and open

Metallic Minerals (M.M.) – Information, Procedure (policy), Rules, M.M. Lease Document.

http://www.michigan.gov/dnr/0,1607,7-153-10368_11800_46635---,00.html

Nonmetallic Minerals (N.M.) – Information, Procedure (policy), Rules,

General N.M. Lease Document, Sand & Gravel Lease Document.

http://www.michigan.gov/dnr/0,1607,7-153-10368_11800_46635---,00.html

Choose Publications & Maps (on Left side), Choose On-line Maps ---open and view

http://www.michigan.gov/dnr/0,1607,7-153-10371_14793---,00.html

Land & Mineral Ownership (Shown as entire 40 acre blocks, number in upper right corner indicates how much land State owns and what type (surface, mineral, surface & mineral, mix.)

http://www.michigan.gov/dnr/1,1607,7-153-10371_14793-31345--,00.html

Mineral Leases (Left County List – County map with Lease numbers. Right County List -

List of Lease numbers and Lessee names for the County).

http://www.michigan.gov/dnr/1,1607,7-153-10371_14793-30992--,00.html

Questions? Wish to discuss our Mineral Leasing programs? Contact us:

Michigan DNR-- Forest, Mineral and Fire Management -- Mineral and Land Management Section,

P.O. Box 30452, Lansing, MI, U.S.A., 48909-7952 Phone: 517-373-7663 Fax: 517-373-2443

Milt Gere, Geologist ... Phone: 517-335-3249 E-mail: gerem@michigan.gov

Tom Hoane, Geologist ... Phone: 517-241-3769 E-mail: hoanet@michigan.gov

More info. ... For additional information about Michigan's minerals, geology, Geological Sample and Drill Core Repository and required permits related to mining, etc. ... Contact:

Michigan Department of Environmental Quality, Office of Geological Survey.

Lansing, MI: 517- 241-1515 Gwinn, MI: 906-346-8300

Website – www.michigan.gov/deq or www.michigan.gov/deqogs Choose Land (on Left side), Choose Geology in Michigan, Geological Mapping, or Gas, Oil, and Minerals, etc. (on Left side).

A Public Benefit from the leasing and production of state-owned oil & gas and minerals ---

Most monies collected in State of Michigan Mineral Lease fees, rentals and royalties go to the Michigan Natural Resources Trust Fund (MNRTF) or the Fish and Game Fund, dependent upon origin of the State land ownership, about a 90/10 split. Local and State governmental units may apply to the MNRTF for grants for the purchase and development of public recreational properties. In Fiscal Year 2008, the State's income from the leasing and production of state-owned minerals and oil and gas was approximately \$104 million. About 90 percent, nearly \$94 million was placed into the MNRTF.

“Explore Michigan's Minerals”

BIRD RIVER BELT IN SOUTHEASTERN MANITOBA – A NEOARCHEAN VOLCANIC ARC IN THE WESTERN SUPERIOR PROVINCE

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The Neoarchean Bird River Belt (BRB) in southeastern Manitoba is currently the focus of geological and geochemical investigations that have led to a revised interpretation of its tectonic setting and geological history. The BRB is part of a 150 km long, east-trending supracrustal belt that extends from Manitoba eastwards as far as Separation Lake in Ontario. It is located in the Bird River Subprovince within the southwestern Superior Province and occurs in a transitional oceanic–continental-margin setting between flanking older cratonic blocks — the 3.0-2.87 Ga North Caribou Superterrane to the north and the 3.4-2.8 Ga Winnipeg River Subprovince to the south (Percival et al., 2006). The predominant 2.724 Ga arc-type volcanic rocks of the BRB are compositionally and stratigraphically distinct from flanking, mid-ocean-ridge basalt (MORB)–type basaltic sequences that are probably relatively older than the arc-type rocks and may be associated with early arc rifting in a back-arc setting (Gilbert et al., 2008). The MORB and arc-type volcanism together spanned at least 20 Ma; a mafic-ultramafic intrusion in the north part of the belt (2.745 Ga Bird River Sill) postdates the MORB-type volcanism but was emplaced prior to the arc-type volcanism. The arc-type volcanic rocks are divided into ‘north’ and ‘south’ structural panels that are each characterized by geochemically and stratigraphically distinct volcano-sedimentary sequences. The north panel rocks are akin to modern subduction-related rocks at active continental margins, whereas the sequence in the south panel documents incipient rifting in an extensional tectonic regime. Subsequent to arc volcanism, orogenic sedimentation (2.71–2.70 Ga) resulted in the deposition of turbidites (Booster Lake Formation) and fluvial-alluvial deposits (Flanders Lake Formation). Detrital zircon data indicate these orogenic sedimentary rocks may be stratigraphically equivalent to epiclastic rocks and metamorphic derivatives in the English River Subprovince, northeast of the BRB.

Base-metal mineralization prospects in the BRB include both magmatic types and stratigraphically associated occurrences of probable hydrothermal origin (Gilbert, 2008). The Bird River Sill hosts base-metal and platinum-group-element (PGE) mineralization; elsewhere, base-metal mineralization commonly occurs at lithological contacts within the volcano-sedimentary sequences. The BRB also contains the TANCO mine at Bernic Lake, wholly owned by the Cabot Corporation. The mine produces Ta, Li and Cs from pegmatite and accounts for approximately 80% of global reserves of Cs.

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GEOCHEMISTRY AND PETROLOGY OF GUNFLINT IRON FORMATION, GUNFLINT TRAIL, MINNESOTA

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Near the NW shore of Lake Superior, along the Minnesota-Ontario boarder, the Gunflint Trail provides access to Paleoproterozoic sedimentary rocks of the Animikie Group (ca. 1870-1830 Ma; Fralick et al., 2002), including the Gunflint Iron Formation. Animikie Group rocks crop out along a NE-SW-trending outcrop belt that extends approximately 175 km from ThunderBay, Ontario, where the unit is unmetamorphosed, to ~19 km west of the Gunflint Trail in northern Minnesota, where it is truncated by the Mesoproterozoic Duluth Complex. Metamorphic grade increases to upper amphibolite facies (Floran and Papike, 1978; Jisra and Weiblen, 2007). Although focusing research on metamorphosed Gunflint banded iron formation (BIF) might seem unusual from a sedimentological perspective when unmetamorphosed equivalents exist, many Archean BIFs the world over are highly metamorphosed, making an examination of the Gunflint Formation in a locale that has been metamorphosed very appropriate for making comparisons between BIFs of varying age.

An ~ 8 m section of BIF from the lower slaty unit of the Lower Gunflint Formation was measured and samples representative of all the major lithologies were collected and facies logged. At field scale, the main lithologies include finely banded magnetite-quartz BIF and coarsely banded magnetite-quartz BIF, with less common centimeter-scale chert-dominated layers containing rip-up clasts of magnetite-rich layers. In thin section, samples range between Fe-silicate and oxide facies BIF, and contain varying amounts of quartz, magnetite, and amphibole. When quartz is present, it is as equant grains with 120° interlocking grain boundaries, which suggests recrystallization, and range in size from ~50 μm to 500 μm . If magnetite is present, it is typically anhedral, ranges in size from ~ 10 μm to 200 μm , and occurs either as disseminated grains between quartz or amphibole grains or as distinct bands. Amphiboles are found in all samples and typically occur as a clotted mass of fine (< 50 μm) equant grains or needles with a few larger (~ 200 μm) grains also present. Similar to the magnetite, the amphiboles occur either as disseminated grains and needles in-between quartz and magnetite grains, or as distinct layers. Some samples also contain trace amounts of very small (5-10 μm) grains of apatite.

Samples from the measured stratigraphic section were also analyzed for bulk major-, trace- and rare earth element geochemistry. The major element chemistry of the Gunflint BIF is typical of other BIFs and is dominated by SiO_2 (~ 36 to 82 wt%) and $\text{Fe}_2\text{O}_3(\text{T})$ (~ 16 to 57 wt%), with much lesser amounts of CaO (~ 0.6 to 3.0 wt%), MgO (~ 0.5 to 5 wt%), MnO (~ 0.1 to 0.5 wt%), Al_2O_3 (~0.3 to 1.7 wt%), Na_2O (~ 0.1 to 0.2 wt%), K_2O (~ 0.1 to 0.3 wt%), and P_2O_5 (~0.1 wt%). Although no evidence for clastic contamination was observed in outcrop or thin section scale, the geochemistry indicates slightly elevated abundances, relative to other very pure chemical sediments, of trace elements typically related to clastic detritus, such as Sc (1 to 3 ppm), Th (0.19 to 1.03 ppm), Hf (0.1 to 0.7 ppm), Zr (3 to 27 ppm), and Rb (1 to 35 ppm). Other evidence for aluminosilicate contamination is the lower $\text{Fe}_2\text{O}_3/\text{Pr}$ ratios (30 to 76) relative to pure BIF (130 to 317) (Bau and Dulski, 1996).

It has been suggested that Precambrian BIFs free from clastic contamination display a similar REE signature, regardless of provenance, age, and metamorphic grade: HREE enrichment, positive La_{SN} , Eu_{SN} , Gd_{SN} , and Y_{SN} anomalies, negative Ce_{SN} anomaly, $(\text{La}/\text{Sm})_{\text{CN}} > 1$, $(\text{Sm}/\text{Yb})_{\text{SN}} < 1$, and $(\text{Eu}/\text{Sm})_{\text{SN}} > 1$ (Bau and Dulski, 1996; Bolhar et al., 2004). The PAAS-normalized REE + Y (REY_{SN}) plots of preliminary metamorphosed Gunflint samples show

positive Ce, Eu, and Y anomalies (~ 1.1 , 1.5 and 33, respectively) with an overall background slope that reflects depletion of the light REE and enrichment of heavy REE (Figure 1). Typically, seawater, and thus BIF, has a strong negative Ce anomaly, however the composition of chemical sediments also reflects the local redox conditions and is strongly influenced by post-depositional changes, which suggests that the Ce anomalies in these samples may not be primary (Derry and Jacobsen, 1990; Rollinson, 1993). The Eu anomalies are only weakly positive, ranging from 1.3-1.7, suggesting only minor hydrothermal input into the depositional basin (Klein, 2005). This is not unexpected as the size of the positive Eu_{SN} anomaly becomes smaller with decreasing age of deposition (Derry and Jacobsen, 1990; Bau and Dulski, 1996). Only one sample has a positive La_{SN} anomaly (1.01), with the others being only slightly negative (~ 0.8), and none of the samples have a positive Gd_{SN} anomaly (range from 0.03 to 0.25). Other BIF “fingerprints” are found in the amphibolite-grade Gunflint samples analyzed here, with $(\text{La}/\text{Sm})_{\text{CN}}$ values ranging from ~ 2.7 to 3.5, $(\text{Sm}/\text{Yb})_{\text{SN}}$ values ranging from ~ 0.7 to 1.1, and $(\text{Eu}/\text{Sm})_{\text{SN}}$ values ranging from ~ 1.4 to 1.9. The one exception is the sample that has a $(\text{Sm}/\text{Yb})_{\text{SN}}$ value slightly greater than 1 (1.14). In conclusion, preliminary analyses of metamorphosed Gunflint BIF geochemistry suggests that BIFs are capable of retaining near original compositions through diagenesis and metamorphism. This coincides with the findings of Frost et al., (2007) which found that Fe isotope heterogeneities in BIF are preserved during diagenesis and metamorphism. However, some of the traditional signatures used to fingerprint BIF, such as a negative Ce anomaly, require further investigation to test their veracity.

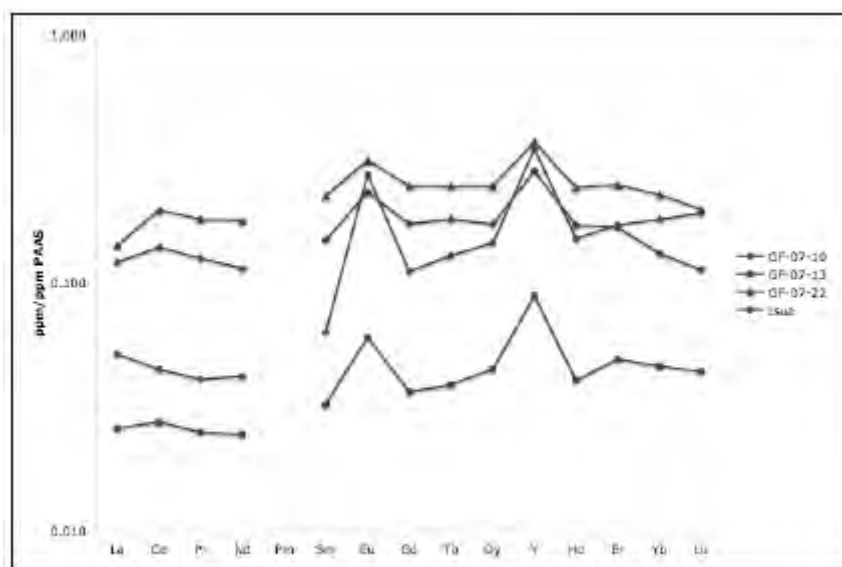


Figure 1. PAAS-normalized REE + Y diagram comparing compositions from three preliminary samples collected from the amphibolite grade Gunflint Iron Formation, along the Gunflint Trail, Minnesota with BIF from amphibolite grade Isua BIF. Note positive Ce, Eu, and Y anomalies in the Gunflint samples.

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TITANITE, PSEUDORUTILE, AND REE-MINERALS IN THE ALLOUEZ CONGLOMERATE, KEWEENAW PENINSULA, MICHIGAN

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The Allouez Conglomerate is an interflow sedimentary unit in the Portage Lake Volcanic Series that has undergone low grade metamorphism, copper mineralization and supergene alteration (Bornhorst, T.J., personal communication, 2008). Mineral associations and textures in 6 samples were investigated with the JEOL LV-4500 scanning electron microscope in the Department of Geophysical Sciences, University of Chicago and selected minerals were analyzed with the CAMECA SX-100 electron microprobe at the GeoForschungsZentrum, Potsdam. Titanite occurs in lamellae within oxide grains, in composite grains with hematite and/or magnetite (Fig.1), and in small independent grains in epidote-rich domains. It is frequently associated with a Ti-Fe oxide with an average Fe/Ti ratio of 2/3 (Fig. 2) and electron microprobe totals of ~ 93%. This appears to be the oxihydroxide pseudorutile that commonly forms as an intermediate product, together with rutile or anatase, during weathering or diagenetic alteration of ilmenite (Schroeder et al., 2004). In the Allouez Conglomerate pseudorutile occurs in three different associations: 1. pseudorutile + titanite + TiO₂, 2. pseudorutile + titanite and 3. pseudorutile + TiO₂. These mineral associations are most easily explained by a model in which ilmenite is first altered to pseudorutile + TiO₂ followed by the formation of titanite by the reaction: $\text{TiO}_2 + \text{CaCO}_3 + \text{SiO}_2 \rightarrow \text{CaTiSiO}_5 + \text{CO}_2$. Calculations done with the Perple_X program suggest an upper limit of 0.015 – 0.002 for x_{CO_2} in the fluid phase during the formation of titanite at temperatures of 240 – 320 °C and inferred pressures of 150 MPa (Livnat et al. 1983) during metamorphism of epidote-bearing assemblages in the Portage Lake Series. Pure CaTiSiO₅ – Fe oxide assemblages in very low-grade rocks require relatively CO₂-poor, oxidizing conditions. Low-grade titanite also frequently contains significant amounts of CaAlSiO₄(OH) (Enami et al., 1993) which may increase its stability. Aluminum concentrations in titanite from the Allouez conglomerate range from near 0 to 30% of the Ti site (Fig. 3). The wide range in Al values indicates disequilibrium. There is a strong correlation between Al and F concentrations and stoichiometry (Fig. 3), indicates that between 50 and 100% of the Al takes the form of a CaAlSiO₄F component. This suggests the presence of F in the metamorphic fluid phase. In medium to high-grade rocks titanite, together with allanite, can play an important role in the REE and Th budget. However both REE and Th were below electron microprobe detection limits in titanite from the Allouez conglomerate. Bright rims and patches evident on epidote grains in BSE images (Fig. 4) indicate an enrichment in LREE elements relatively late in the growth of the epidote. While cores of epidote grains generally contain no detectable LREE bright rims range up to 0.22 REE per 8 cations (Fig.5): close to the boundary between REE-rich epidote and allanite. The other major host for REE elements appears to be synchysite ((REE)CaF(CO₃)₂) which occurs as acicular crystals associated with calcite in veins and amygdulites.

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FIGURES

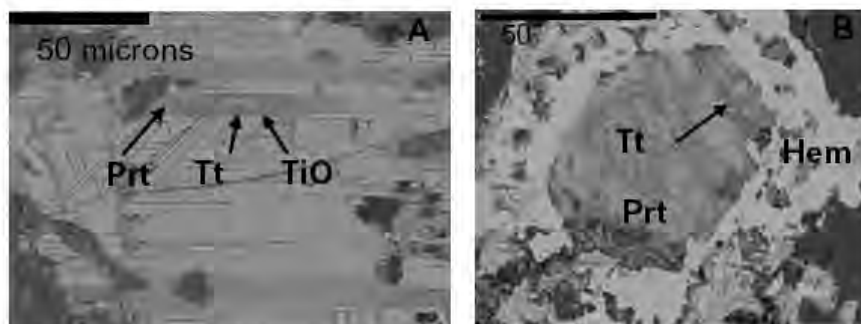


Figure 1. BSE SEM images. A. Pseudorutile (Prt), titanite (Tt) and TiO₂ in lamellae inside magnetite. B. Pseudorutile and titanite intergrowth surrounded by hematite.

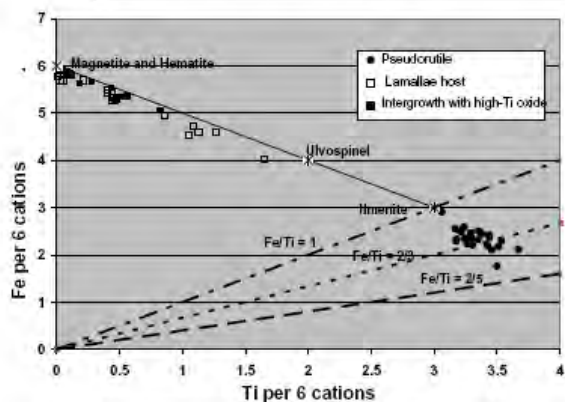


Figure 2: EMP oxide analyses.

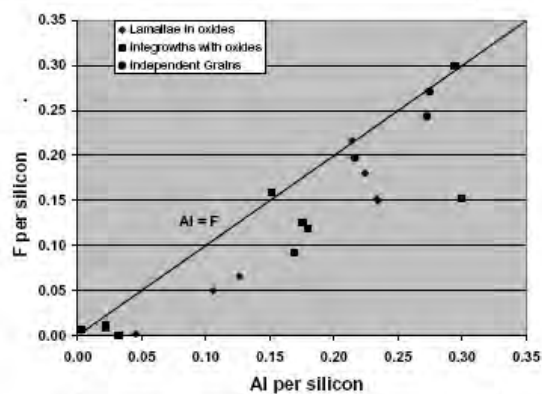


Figure 3: EMP titanite analyses



Figure 4. BSE-SEM image of epidote showing bright REE-enriched rims.

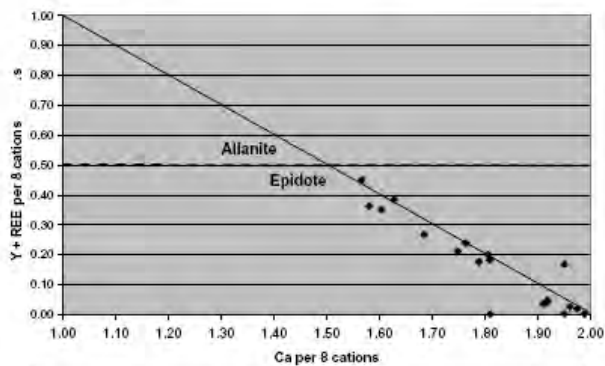


Figure 5: EMP epidote analyses

A FOLLOW-UP GLACIAL TILL INDICATOR MINERAL SURVEY IN MINNESOTA: WHAT DOES IT INDICATE ABOUT EXPLORATION FOR DIAMONDS AND OTHER MINERAL DEPOSITS?

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Why should there be diamondiferous kimberlites in Minnesota? Minnesota has the following attributes that meet the requirements to host diamondiferous kimberlites; 1) an Archean-aged Superior Craton root that underlies 2/3s of MN, including a 3.2-3.8b.y cratonic fragment in SW MN that is required to produce diamonds (Helmstaedt, 2006), and diamondiferous kimberlites that have been found elsewhere within the Superior Craton in Ontario and Michigan; 2) major crustal structures cross-cut MN's cratonic root, e.g., Vermilion Fault Zone, Great Lakes Tectonic Zone, Quetico Fault, etc., which are excellent kimberlite exploration areas; 3) Kenora-Kabetogama and Keweenaw dike swarms that intersect these and other structures and could have provided pathways for kimberlite emplacement, e.g., kimberlites found in the Kyle Lake and Attawapiskat kimberlite clusters in N. ONT.; 4) an Archean terrain with calc-alkaline

lamprophyres and ultramafic volcanics that are time-equivalent with the Michipicoten greenstone belt, i.e., Wawa area, in ONT that has diamondiferous calc-alkaline lamprophyres/volcanics associated with diamondiferous heterolithic breccias and conglomerates. A diamondiferous ultramafic pyroclastic unit (Grassy Ultramafic Pyroclastic, MetalCORP Ltd.) occurs just north of the Minnesota border in Ontario (Ont. Geol. Survey, 2008).

Since 2004, samples from the B- or C-horizon soils of various glacial tills throughout MN were collected for indicator minerals and/or related geochemistry, including pristine (1,189gr.), modified (321gr.), and reshaped (1,606gr.) gold grains (Heine et al., 2008). The six indicator mineral and geochemical sampling campaigns included: 1) one statewide C-horizon survey (WMC-MGS; Thorleifson et al., 2007); 2) two regional C-horizon surveys (NRRI-MGS, 2006-2007, in prep.; Heine et al., 2008, 2009); 3) two local B-horizon surveys (MnDNR; Dahl, 2005; Elsenheimer, 2006, respectively); and 4) Larsen (2004) reported on the -63μ geochemistry from C-horizon tills in the western Vermilion District in NE MN. Also, Martin (1995) reported on a select number of kimberlitic indicator minerals in MN, and additional till geochemistry on buried tills (Martin et al., 1988, 1989, 1991).

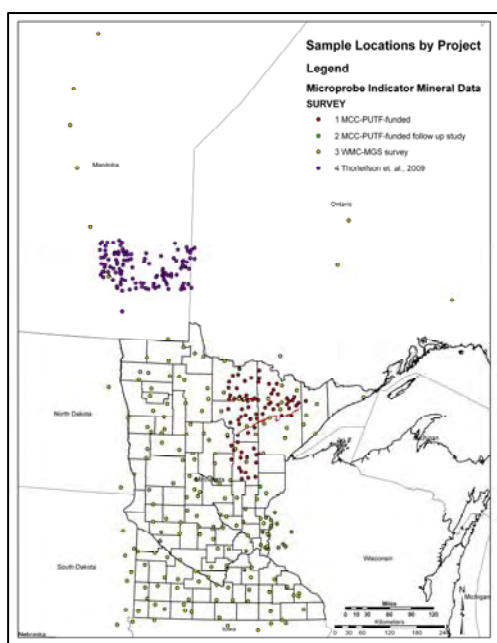


Figure 1. Location of various indicator mineral surveys.

As a follow-up to the 2004 WMC-MGS glacial till sampling program (30 km spacing) in MN, a jointly funded Minerals Coordinating Committee (MCC) and Permanent University Trust Fund (PUTF) project collected glacial till samples on a 10 km spacing in NE and E-central MN. The WMC-MGS survey found carbonate clasts and carbonate matrix material throughout most of the State, except in the area of the MCC-PUTF-funded survey (Fig. 1). This thin drift area was deemed an area where closer spacing would be required in this heterogeneous area. The WMC-MGS survey collected 270 till samples, and the follow-up survey collected 79 samples. A 3rd survey collected 42 older till samples. The rationale for this survey was based upon a number of Cr-pyroxene samples located during the initial WMC-MGS survey (Fig. 2). These samples were collected from rotosonic drill core in older glacial tills and exposures of Superior tills. Much of the previous sampling was in Des Moines tills. Also, unanalyzed indicator minerals from a previous Manitoba survey were analyzed using PUTF funds to understand the provenance of the G2, G7, G9, and G11 garnets found in southern MN (Figs. 1, 2; Thorleifson et al., 2009) and Mg-chromites and Mg-ilmenites found near MN northern border (Fig. 2). Data from the Manitoba Geological Survey indicator database will be combined with these data to better understand the provenance of MN Des Moines till samples.

The data from these surveys indicate: 1) there is an anomalous gold, plus As, zone south of the Vermilion Fault in NE MN; 2) an anomalous area west of the basal contact of the Duluth Complex that extends into the Western Vermilion District, and is anomalous in Au, As, Ag, Pt, Pd, Cu, Co, Ni, chromite, gahnite, etc. (Fig. 2); 3) several concentrations of Cr-diopsides in the 1st survey and 2nd survey that may relate to older tills; 4) the anomalous garnets in the 1st survey area are probably related to: a) reworked older till in MN; or b) they were transported from Manitoba; and 5) a combination of Mn-epidotes, gahnites, corundum, tourmalines, , and geochemical Cu,

Co, and Ag anomalies in the old tills suggest a relationship the Wisconsin VMS belt and/or its MN extension.

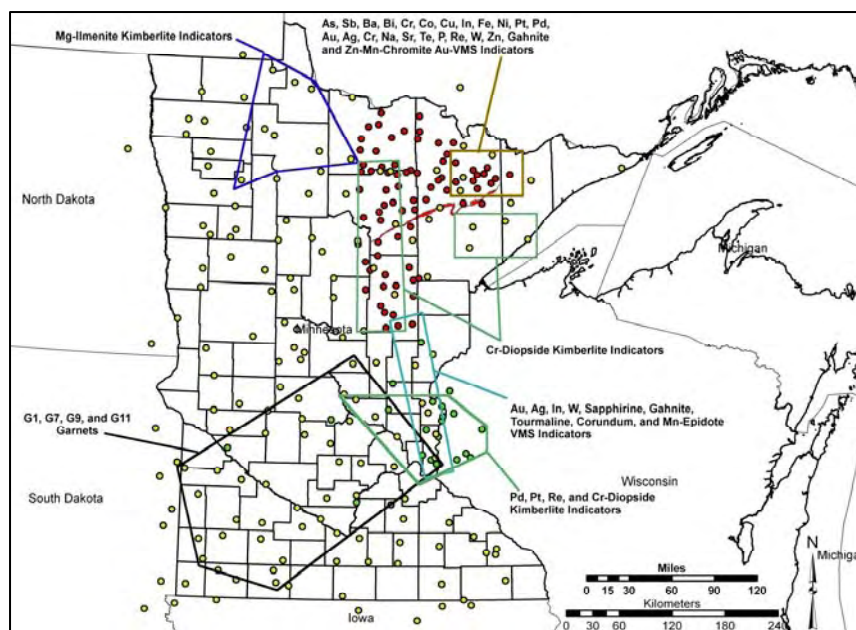


Figure 2. Results of indicator mineral and geochemistry surveys in MN.

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Developing a 21st Century Geoscience Major: Melding the Old with the New

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Many Geology Programs are facing uncertain futures due to budgetary constraints and poor communication of the role Geoscientists play in our world. According to the U.S. Bureau of Labor (<http://www.bls.gov/oco/ocos288.htm>), Geoscience—which incorporates fields such as geology, geography, biology, chemistry, physics, climatology and oceanography—is anticipating over 20% job growth during the next 15 years as existing workers retire, and energy and water resource needs expand. In response to this need, the University of Wisconsin-Stevens Point (UWSP) Department of Geography and Geology recently received a \$1.7 million dollar grant to develop a GIS (Geographic Information Systems) Center for geospatial studies. This GIS Center will provide a means for undergraduate students to apply GIS, remote sensing, and other geospatial techniques to address local, regional, and global issues. UWSP's Department of Geography & Geology has also implemented a new Geoscience Major for the Spring 2009 semester. Our goal is to retain fundamental elements of traditional geology programs and to incorporate high-technology geospatial skills applicable to the 21st Century workforce. Fundamental geology courses in physical geology, Earth history, Earth materials, structural geology, and sedimentary geology are coupled with remote sensing, GIS, environmental, and hydrogeology course offerings. Perhaps most important of all is a 3-credit field component within the U.S.A. that represents the keystone experience for Geoscience majors. Field research is a key training element for geoscientists, and is essential for understanding Earth processes. With respect to pedagogical developments, we present the recently-published Physical Geography Laboratory Manual (Lemke, Ritter and Heywood, 2008) and the imminent Earth Materials textbook (Hefferan and O'Brian 2010). Both texts expose students to the question, “*What does contemporary society need, and expect, from Geoscientists?*” We believe the new UWSP Major encompasses three critical elements to a contemporary undergraduate Geoscience Program: 1) fundamental Geoscience courses coupled with computer-based instruction; 2) active field experience; and 3) pedagogical innovations that reflect and adapt to the evolving field of Geoscience. Communication between the general public, industry and scientists are critical for successful Geoscience programs. At this interactive poster, we would appreciate a lively dialogue with other Geoscience faculty, students and professionals to learn of their approaches to future needs and demands.

This is a Poster Presentation by Two UWSP Faculty Members

DETAILED PETROGRAPHIC ANALYSIS OF ANTHRAXOLITE MORPHOLOGY IN THE BIWABIK IRON- FORMATION, NORTHERN MINNESOTA

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Anthraxolite is a pyrobitumin composed of ~95% carbon (Morey 1994). It is widely believed to be the product of metamorphosed petroleum having had nearly all of its volatiles driven off. In the Biwabik Iron-Formation in northern Minnesota, anthraxolite has been found in a variety of locations but is generally constrained between the Intermediate Slate and the stromatolite layers of the Lower Cherty member (Morey 1994). This has led some to believe that the anthraxolite was sourced from the overlying Intermediate Slate, interpreted as a carbon-rich ash layer. The goal of this research is to study the morphology of anthraxolite at varying depths to provide a clearer explanation and understanding of the pattern of migration. This is accomplished by analyzing thin-sections at varying depth from core.

The anthraxolite in core MGS-5 is located from 947'-995' (Severson 2005) and is found between the Intermediate Slate and the Lower Cherty stromatolites, consistent with Morey's (1994) observations. Five thin sections were made from several depths in order to better understand the events leading to the present distribution and morphology of the anthraxolite: 950', where thin sections were made parallel and perpendicular to bedding; 963', 988.5' and 995' where thin sections were made perpendicular to bedding. At 950', the anthraxolite ranges from 69-235 μm across (averaging 110 μm), is almost exclusively in the carbonate veins, and fills the void space between crystals. The anthraxolite is also found as rounded blebs when viewed parallel to bedding, with both concave and convex surfaces. Where it is found outside of the vein fill, the blebs range from 7-67 μm with an average diameter of 20 μm . These fragments are highly fractured and appear to be cutting the cherty matrix. At 963' the anthraxolite is in chert, between and overprinting 97-345 μm diameter grains of calcite. Here, the crescent-shaped blebs open in the upward direction with the up-side fractured and the down-side cutting across older minerals. The crescents range in size from 268-843 μm in diameter and are spherical to crescent-shaped. The anthraxolite is also found in both cherty matrix and carbonate veins as spherical blebs.

This distribution and morphology suggest movement as a liquid. Anthraxolite is also found as irregularly fractured grains suggesting movement after solidification. The cross-cutting relationships associated with the anthraxolite in the Biwabik Iron- Formation is evidence of a complex history leading to its present location and morphology. There is, however, very little evidence of the original source of the anthraxolite despite previous hypotheses.

Proposed future work includes analyzing pure anthraxolite samples that have already been isolated, using catalytic hydrolysis (HyPy) to drive off volatiles not removed during the solvent extraction. HyPy allows for more product to be analyzed by gas chromatography mass spectrometry (GC-MS) without damaging the larger organic ring structures (Marshall et al. 2007). The HyPy analysis should allow better identification of possible biomarkers and will significantly aid in the determination of a source.

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MESOPROTEROZOIC MIDCONTINENT RIFT-RELATED MAFIC INTRUSIONS IN NORTHWESTERN ONTARIO: CONTINUING GEOCHEMICAL, PALEOMAGNETIC, PETROGRAPHIC AND GEOCHRONOLOGIC STUDIES

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During the summer of 2008 a detailed sampling program of the Midcontinent Rift-related intrusions was initiated around Thunder Bay. This sampling built upon previous work undertaken between 1999 and 2007 by M. Smyk and/or P. Hollings (Hollings et al, 2007a; Hollings and Smyk 2008) who collected and analyzed over 100 samples. Over 150 additional samples were collected during the 2008 field season for geochemistry, petrography, geochronology, radiogenic isotopes and paleomagnetism studies.

The whole rock geochemistry of the gabbroic sills to the south of Thunder Bay supports earlier observations by Hollings and Smyk (2008) that Logan-type sills predominate in this area, with the exception of the recently recognised Riverdale sill. Logan sills are typically composed of sub-ophitic gabbro and are distinguished geochemically by elevated Gd/Yb_n (ca. 2.0 to 2.7) and La/Sm_n (2.0 to 2.5), as well as elevated TiO_2 (ca. 3.0 to 4.5) as compared to Nipigon sills (Hollings et al. 2007b). Gabbro dykes containing anorthositic gabbro blocks crosscut Logan sills but share a similar rare earth chemistry. In contrast, the majority of the dykes analysed are geochemically comparable to the Nipigon sills suggesting that they do not represent feeders for the Logan sill complexes. However, limited data suggest that there is no significant geochemical difference between the Pigeon River, Cloud River and Mt. Mollie dyke suites, despite their different orientations and reported ages. Preliminary results suggest the presence of two other distinct dyke suites: one north-trending suite which intruded Rove Formation rocks southwest of Thunder Bay and a west-northwest-trending suite sampled on the Sibley Peninsula which intruded Sibley Group sedimentary rocks.

Samples for paleomagnetic study were collected at four sites (Smyk et al. 2008).

- 1) The Riverdale sill and a geochemically distinct dyke which intruded both sill and Rove Formation sedimentary rocks exhibit reversed magnetic polarity. Directions obtained from the sill and the dyke are indistinguishable.
- 2) A 40 m wide, northeast-trending Pigeon River dyke near Arrow River (1078 ± 3 Ma; Heaman et al. 2007) yielded a normal polarity.
- 3) An 85 m wide, northeast-trending Pigeon River dyke (Rita Bolduc locality; 1141 ± 20 Ma, Heaman et al. 2007). Like the dyke near Arrow River, this dyke also exhibits normal magnetic polarity. Site directions in these two Pigeon River dykes are not significantly different at the 95% confidence level.
- 4) A 100 m wide, northwest-trending Cloud River dyke in Crooks Township yielded a reversed polarity.

Samples were also collected for geochronologic study. Samples taken from the Riverdale sill yielded no dateable material and baddeleyite ages for the Cloud River dyke are pending. Preliminary data from baddeleyite from the Mt. Mollie dyke indicate an age of 1109.3 ± 6.3 Ma. This is older than the age of 1099.6 ± 1.2 Ma (Heaman et al. 2007) that has been reported for the Crystal Lake gabbro with which the Mt Mollie dyke has been traditionally associated (Smith and Sutcliffe 1987). Additional geochronologic and radiogenic isotope data are pending.

An enigmatic volcanic unit mapped by Tanton (1936) in central Devon Township was also sampled in 2008. Initially mapped as Rove Formation basalt, the unit consists of massive to columnar-jointed basaltic andesite flows and perhaps subvolcanic sills amongst Rove Formation clastic sedimentary rocks. Flows exhibit vesicular and amygdaloidal textures and locally have ropy tops. Although the rare earth element geochemistry of this volcanic unit is similar to that of the Riverdale sill, its magnesium content is lower. The remarkably coherent rare earth element geochemistry of this volcanic unit has been used to discriminate it from nearby Logan sills.

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PRELIMINARY RESULTS OF $^{40}\text{Ar}/^{39}\text{Ar}$ THERMOCHRONOLOGY FROM THE CENTRAL YAVAPAI PROVINCE, U.S. MIDCONTINENT

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Much is known about the Precambrian U.S. tectonic and crustal evolution in regions where bedrock is exposed for direct observation (i.e. Rocky Mountains, Lake Superior region; Karlstrom & Keller, 2005; Holm et al., 2007). However, Phanerozoic sedimentary cover overlying the central Yavapai Province (YP), between the Rockies and the Great Lakes, limits our knowledge of that important region. Ar-Ar thermochronology from the upper Great Lakes region and western U.S. has proven critical for assessing Proterozoic tectono-metamorphic overprinting and cooling during and following growth and stabilization of southern Laurentia. Here we present the first results of Ar/Ar thermochronology on Paleoproterozoic basement drill core rocks in easternmost Colorado, Nebraska, and southern South Dakota (see figure).

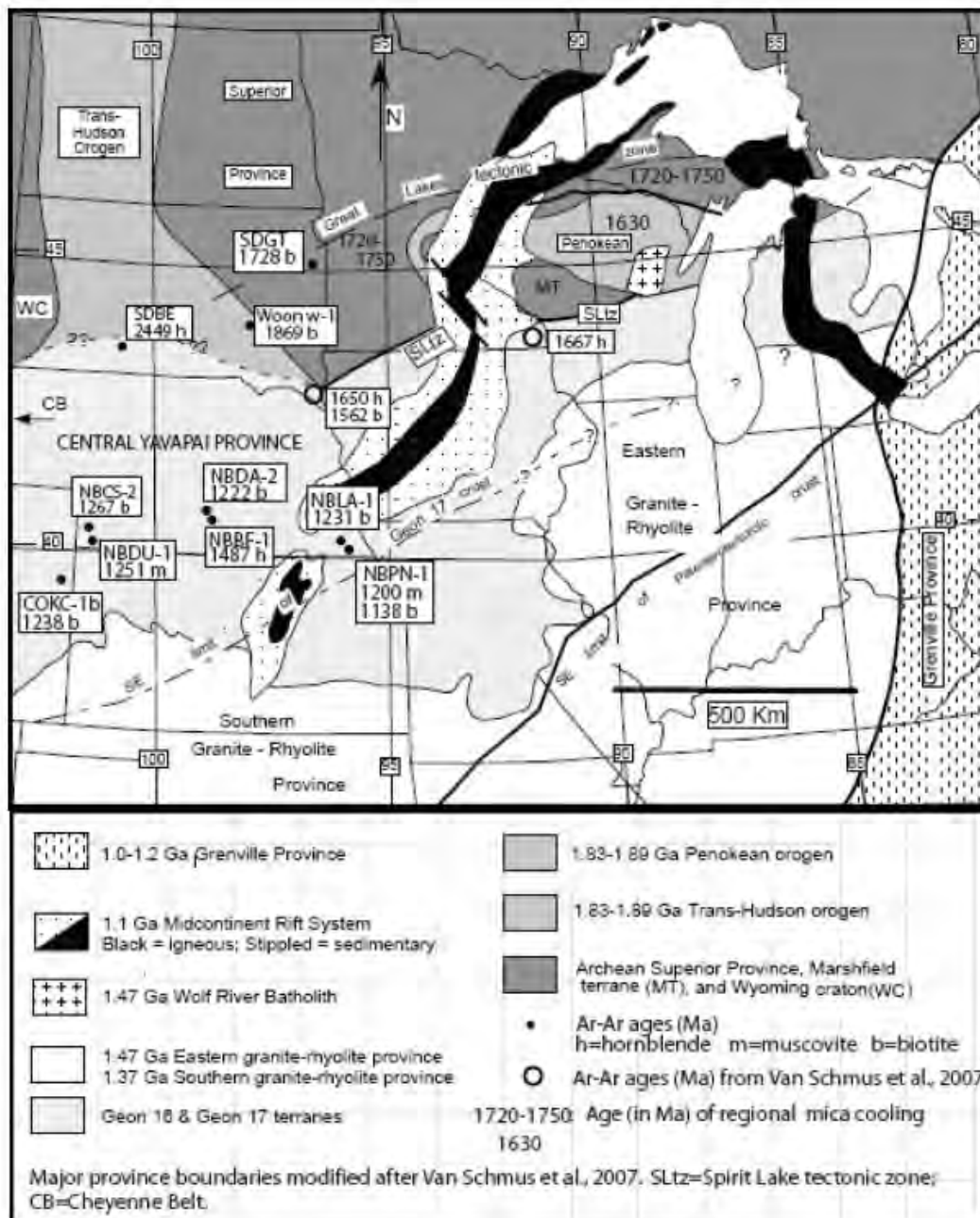
South Dakota. Hornblende from medium grained metabasalt in south central SD (SDBE) yields a complicated age spectra with a total gas age of 2268 Ma and a preferred age of 2449 Ma from selected steps constituting 31% of the gas released. Further east, a garnet rich gneiss (Woon W-1) yields a biotite plateau age of 1869 Ma (7 steps; 86% of total gas released). In easternmost SD, biotite from a granite gneiss (SDGT) yielded a plateau age of 1728 Ma (5 increments; 59% of total gas released).

Southern Nebraska. Muscovite from a granite (NBDU) yields a plateau age of 1251 Ma (12 steps; 70% of the gas released). Farther north, biotite from a granite gneiss (NBCS-2) yields a plateau age of 1267 Ma (5 increments; 51% of the gas released). In the central region of southern NE, hornblende from a sheared tonalite (NBBF-1) yields a complicated age spectra with a total gas age of 1468 Ma and a preferred age of 1487 Ma from a large step constituting 36% of the total gas released. Nearby, biotite from a granite gneiss (NBDA-2) yields a plateau age 1222 Ma (6 increments; 75% of the total gas). In the southeast corner of NB, both biotite and muscovite from a granite (NBPB-1) were analyzed. The biotite yielded a slight saddle-shaped spectra, indicating possible excess argon, with a total gas age of 1138 Ma; muscovite yielded a plateau age of 1200 Ma (11 increments; 69% of the gas released). Slightly northeast of this locale, biotite from a granite yields a complex spectra and a total gas age of 1231 Ma.

Eastern Colorado. Biotite from a deformed gabbro in Kit Carson Co. yielded a plateau age of 1238 Ma (7 increments; 85% of the total gas).

In the north, the 1.86 Ga biotite age is consistent with rapid cooling after peak Trans-Hudson/ Penokean metamorphism. The 1728 Ma biotite age (SDGT) is similar to abundant 1750-1720 Ma hornblende/ biotite ages reported in east-central Minnesota, suggesting that geon 17 metamorphic affects extend westward into SD. Most surprising is the 2449 Ma hornblende age, which suggests the presence of Archean crust within the Proterozoic mobile belts of southern Laurentia. In the south, our results demonstrate the YP experienced the affects of younger, Proterozoic events largely unfelt throughout neighboring regions. Mica ages are consistently young across a >700 km swath of southern NE and eastern CO. Similarly young ages are reported from only a handful of the hundreds of samples dated in the Rockies and the upper Great Lakes region. Because Proterozoic crust in the southern Lake Superior were virtually unaffected thermally by 1.1 Ga rifting, we consider it unlikely that our 1130-1260 Ma mica ages represent widespread partial resetting during rifting. In CO and NM, similarly young mica ages are interpreted as partially reset by Tertiary igneous activity or representing deeper, and therefore more slowly cooled crustal levels (Shaw et al., 2005). However, both interpretations seem unlikely for our study area. We tentatively suggest that a regional thermal

event possibly related to Neoproterozoic deformation may be responsible for the anomalously young Ar/Ar ages reported here.



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**LITHOGEOCHEMICAL EVALUATION OF NEOARCHEAN
MAFIC VOLCANIC ROCKS COMPRISING THE FOOTWALL OF THE SOUDAN
MEMBER OF THE ELY GREENSTONE FORMATION,
NORTHEASTERN MINNESOTA**

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The Ely Greenstone Formation (EG) comprises a steeply north- to southwest-dipping, north – to southwest younging sequence of Neoarchean supracrustal and associated intrusive rocks that are warped about the Tower-Soudan anticline in the Vermilion District of northeastern Minnesota. The EG has historically been broken up into three members. Up-section, these are: a) the Lower Member of the Ely Greenstone Formation (LMEG, composed of calc-alkaline to tholeiitic basalt and basalt andesite lava flows and tuffs with subordinate felsic lava flows, volcanoclastic and epiclastic rocks, and iron formations); b) the Soudan Iron Formation Member (SMEG, composed of Algoma-type banded iron formations, basalt lava flows, epiclastic rocks and minor felsic lava flows and tuffs); and c) the Upper Member of the Soudan Iron Formation (UMEG, composed of a monotonous sequence of tholeiitic basalt lava flows and local Algoma-type iron formation lenses (Schulz, 1980; Southwick et al., 1998; Hudak et al., 2002; Peterson, 2001; Peterson and Patelke, 2003; Hudak et al., 2007). Schulz (1980) and Hudak et al. (2007) interpret volcanic textures, sedimentary textures, and lithological characteristics to indicate a transition from a subaerial/shallow subaqueous setting to a deeper subaqueous environment during the temporal genesis of the EG.

Southwick et al. (1998) indicate that a sharp transition from basaltic and basaltic-andesitic rocks with arc-like geochemical signatures in the LMEG, to basaltic rocks with MORB-like geochemical signatures in the UMEG, occurs abruptly at the top of the SMEG. More recent studies in the vicinities of Fivemile-Needleboy-Sixmile Lakes (Hudak et al., 2007) and Armstrong Lake (Jirsa et al., 2001) indicate that the transition from arc-like magmatism to MORB-like magmatism is more complicated than previously thought, with MORB-like basalts first occurring in the uppermost parts of the LMEG approximately 50-100 meters into the footwall of the SMEG (Hudak et al., 2007), as well as locally within the SMEG (Jirsa et al. 2001). A model encompassing initial volcanic arc development followed by back-arc rifting immediately prior to the deposition of the SMEG has been proposed (Hudak et al., 2007).

The purpose of this investigation was to evaluate, on a more regional scale than had been previously performed, the lithogeochemistry of mafic and intermediate volcanic rocks that occur in LMEG in the footwall to the SMEG. In addition to field and lithogeochemical data from the Fivemile-Needleboy-Sixmile Lake areas (Hudak et al., 2007) and Armstrong Lake areas (Jirsa et al., 2001), detailed mapping (1:2500-1:5000 scale) and sampling was performed south of Twin Lakes (on the northeastern part of the Vermilion District) as well as in the vicinity of Putnam Lake (in the southwestern part of the Vermilion District). Following field mapping, petrographic and lithogeochemical studies were performed. Petrographic work was utilized to distinguish between fin-grained massive flows and diabase sills and

dikes. Whole rock major and trace element lithogeochemical analyses utilizing a wide variety of analytical methods (ICP/MS, instrumental neutron activation analysis, coulometry, and gravimetric) were employed.

In the Twin Lakes area, mafic volcanic rocks with arc-like lithogeochemical signatures transition up-section into mafic volcanic rocks with MORB-like lithogeochemical signatures consistent with back-arc basin basalts in the immediate footwall (<100 meters) to the SMEG. The same lithogeochemical transition has also been documented in the immediate footwall rocks to the SMEG in the vicinity of Putnam Lake. Our results allow us to, for the first time, to document a change from arc-like to MORB-like (back-arc basin consistent) magmatism in the immediate footwall rocks to the SMEG on a regional basis.

The development of a back-arc basin in a volcanic arc not only enables the occurrence of MORB-like volcanism, but also is commonly associated with the development of vigorous, regional hydrothermal activity which can produce chemical sedimentary rocks (e.g Algoma-type iron formations) as well as volcanogenic massive sulfide deposits (Franklin et al., 2005; Piercey et al., 2004). It is therefore not surprising that the SMEG occupies a position immediately up-section from the arc- to MORB lithogeochemical transition within the EG. The presence of this transition, apparently across the entire strike length of the SMEG may be explained if the current erosional surface is sub-parallel to a rift structure which occurred within the proposed back arc basin.

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GEOLOGIC MAPPING OF NEOARCHEAN ROCKS NEAR PAULSEN LAKE, BOUNDARY WATERS CANOE AREA WILDERNESS, BY STUDENTS OF THE PRECAMBRIAN RESEARCH CENTER'S 2008 FIELD CAMP

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The Precambrian Research Center—a branch of the University of Minnesota, Duluth—conducted its second season of field camp in 2008. After 5 weeks of field training, students were assigned “Capstone Projects” that provide an opportunity to create new geologic maps in areas of poorly understood geology. Junior authors listed above are students who mapped Neoproterozoic bedrock in the Paulsen Lake area, which was burned by the 2006 Cavity Lake forest fire in the northeastern part of the BWCAW. The fire greatly improved access to and visibility of geologic features, allowing detailed mapping of rock units and complex contact relationships. The 2008 map area (Fig. 1) lies in the northeastern part of the U.S.G.S. Gillis Lake 7.5-minute quadrangle. Previous mapping was fairly detailed (Vervoort, 1987), but contacts were not well constrained. The map and geologic descriptions presented here are based on literature review and the observations from several days of field work—no petrographic or geochemical data were acquired.

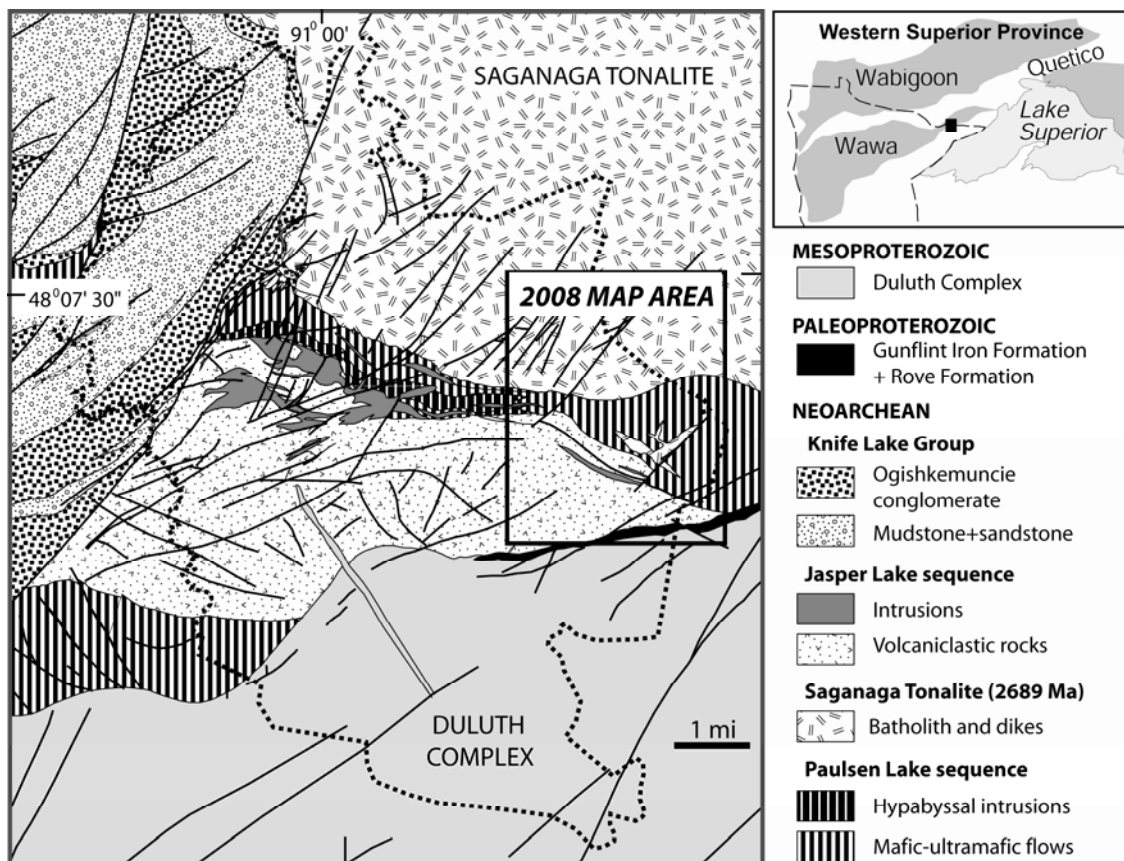


Figure 1. Simplified geology of the Cavity Lake fire area (fire=dotted outline), showing location of detailed mapping described here. Small inset map shows location within the Wawa subprovince of Superior Province. Geology modified from Jirsa and Starns, 2008.

The principal Neoproterozoic rock units (from oldest to youngest) in the 2008 map area are:
Paulsen Lake sequence—a vertically dipping basement package of back-arc or ocean floor origin, consisting of pillowed and massive basalt flows, and hypabyssal, mafic-ultramafic sills. The age of the sequence is unknown. Well developed spherulitic and spinifex textures, and the presence of peridotite sills imply correlation with the largely ultramafic Newton Lake Formation, which lies to the west and southwest.

Saganaga Tonalite (2689 Ma; Corfu and Stott, 1998)—coarse-grained, polyphase intrusion and apophosial dikes that intrude and cut out the base of the Paulsen Lake sequence. The tonalite has a distinctive texture marked by the abundance of quartz "eyes" and presence of hornblende.

Jasper Lake sequence—hornblende- and pyroxene-porphyritic, dacitic to trachyandesitic volcanic and volcanoclastic rocks, cut by similarly porphyritic hypabyssal intrusions. Geochemical data and mineralogic similarity indicate that the Saganaga Tonalite may represent the magma chamber from which these rocks erupted.

Bedding in supracrustal rocks dips steeply and stratigraphic younging is generally southward, as deduced from pillow morphology in flows and graded bedding and scour structures in conglomeratic rocks. Angular relationships of bedding imply that volcanic conglomerate units of the younger Jasper Lake sequence lie unconformably on the Paulsen Lake mafic-ultramafic rocks. Metamorphic grade appears to be low greenschist facies, except immediately adjacent to the Saganaga Tonalite where amphibolite facies assemblages are well developed and the rocks contain cleavage and a strong, shallow east-plunging mineral lineation. The boundary between rocks of contrasting metamorphic grades is a fault. We infer considerable uplift on the north side immediately adjacent to the Saganaga Tonalite.

Conglomerate layers in the Jasper Lake sequence are white to brownish-gray, and clast-supported. Clasts are moderately to well rounded, moderately well sorted, and range from 1 cm to 20 cm in diameter. Clasts consist of porphyritic to aphyric hornblende dacite to trachyandesite, and some fragments have textures similar to phases of the Saganaga Tonalite—supporting the inference that it represents magmatic source to the Jasper Lake volcanoclastic strata.

A preliminary geologic map of the Cavity Lake fire area, created prior to the student work, was published as an open-file map (Jirsa and Starns, 2008). A final map that incorporates student work and recent thesis mapping will be published in coming months. Support was provided by the U.S. Geological Survey's 2007 State Geologic Mapping Element (STATEMAP) of the National Geologic Mapping Program, the Precambrian Research Center (2007 and 2008 capstone projects), and the State Special Appropriation to the Minnesota Geological Survey.

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NEOARCHEAN WEATHERING AND ATMOSPHERIC pO_2 INFERRED FROM PALEOSAPROLITE BETWEEN GRANITE-GREENSTONE AND SUPERJACENT CONGLOMERATE IN THE BOUNDARY WATERS CANOE AREA, NE MINNESOTA

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Neoproterozoic rocks in parts of the Boundary Waters Canoe Area are exceptionally well exposed after recent forest fires that were the largest in Minnesota since 1894. New mapping in the burns reveals considerable detail, particularly about complex contact relationships (Jirsa and Starns, 2008). For example, the contacts between the Ogishkemuncie conglomerate and the volcano-plutonic country rocks from which it was derived are both faults and unconformities. Where not faulted, the contacts are marked locally by paleosaprolite developed in both the 2.689 Ga Saganaga Tonalite (Corfu and Stott, 1998), and the adjacent ca. 2.7 Ga metavolcanic rocks that it intruded. Petrographic and geochemical analyses of 2 suites of samples taken across the paleosaprolitic contact zones will constrain our understanding of environmental conditions during the Neoproterozoic.

The Neoproterozoic rocks (from oldest to youngest) are:

Paulsen Lake sequence—a vertically dipping package of back-arc or ocean floor origin, consisting of pillowed basaltic to komatiitic flows, hypabyssal sills, and rare tuff, chert, and distal turbidite.

Saganaga Tonalite—coarse-grained batholith and dikes that cut the Paulsen Lake sequence and have distinctive textures marked by abundant quartz "eyes" and hornblende.

Jasper Lake sequence—hornblende- and pyroxene-porphyritic, dacitic to trachyandesitic, volcanic and volcanoclastic rocks cut by similarly porphyritic hypabyssal intrusions.

Ogishkemuncie conglomerate—conglomerate and sandstone containing readily recognizable fragments of all the rock sequences described above. Sedimentary structures indicate deposition in coalescing alluvial fans, with fluvial transport locally into standing water. The strata are similar in many respects to other Timiskaming-type assemblages in the Superior Province that are inferred to represent deposition in successor-basins (e.g., Jirsa, 2000).

Characteristics of the inferred 2.7 Ga paleosaprolite satisfy most of the 5 diagnostic criteria proposed by Rye and Holland (1998) for identification of pre-land plant paleosols. The unconformity dips 30-60°, in contrast to the vertical dip of underlying country rock. Macroscopic and microscopic features of the paleosaprolite include alteration, destruction of igneous texture, and diminution of feldspar expressed in increased content of quartz eyes in paleoweathered tonalite (Fig. 1); and oxidation, microfracturing, conversion of Fe-Mg minerals to chlorite, and semi-ductile ("soft") deformation in metavolcanic rocks. The effects differ from those of tectonic cataclasis primarily in the irregularity of altered zones, locally producing equant paleo-corestones of tonalite, with annealed concentric exfoliation structures.

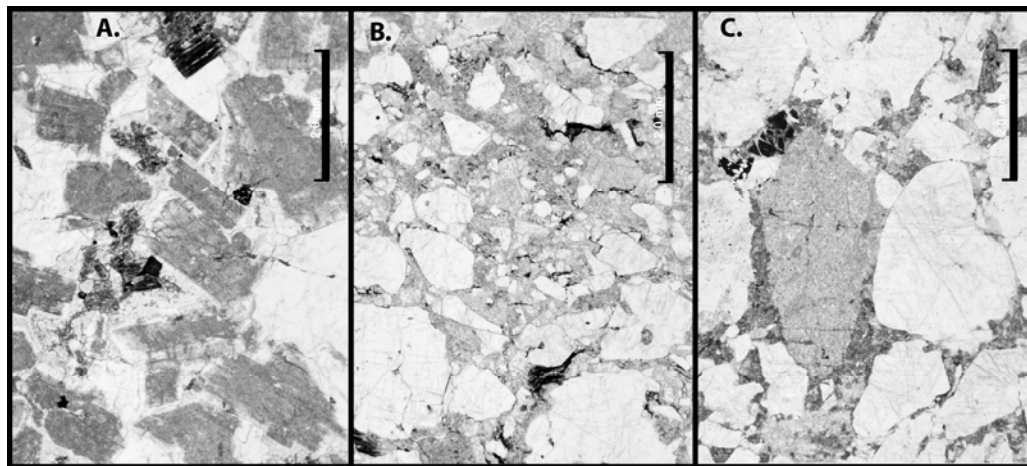


Figure 1. Photomicrographs showing textures of **A.** comparatively fresh Saganaga Tonalite 55 m below Ogishkemuncie conglomerate; **B.** weathered tonalite 15 m below conglomerate; and **C.** conglomerate 7 m above tonalite (note rounded to angular quartz and rock fragments). All in plane light; scale-bar 2 mm.

Although primary paleosaprolite microfabrics and mineralogy of weathered granitic rocks are modified by low-to medium-grade metamorphism that is typical here, whole-rock geochemical patterns related to paleoweathering are commonly well-preserved, except for general K_2O increases related to metasomatism (Driese et al., 2007; Driese and Medaris, 2008). Calculations of elemental gains and losses relative to fresh parent material for both the Saganaga Tonalite and the adjacent metavolcanic rocks will permit estimation of Neoproterozoic paleoatmospheric pO_2 , based on theoretical differences in the ratio of O_2 demand to CO_2 demand during weathering of granitic vs. mafic rocks, as well as Fe gains and losses (Pinto and Holland, 1988). Paleoatmospheric pO_2 is inferred to have been quite low at 2.7 Ga, well before the circa 2.2 Ga “Great Oxidation Event” of Rye and Holland (1998), as illustrated in Figure 2. Additional information about pCO_2 can also be extracted using mass-balance geochemical methods of Sheldon (2006). Analytical work is underway.

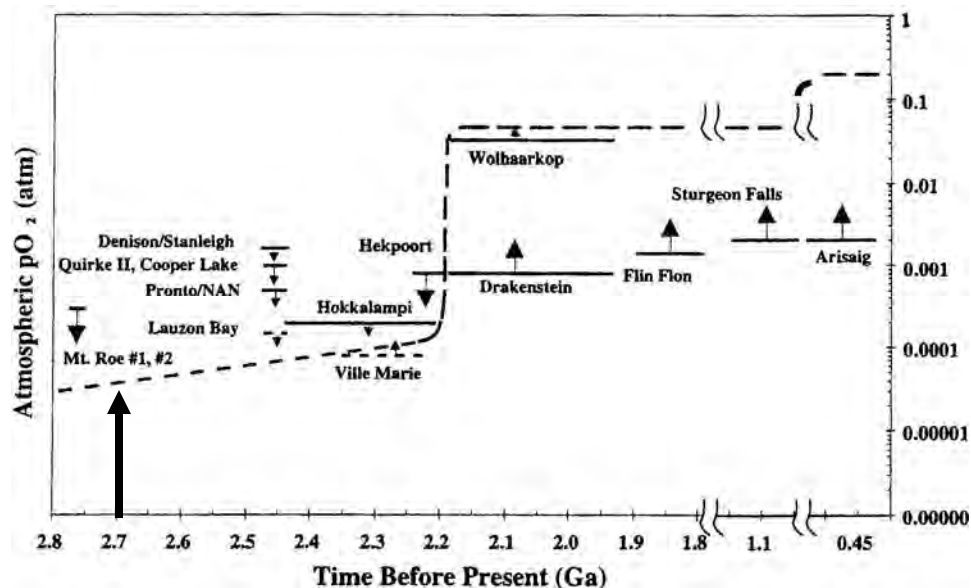


Figure 2. Comparison of 2.7 Ga Ogishkemuncie paleosaprolite with other paleosols. (after Rye and Holland, 1998)

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STRUCTURAL, KINEMATIC, AND LITHOGEOCHEMICAL INVESTIGATION OF THE MURRAY SHEAR ZONE, NORTHEAST MINNESOTA

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Archean (3.8-2.5 Ga) cratons host gold-bearing quartz vein systems in zones of inhomogeneous structural architecture. In the Superior craton, the largest and most gold-productive zones of multifarious structure include the Porcupine-Destor and Larder Lake-Cadillac breaks of the Abitibi Greenstone Belt, Canada. Previous geologic mapping and mineral exploration in southern reaches of the Superior craton of northeastern Minnesota revealed anomalous quartz vein-hosted gold in the Murray Shear Zone (Peterson and Patelke, 2003). This investigation of the Murray Shear Zone attempts to better understand unique characteristics shared with gold-rich belts in Canada, and the paucity of developed gold districts in northeastern Minnesota, through research into structural architecture, crustal kinematics, and geochemistry.

The Murray Shear Zone cuts an arcuate succession of rocks comprising the Lower and Soudan Members of the Ely Greenstone, and the Lake Vermilion Formation. The 19-km shear zone strikes east-west, extending from the Tower-Soudan area to the Giants Range Batholith to the east. Investigation uncovers microstructural evidence for exclusively dip-slip shear, parallel to steep-plunging mineral lineations (089/68) within steeply dipping foliation. Strain appears to be partitioned along east-striking, steeply-dipping metamorphic foliation planes that describe an anastomosing network. In the western portion of the study area curvilinear splays of focused strain fabric diverge to 4 km in width (map view) from 0.4 km width to the east.

Strain heterogeneities exist within the Murray Shear Zone. Metamorphic foliations diverge around coherent lithologic blocks devoid of penetrative foliation. Brittle deformation features overprint ductile features in the form of extensional quartz veins that cut metamorphic foliations at high angles. Interpretations of instantaneous principal stress orientations attempt to correlate rheological behavior of rocks with field observations for a conceptual gold model. Strain asymmetry and steep planar and linear fabric coexist with quartz vein systems that host gold. Structurally-hosted gold materializes from: 1) differential stresses in the crust; 2) metamorphic devolatilization; and 3) corresponding fluid pressure fluctuations (deviatoric stresses) at the brittle-ductile transition.

Geochemical data show zones of hydrothermal alteration enclosing gold-bearing quartz veins of anomalous gold mineralization in regionally-prevalent greenschist grade to locally amphibolite grade metamorphism. Alteration envelopes approaching the veins include chlorite schist, carbonate-chlorite schist, and carbonate-sericite $\pm$ green mica schist. Correspondingly, mass balance analysis utilizing the isocon method (Grant, 1986) indicates gains in Fe, Mg, Mn, Ca, Co, CO₂, Cr, K, Ni, V, Sr, Sn, Rb, Ba, and Eu, and losses in Cu, Er,

Na, SiO₂, and Zn. Silica leaching occurs adjacent to gold-bearing quartz veins in a matter similar to that illustrated at the Yellowknife gold deposit, Northwest Territories, Canada (Boyle, 1955).

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FLUID MOVEMENT THROUGH THE MESABI IRON RANGE, MINNESOTA

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The Mesabi Iron Range in northern Minnesota has been an important contributor of iron necessary for products that we use every day. The iron-rich sedimentary rocks were initially deposited in a shallow sea about 1.8 billion years ago. Later, fluids flowed through the rocks dissolving everything but the iron oxides and concentrating them into high-grade ore. Previous work has described these fluids as meteoric waters that have percolated downward through the rocks from the surface. G.B. Morey (1999) has stated that these fluids were driven up through the rocks due to the Penokean Orogeny.

To determine the source of fluids associated with high-grade (natural) ore, we have sampled veins in low to high angle faults exposed in the Hibbtac, Thunderbird (UTac), and LTV #6 pits. Brecciated quartz cemented by quartz-hematite is found primarily in the high angle faults of this region. The sampled high-angle faults locally define boundaries between unoxidized and oxidized ore and are thought to have served as conduits for fluids that dissolved chert from taconite. Some of the movement on these faults was associated with collapse due to chert dissolution. Thus the quartz in these faults may have been precipitated from the same fluid that was responsible for leaching the taconite.

The properties of the fluid that affected these rocks are being determined using cathodoluminescence and fluid inclusion techniques. Microscope examination of the iron ores revealed that the early-formed iron-rich mineral greenalite was replaced by other iron-rich minerals, minnesotaite and stilpnomelane during diagenesis. Samples taken from the Thunderbird and Hibbtac mines have been analyzed using cathodoluminescence. Quartz in the veins and in the iron formation display growth banding produced by pulses of fluid moving through the rock and precipitating minerals episodically. Along with growth banding, differences in the vein quartz and matrix quartz due to fluid interactions with the rock can be seen.

The source of fluids has been studied by analysis of fluid inclusions, which can give both the homogenization temperature and the salinity of fluids that are trapped in minerals. Fluids that ascended through the rocks would be expected to have a relatively high temperature and salinity, whereas meteoric fluids that descended from the surface would be expected to have much lower temperatures and salinities. One sample from a fault associated with high-grade iron ore in the Thunderbird mine near Eveleth showed high homogenization temperature values, 85.8-141.5°C (mean 125°C, n=26) and a high weight % NaCl equivalent (mean 3.98 weight %, n=12), suggesting the fluids that precipitated quartz in the faults ascended from depth. These values largely overlap temperatures and salinities of fluid inclusions from quartz breccia in faults in the Hibbtac Mine, as well as in bedding-parallel veins in the LTV6 samples. All of this data supports the idea of fluids rising from depth, not percolating downward.

Geochemical data will also be presented for rocks in veins and in traverses from oxidized, leached iron formation into unoxidized iron formation to determine the nature and effects of the fluids responsible for the high-grade ore.

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INTERPRETATIONS OF THE EMPLACEMENT AND COOLING HISTORY OF A THIN DIABASE SILL, NIPIGON, ONTARIO

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Thin dikes and sills are often produced by single instantaneous injection events (e.g., Gray, 1978). Textural and compositional evidence of this type of formation typically includes the lack of internal chills or accumulation of phenocrysts into distinctive horizons. However, complex injection histories are being recognized in an increasing number of intrusions (e.g., White, 2007). In this study, we examine a thin diabase sill from the Nipigon embayment, Ontario. This sill is located beneath the main sill at Kama Hill, east of Nipigon. Textural and mineralogical evidence suggest that it was emplaced in a single injection, and thus represents an important end-member style of sill formation.

Petrographic examination of the rocks in this sill focused on opaque oxides, as they can be characterized easily using automated image processing techniques. Digital photomosaics (transmitted, plane-polarized light) were prepared from thin sections of 18 samples spanning the 1.25 m thick sill. Randomly oriented test lines were used to determine mean crystal length using a method reviewed in Higgins (2006): $L_{mean} = V_V/P_L$, where V_V is the modal fraction of the mineral of interest, as determined by both automated image analysis and by point counting, and P_L is the number of crystals intersected along the test line. This analysis reveals smooth variations in grain size with distance, from smaller grains at the chilled margin to larger grains in the center of the sill, indicating that the magma cooled as a single unit. Unit cooling is consistent with emplacement of magma as a single injection event.

The modal abundance of opaque oxide minerals in the sill was determined by digital thresholding and by point counting ($N \sim 1200$). The abundance of oxides throughout the sill is statistically uniform. This lack of significant variation in mineral abundances is further evidence supporting unit emplacement: multiple injections would likely have disrupted the solidification fronts established in the cooling magma and resulted in identifiable mineralogical discontinuities.

Using a numerical cooling model, we can extract crystallization kinetics (growth rates) from the grain size data, and predict texture variations in a variety of scenarios, in particular predicting the magnitude of the “chilling” signature in the case of reinjection events.

Based on mineralogy and texture, the sill in this study was almost certainly emplaced in a single injection event. Using this as a baseline, we can identify complex injection histories as departures from the textural profile observed here. This makes it useful as a null hypothesis for testing formation history: unless textures depart significantly from those presented here, we must assume that the intrusion was formed in a single injection. Such textural criteria are particularly important when the magma composition remained constant through several injections, in which case the recognition of multiple injection events would not be reflected in the modal mineralogy of the rocks.

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METAMORPHIC PSEUDORUTILE IN THE SEELEY SLATE, BARABOO RANGE, WISCONSIN

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Pseudorutile is a hexagonal mineral, whose composition is $\text{Fe}_{(2-x)}^{3+}\text{Ti}_3\text{O}_{(9-x)}(\text{OH})_{3x}$ (Grey *et al.*, 1994). It occurs as an intermediate product in the weathering or early diagenetic alteration of ilmenite to rutile or anatase, and it has been reported in weathering profiles (Melcher, 1991; Pe-Piper *et al.*, 2005) and heavy-mineral placers in a variety of depositional environments (Bailey *et al.*, 1956; Grey and Li, 2003; Hebert and Gauthier, 2007).

Pseudorutile has been discovered in the Seeley Slate, which occurs stratigraphically above the Baraboo Quartzite in the core of the Baraboo syncline. The Seeley Slate consists of a low-grade metamorphic assemblage of quartz, muscovite, and chlorite, and pseudorutile occurs in drill core 4049 as small, tabular grains that are oriented parallel to the slaty cleavage, S1 (Fig. 1A). The pseudorutile is poikiloblastic, containing inclusions of quartz, muscovite, and chlorite, and is accompanied by small, subequant clusters of tiny rutile grains (Fig. 1B).

Back-scattered electron images of pseudorutile reveal a mottled appearance (Fig. 1C), which is due to intragrain compositional heterogeneity, *e.g.* a variability in Fe/Ti ratio, which is likely associated with variable (OH) contents.

Opaque crystals that are morphologically similar to the pseudorutile in drill core 4049 occur in drill cores 3601 and 3941, but in these instances the grains are rutile (Fig. 1D), or rutile with a small amount of relict pseudorutile. Such grains most likely represent pseudomorphs after preexisting pseudorutile.

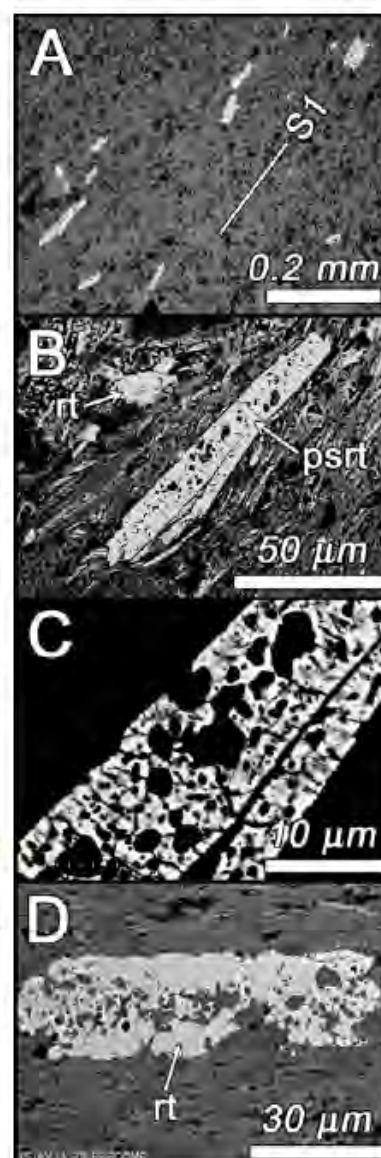
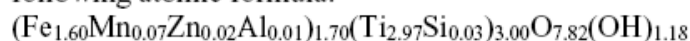


Figure 1

- A: Reflected light photomicrograph of drill core 4049, illustrating oriented, tabular pseudorutile grains (bright); S1, slaty cleavage.
 B: Back-scattered electron (BSE) image of poikiloblastic pseudorutile (psrt) and rutile (rt) in a matrix of chlorite (light grey), muscovite (medium grey), and quartz (black).
 C: BSE image of poikiloblastic pseudorutile. Note the variable shades of grey in psrt, reflecting compositional heterogeneity.
 D: BSE image of rutile (rt) pseudomorph after pseudorutile; drill core 3941.

The chemical composition of the Seeley pseudorutile was determined with a Cameca SX50 microprobe. Aside from Ti and Fe, the only other cations detected were Si, Al, Mn, and Zn. Oxygen was analyzed, and the excess over that required for the cations was calculated as H₂O, assuming all Fe and Mn to be trivalent. The mean composition of the Seeley pseudorutile is given in Table 1, where it is compared to that for type pseudorutile. When normalized to 3.0 atoms of Ti + Si per formula unit, the mean composition of the Seeley pseudorutile yields the following atomic formula:



The range in composition of Seeley pseudorutile is illustrated in Fig. 2, where it is compared to that in ideal pseudorutile, in which the compositional parameter “x” varies from 0 to 1. For Seeley pseudorutile, the [sum of cations – (Ti+Si)] ranges from 1.93 to 1.59, and [(Ti+Si)/total cations] ranges from 0.61 to 0.65, corresponding to a variation in the parameter, “x”, from 0.07 to 0.41.

Despite performing a complete microprobe analysis, the totals for the Seeley pseudorutile are low by ~4 wt. %, raising the possibility that non-structural H₂O (volatilized during analysis) may be adsorbed on the surfaces of nano-scale domains, as is the case for hydroxian pseudorutile (Grey and Li, 2003). If so, 0.9 molecules of H₂O per mean formula unit of pseudorutile could account for the analytical difference from 100%.

Based on its textural features and the absence of relict ilmenite, pseudorutile in the Seeley Slate is interpreted to be metamorphic in origin, having crystallized at the lowest grade of the greenschist facies. This is the first recognized occurrence of pseudorutile as a metamorphic mineral, and the apparent scarcity of metamorphic pseudorutile may be due to its instability at higher grades of metamorphism, where it is replaced by rutile.

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Table 1. Pseudorutile analyses

	Seeley psrt mean $\pm 1\sigma$ n = 28	type psrt*
SiO ₂	0.45 $\pm$ 0.21	0.00
TiO ₂	59.15 $\pm$ 0.84	58.84
Al ₂ O ₃	0.14 $\pm$ 0.15	0.00
Fe ₂ O ₃	31.85 $\pm$ 1.76	36.03
Mn ₂ O ₃	1.38 $\pm$ 1.63	0.60
ZnO	0.35 $\pm$ 0.30	0.00
H ₂ O	2.65 $\pm$ 1.09	3.24
Sum	95.97	98.71

*Grey *et al.* (1994)

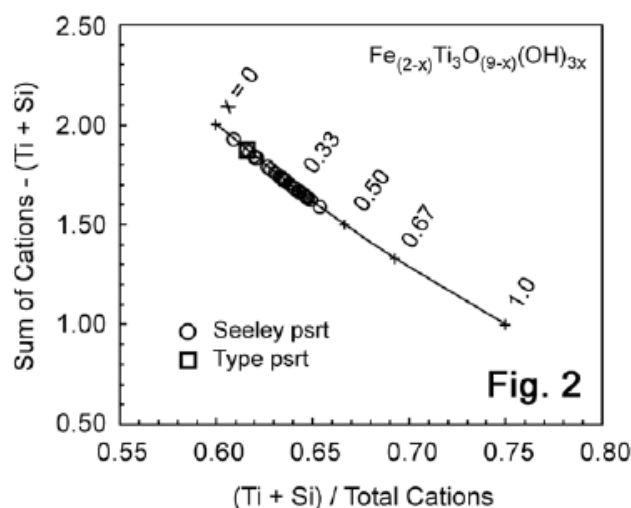


Fig. 2

A 1465 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ age for the Seeley Slate: implications for metamorphism and deformation in the Baraboo Range, Wisconsin

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The Baraboo syncline is the most prominent Precambrian structure in southern Wisconsin. Based on the regional distribution of $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages of amphibole and micas in the pre-Baraboo Interval basement, the syncline has been thought to have formed at 1630 Ma in response to foreland deformation of the Mazatzal Orogeny (Holm et al., 1998; Romano et al., 2000; Holm et al., 2007). To explore further the metamorphic and deformational history of the Baraboo Range, we have undertaken a $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronologic investigation of muscovite in the Seeley Slate, which is one of the Statherian stratigraphic units in the range.

In the Baraboo Range, the Baraboo Quartzite is overlain conformably by the Seeley Slate (~120 meters thick), which in turn is overlain by the Freedom Formation (~300 meters of dolomite and discontinuous Fe-formation). The latter two formations occur only in the subsurface in the hinge of the Baraboo syncline, which restricts their investigation to drill core samples.

The Seeley Slate is predominantly a gray slate, with variable amounts of thin layers and lenses of quartz silt (Fig. 1), rare lenses of quartz sand, and dispersed laminae of siderite. The degree of transposition of sedimentary stratification, S_0 , into the plane of slaty cleavage, S_1 , in a given sample is a function of the proportion of clay-sized and silt-sized material (Fig. 1).

The chemical composition of the Seeley Slate is high in Al_2O_3 , reflecting its pelitic nature, but it is unusual for shale in being virtually devoid of CaO and Na_2O (Table 1). Such a composition may represent either a relatively mature illite-rich shale, or an extremely mature kaolin-rich shale, to which potassium was subsequently added, promoting the growth of muscovite.

The slate contains a lower greenschist facies assemblage of quartz + muscovite + chlorite + tourmaline + rutile $\pm$ siderite $\pm$ various opaque phases, including hematite, pseudorutile, and pyrite. The layer silicates have a strong, shape-preferred orientation, which is responsible for the slaty cleavage. The absence of biotite in the slate and presence of the assemblage, quartz + muscovite + pyrophyllite, in hydrothermal veins in the Baraboo Quartzite indicate a temperature of ~350 °C for

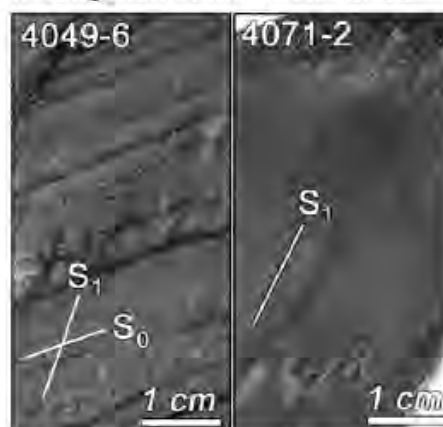


Fig. 1 Polished drill cores, Seeley Slate. Note competency contrast between silt-rich (left) and silt-poor (right) samples

Table 1. Composition of the Seeley Slate (anhydrous)

	avg (n=4)	1 σ
SiO_2	67.71	2.80
TiO_2	0.69	0.06
Al_2O_3	17.71	1.62
Fe_2O_3	5.82	1.20
MnO	0.02	0.01
MgO	2.10	0.03
CaO	0.07	0.03
Na_2O	0.07	0.02
K_2O	5.79	0.84
P_2O_5	0.03	0.01
Sum	100.00	

recrystallization of the Seeley Slate.

Separation of muscovite from the Seeley Slate is impractical because of its extremely fine grain size. Accordingly, four whole-rock samples of slate were selected for Ar analysis by step heating, using a defocused CO₂ laser, following the methods of Smith et al. (2006). By this abstract deadline, analysis of two samples was complete, the results of which are shown in Fig. 2. Both samples yielded discordant spectra with well-defined plateaux at 1470 and 1460 Ma, representing ~55% of the ³⁹Ar released. These ages are within error of those obtained for muscovite in hydrothermal veins, metasaprolite, and quartzite breccia in the Baraboo Range and muscovite in the correlative Waterloo Quartzite (Medaris et al., 2002, 2003). Considering the low recrystallization temperature of the Seeley Slate, ~350 °C, it is likely that the ⁴⁰Ar/³⁹Ar plateau ages approximate the time of muscovite growth, which is similar to the 1470-1476 Ma age of the Wolf River batholith (Dewayne and Van Schmus, 2007)

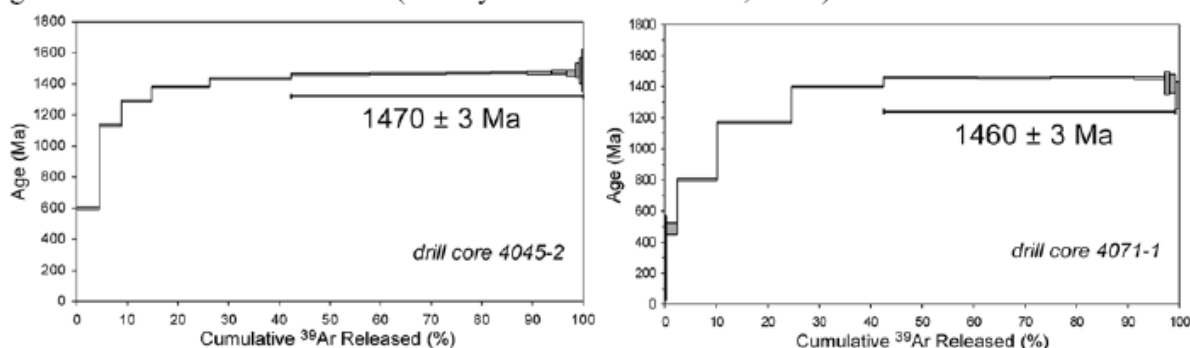


Fig. 2 ⁴⁰Ar/³⁹Ar age spectra for two samples of Seeley Slate. Lengths of the horizontal bars indicate the steps included in the plateau age calculation for each sample.

The petrological, chemical, structural, and isotopic data for the Seeley Slate may be explained by several hypotheses, among which the most plausible are:

- 1) The Seeley Slate was recrystallized and deformed at ~1465 Ma during folding of the Baraboo syncline, which may thus represent a previously unrecognized structural consequence of the Wolf River magmatic event.
- 2) Potassium was introduced into the Seeley Slate by hydrothermal fluids at ~1465 Ma, promoting the growth of muscovite parallel to a pre-existing slaty cleavage, which was the result of 1630 Ma Mazatzal deformation.

Regardless of structural interpretation, our new Ar data confirm a significant Wolf River influence on the Baraboo Range, the full expression of which deserves further exploration.

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GEOLOGY AND MAGNETIC TACONITE RESOURCES OF WESTERN GOGEBIC IRON RANGE, WISCONSIN

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The Gogebic Iron Range is 60 miles long, extending from the western Upper Peninsula of Michigan into northeastern Wisconsin. From 1886 to 1964 over 300 million tons of high grade, direct-shipping, natural iron ore was mined from the Gogebic Iron Range, largely by underground mining in Michigan and Wisconsin. The iron in these ores occurred primarily in hematite, goethite and limonite. Only one operation, the Berkshire Mine, in 1922-1924 mined and processed magnetite ores (4,000 tons) that required concentration to make a marketable grade product. The Berkshire operation, along with those early magnetic taconite operations in Minnesota and Michigan, marked the beginning of the Lake Superior taconite industry which now produces nearly all of the iron ore mined in the United States for the U. S. steel industry.

The geology of the western Gogebic Iron Range has most recently been described by Cannon, LaBerge, Klasner and Schulz (2008). The iron ore-bearing members are part of the Paleoproterozoic Ironwood Iron Formation. The direct-shipping natural iron ores were mined along 25 miles of strike from Upson, Wisconsin, to Wakefield, Michigan. The natural ores were likely formed by circulating groundwater that oxidized the iron minerals and removed silica. A large magnetic taconite resource has been identified on the western Gogebic Iron Range from Upson to Mineral Lake (21 miles) in Wisconsin and a smaller, less defined magnetic taconite resource east of Wakefield, Michigan, west and east, respectively, of the 25 miles of the Gogebic Iron Range where natural iron ores were mined from Wakefield to Upson. The Ironwood Iron Formation underwent Mesoproterozoic deformation which tilted the strata 40° to 90° north (Cannon, LaBerge, Klasner and Schulz, 2008). For the 21 miles from Upson to Mineral Lake, we estimate an average dip of 65°, with the thickness of the potentially economic magnetic taconite 400 to 560 feet thick. The potentially economic magnetic taconite occurs in most of the lowest member (Plymouth) of the Ironwood Iron Formation and in the upper part of the Yale and lower part of the Norrie members, both of which occur stratigraphically above the Plymouth member, respectively. Diabase and gabbro dikes and sills have intruded the Ironwood Iron Formation in the western Gogebic Iron Range.

LaPointe Iron Company has estimated the Wisconsin magnetic taconite resource located in the 21 miles from Upson to Mineral Lake to be 2.1 billion tons at a 1:1 maximum strip ratio which, based on Davis Tube magnetic concentrates from exploration drilling, could produce over 600 million tons of concentrate with greater than 65% iron and an average strip ratio of 0.40. Marsden (1978), in a study conducted for the U. S. Bureau of Mines using 1970's technologies, costs and product prices, estimated that 3.7 billion tons of magnetic taconite could be profitably extracted over the same 21 miles.

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NEW EDUCATIONAL INITIATIVES AT THE UNIVERSITY OF MINNESOTA DULUTH: PREPARING STUDENTS FOR FUTURE JOBS IN THE MINING AND MINERALS EXPLORATION INDUSTRIES

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The departments of Geological Sciences, Civil Engineering and Chemical Engineering along with the Natural Resources Research Institute (NRRI) at the University of Minnesota Duluth are collaborating to develop new courses and new degree options that will prepare students for professional jobs in mining and minerals exploration industries, both locally and globally. These new course offerings and degree options are expected to be in place by the fall term of 2010 or soon thereafter.

The Department of Geological Sciences will offer a BS degree with a mining and mineral exploration emphasis. To qualify for this option, students will be required to take the standard coursework required for a B.S. in geology (including two semesters each of calculus, chemistry, and physics and a six-week summer field camp), along with seven other required courses. These additional courses are Geologic Maps, Engineering Geology, Probability and Statistics, Economic Geology, Minerals Exploration, Mine Design and Operation, and Mineral Processing. Course proposals for the last three courses will be submitted this summer. The Geological Sciences department is also looking into developing a five-year professional masters degree in mining and exploration geology. Preliminary ideas for this degree program are that it will require advanced graduate level courses in geology, mining, exploration, and business and an internship with a mining or exploration company.

The Civil Engineering department at UMD, which was initiated in 2008, has developed plans to offer a BS in Civil Engineering with a mining engineering minor. The mining minor will require students to take courses in soil mechanics, rock mechanics, engineering geology, mine safety, mine design and operation, excavation design, and mineral processing. Soil and rock mechanics are currently offered and the others will be developed in the coming year or two as faculty personnel allow.

The Department of Chemical Engineering intends to offer a minor in Mineral and Material Process Engineering that builds on the department's history of activity in education and research in this area. In developing this minor, the Chemical Engineering department is looking to partner with the Natural Resources Research Institute to offer courses in mineral processing and extractive metallurgy.

Involving the experienced staff and research facilities of the NRRI in both teaching and research is a key component to these initiatives. The NRRI Coleraine Minerals Research Laboratory can provide a great resource for teaching and conducting applied research into mineral processing and extractive metallurgy. In addition, the economic geology group at the NRRI may be tapped for their experience in mineral exploration and ore deposits.

In addition to teaching and research collaboration between our three academic departments and the NRRI, we are also hoping to tap into the practical expertise of local mining and exploration company personnel.

We consider these course additions and curriculum modifications as a modest first step toward addressing the severe manpower and talent shortages that existed in the mining and minerals exploration industries prior to the recent economic downturn. When the recovery comes, we expect that these curricula changes will put UMD in a position to readily supply the exploration and mining industries with the well-trained geologists and engineers they will desperately need once again. We especially want to be the source of human capital for the venerable iron ore industry and the nascent base metal mining industry in northern Minnesota. Both of these industries can provide well paying and fulfilling jobs for decades to come.

To fully serve the needs of the local, as well as the global mining industry, we are considering a grander plan that we are tentatively calling the Center for Mining and Mineral Exploration at UMD. The center would include a well integrated and more robust curriculum among our three departments and would seek support for basic and applied collaborative research by faculty and student for the benefit of the mining and exploration industries, especially locally. Of course, to fully realize this plan will require the support of the mining and exploration industries in the form of endowed faculty positions, funds to support faculty and student research, and in-kind contributions from local mining experts in teaching and research. So while these admittedly grandiose plans will have to at least wait for the mining industry and the rest of the economy to recover, the curriculum and program changes outline here will implemented regardless. Hopefully, these changes will be well received by the industry and will lead to support for our larger goal in the future.

THE NOKOMIS CU-NI-PGE DEPOSIT, DULUTH COMPLEX, MINNESOTA

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Duluth Metals Limited's Nokomis deposit is the most recently discovered Cu-Ni-PGE deposit in the 1.1 Ga. Duluth Complex, Minnesota. The deposit was discovered utilizing a genetic ore deposit model that identified and back-tracked channelized magma flow within the South Kawishiwi intrusion (SKI). The model led to exploratory drilling in 2006, deposit discovery and initial resource estimation in 2007, and significant resource expansion in 2008, all in a period of 18 months.

The deposit's updated 2008 NI 43-101 compliant Resource Estimate, based on 108 holes drilled by Duluth Metals and 52 historic drill holes on and off the property, contains 449 million tonnes of Indicated Resources grading 0.624% copper, 0.199% nickel, and 0.600 grams per tonne of total precious metals (TPM = Platinum+Palladium+Gold), and an additional 284 million tonnes of Inferred Resources grading 0.627% copper, 0.194% nickel, and 0.718 grams per tonne of TPM. The combined Indicated and Inferred Resources contain approximately 10 billion lbs Cu, 3.1 billion lbs Ni, 165 million lbs Co, 4 million ounces Pt, 9 million ounces Pd, and 2 million ounces of Au. Within these NI 43-101 resources are large tonnages of higher grade material, and the company has commenced an internal research program to identify the geologic controls on the formation nickel-rich and PGE-rich mineralization in the SKI, as well as copper-PGE rich mineralization in the footwall Archean rocks. To date, Duluth Metals has drilled more than 500,000 Ft. (~152,000 m) of core in 154 holes into the deposit, and has only drilled about half of the property.

The ore deposit model was developed in cooperation with researchers from the Natural Resources Research Institute of the University of Minnesota, Duluth. A fundamental aspect of the ever-developing ore deposit model is an understanding of the initial conditions of the magmatic system – its crystallinity, sulfur capacity, geochemistry, and geometry – and how the sulfur saturated SKI magma lived, worked, and died. Such understanding includes the realization that the magma was a crystal-liquid (silicate and sulfide liquids) slurry and the identification of magma channelways and sub-channels and their associated thermal anomalies. In addition, the SKI magmas locally melted the footwall granitoid rocks, and such melts have been incorporated into the sulfide-bearing troctolitic melts of the SKI. In the end, hard work and intellectual geologic thought has been used to identify one of the world's largest resources of Cu-Ni-PGEs.

Ore Textures and Mineral Chemistry within the Oxide-Carbonate-Silicate Flotation Ores at the Cliffs Natural Resources' Tilden Mine, Michigan

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The Cliffs Natural Resources' Tilden Mine is located within the Negaunee Iron Formation, the uppermost member of the Menominee Group of the Paleoproterozoic Marquette Range Supergroup. The Negaunee Iron Formation is thought to represent terminated trailing margin sedimentation and its re-working initiated by Penokean foreland basin sedimentation by 1850 Ma (Schneider et al., 2002). The age of the Negaunee Iron Formation is not well constrained but its depositional history could span up to 200 Ma, if the interlayered greenstone sills approximate 2100 Ma (Han and Runnegar, 1992). Greenstone sills are confined to the Negaunee, with the lowest sill within the pit intruding the transition from martite to platy specularite ores. Both sills and feeder dikes are strongly hydrated suggesting greenstone sill emplacement was dynamically connected to dewatering, diagenesis and lithification.

The iron ore exposed at the base of the Tilden pit is texturally complex. Compositional and textural variations in the oxides, carbonates and silicates affect plant efficiency, ore control and mine planning decisions. Understanding the evolution of the depositional, diagenetic and hydrothermal stages will provide a basis for mine modeling. Detailed microscopic examination of four strategic exploration drill holes shows a stratigraphically upward change from basal coarse clastics to well banded siderite-oolitic chert to upper oolitic hematite chert. Basal coarse clastics grading upward into well banded siderite-oolitic hematite chert suggests a shoaling or decrease in clastic input of a restricted basin. The interlayered siderite-oolitic hematite chert bands signify chemical precipitation accompanied by rapid redox boundary fluctuations. The reduced basinal water precipitated siderite, but may have been biogenically modified in the photic zone or reacted with oxygenated atmosphere to produce hematite ooids.

This lithologic history is supported by the mineral chemistry of the silicate and carbonate minerals associated with the dominantly oxide ores; both magnetite and hematite are stoichiometric Fe end members. Microprobe analyses demonstrate that chlorite chemistry is dominantly controlled by primary lithology (Figure 1). The chlorites in magnetite-martite-hematite ores show a decrease in iron content upward (35-15 wt %). Late fracture controlled high-Fe chlorite (30-42 wt %) that commonly has trace associated chalcopyrite is primarily restricted to the basal clastic layer and specific fracture zones within the oxide ores (Figure 1). This late overprint may relate to hydrothermal conditions along the Southern Fault, the northern margin of the 1750 Ma Republic Metamorphic Node (Haase, 1982).

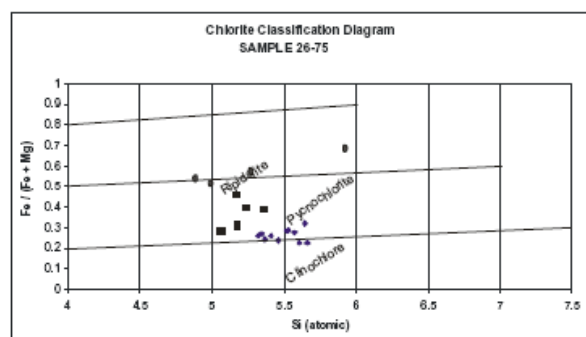


Figure 1. Chlorite classification diagram of representative samples from hole 26-75. Circles: hydrothermal high Fe-chlorites; Squares: chlorites in clastics and; Stars: low-Fe chlorites in oolitic chert beds.

Most carbonate chemistry reflects diagenetic processes with an increase in iron content with

depth (7-36 wt %) (Figure 2). Mn-ankerites are restricted to cross-cutting veinlets that are most abundant in the upper oolitic chert zones and less common within the underlying well banded magnetite carbonate ores. Late siderite accompanies the hydrothermal chlorite and commonly displays a zonal growth pattern from Mg-rich cores to more Fe-rich rims.

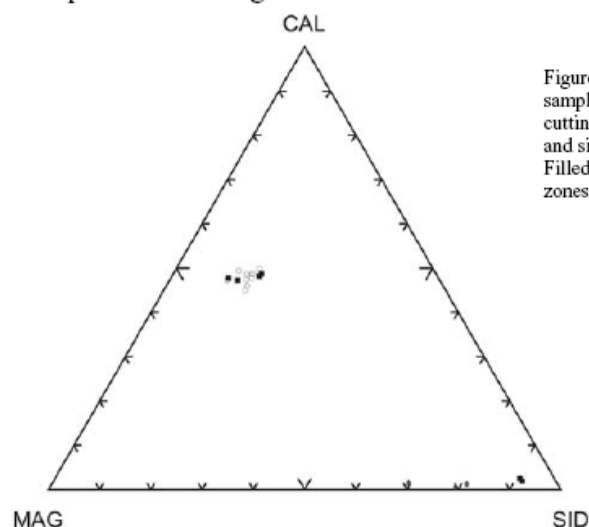


Figure 2. Carbonate classification diagram of representative samples from hole 26-75. Open circles: Mn-ankerites in cross-cutting veinlets within the oolitic cherts; Filled squares: Ankerites and siderites in the interlayered oolitic cherts and clastic bands; Filled polygons: siderites in the lower clastics and brittle banded zones.

The oxidation of primary siderite to magnetite to hematite may be linked to dewatering during diagenesis and lithification. Magnetite is apparently not a primary constituent but replaces both iron carbonate and hematite ooids and is in turn replaced by martite and platy specularite. Oxidation of magnetite to martite occurs at temperatures above 200°C (Sironi, 1965), with the elevated temperatures possibly relating to the emplacement of the greenstone sills. Martite replacement of magnetite to platy specularite is greatest in the oolitic hematite chert layers where Mn-ankerite veinlets concentrate. Martite appears to be buffered by siderite as the degree of martitization progressively decreases with depth. Chlorite and carbonate chemistries suggest that diagenetic processes led to the breakdown of siderite to magnetite; magnetite to martite; then to platy hematite. Partitioning of Fe into the iron oxides released CO₂, Mg-Mn by products from the breakdown of siderite that were removed during basin dewatering and lithification. The Mn-ankerite in the upper cross-cutting veinlets may be a result of siderite decomposition. Late hydrothermal high-Fe chlorite and siderite with trace associated chalcopryrite overprints brittle structures proximal to the Southern Shear and the sedimentary/diagenetic systems.

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Geochemistry of Midcontinent Rift-related mafic dikes and mafic-ultramafic intrusions in the Baraga basin, northern Michigan: Implications for the nature of rift magmatism and Ni-Cu-PGE mineralization

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Mafic dikes and sills and small mafic-ultramafic intrusions are important components of Midcontinent Rift magmatism and are well-exposed north of Lake Superior in northeastern Minnesota and the Lake Nipigon and Thunder Bay areas of Ontario. Recent geochronologic studies (Heaman et al., 2007) have shown that the intrusions in the Lake Nipigon area represent some of the earliest expressions of igneous activity related to the development of the Midcontinent Rift (~1115 to 1106 Ma). Although smaller than the intrusions of the Duluth Complex, these subvolcanic intrusions can host Ni-Cu-PGE mineralization (Ware et al., 2008) and are the focus of ongoing exploration efforts. In contrast to the areas north of Lake Superior, mafic dikes and mafic-ultramafic intrusions are poorly known south of Lake Superior, in large part due to extensive glacial cover. However, recent mineral exploration efforts in the Baraga basin of northern Michigan reveal the presence of numerous mafic dikes and lesser small layered mafic-ultramafic intrusions, including the Eagle Ni-Cu sulfide-bearing mafic-ultramafic intrusion currently under development by Kennecott Minerals Company. The majority of the known dikes are reversely polarized and form prominent magnetic linear anomalies on magnetic maps. For this study, we sampled drill core from several of the newly discovered intrusions in the Baraga basin as well as scattered outcrops of dikes in the basin area.

Geochemical data for the sampled dikes and mafic-ultramafic intrusions show several distinct compositional types (Figure 1a, b). Olivine gabbro, pyroxenite, and feldspathic peridotite from the Roland Lake intrusion and related picritic dikes with euhedral to skeletal olivine generally have high Mg numbers ($Mg/(Mg+Fe) > 60$), show increasing TiO_2 with decreasing Mg number (Fig. 1a), enriched light REE and moderately depleted heavy REE (Fig. 1b), and negative Nb-Ta anomalies on primitive mantle-normalized (PMN) trace element plots (not shown). The Roland Lake samples generally have lower Mg numbers than those of the Eagle intrusion (Fig. 1a), but have REE ratios (Fig. 1b) that overlap those of Eagle (A. Ware, 2008, pers. comm.). The Roland Lake intrusion also is compositionally similar to the Jackfish mafic-ultramafic intrusion in the Lake Nipigon area (Fig. 1a, b). High-MgO dikes (picrite and olivine gabbro) from other locations around the Baraga basin are mostly similar in composition to the Roland Lake samples (Fig. 1a, b), although the majority have smaller negative Nb-Ta anomalies on PMN trace element plots.

Two groups of high- TiO_2 diabase dikes are recognized. First, one group is characterized by low Mg numbers (~40), TiO_2 ~3.0 to 3.5 wt. % (Fig. 1a), enriched light REE and slightly depleted heavy REE (Fig. 1b), negative Nb-Ta anomalies, and $Cu > 200$ ppm. These dikes overlap the McIntyre and Shillabeer intrusions in TiO_2 -Mg number (Fig. 1a), but have REE ratios that partially overlap those of the Nipigon sills (Fig. 1b). Second, the other high- TiO_2 group has similar Mg numbers to the first, but has higher TiO_2 contents (4-5 wt. %; Fig. 1a), more enriched light REE and depleted heavy REE (Fig. 1b), positive Nb-Ta anomalies, and $Cu < 100$ ppm. These dikes plot as alkali basalt and are compositionally similar to ocean island basalts on PMN trace element plots. They do not appear to have a counterpart in the Lake Nipigon area. Gabbro, Fe-Ti oxide-rich clinopyroxenite, clinopyroxenite, and feldspathic peridotite from the layered BIC mafic-ultramafic intrusion on the west side of the Baraga basin (Rossell, 2008) show a range of major element compositions reflecting their cumulate nature; however, their trace element characteristics generally overlap those of high- TiO_2 alkali basalt dikes in the area (Fig. 1b), suggesting that they may be related petrogenetically.

Yet another diabase compositional group in the Baraga basin area is characterized by intermediate Mg numbers (40-50), low TiO_2 contents (<2 wt. %; Fig. 1a), enriched light REE but undepleted heavy REE (Fig. 1b), and prominent negative Nb-Ta anomalies. Several of these dikes have a greenschist-facies mineral assemblage (chlorite+actinolite±epidote). It is unclear whether this is the result of local thermal conditions that affected these dikes or whether they are older and unrelated to the Midcontinent rift. Compositionally they overlap with the Nipigon sills (Fig. 1a, b).

Ages of the intrusions in the Baraga basin have not yet been determined (samples are currently being processed), but the reversed polarity of the majority of the dikes suggests they are older than ~1100 Ma and may overlap in age with intrusions in the Lake Nipigon area. Trace element comparison of the Baraga samples with those of more recent, large igneous provinces (Condie, 2005) suggests that the magmas for the majority of the intrusions were derived largely from enriched subcrustal lithosphere, whereas the high- TiO_2 alkali basalt dikes and BIC intrusion were likely derived from an enriched, ocean island basalt-like mantle (plume tail?). Our Baraga samples show a range in Ni, Cu, and PGE contents; however, except for the high TiO_2 -high Cu diabase dikes, samples generally have high Cu/Pd ratios ($>10,000$), suggesting that the original magmas experienced sulfur saturation and fractionation of sulfide melt prior to intrusion.

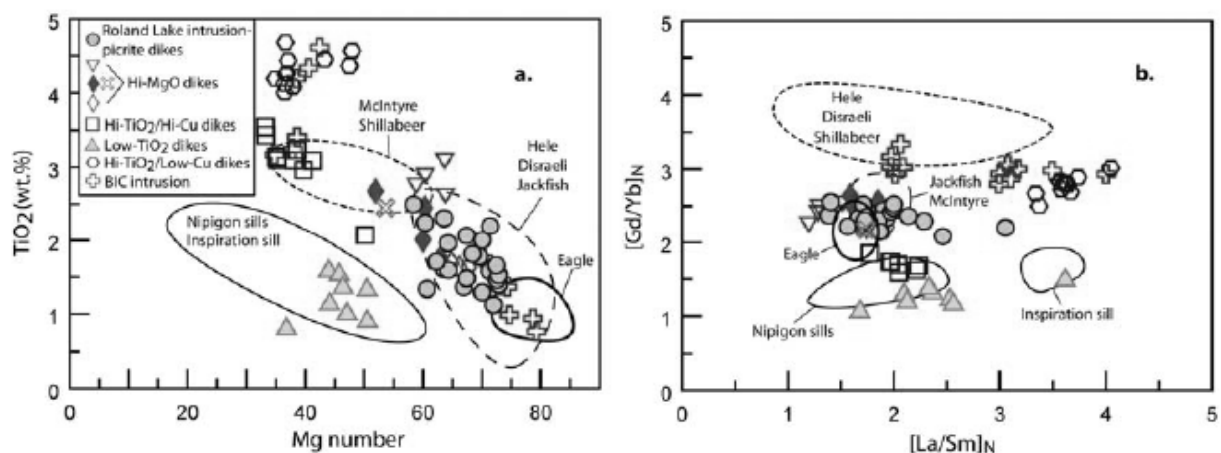


Figure 1: Major (a) and rare earth element (chondrite normalized ratios) (b) variation diagrams illustrating the geochemical characteristics of the intrusions in the Baraga basin, northern Michigan. Fields for the Eagle intrusion and intrusions in the Lake Nipigon area are shown for comparison (Eagle data, A.Ware, 2008, pers. comm.; Nipigon data, Hollings et al., 2007).

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ALTERATION OF STROMATOLITE BIOSIGNATURES IN THE BIWABIK IRON-FORMATION: RELEVANCE TO ASTROBIOLOGY

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Stromatolites, the macrofossil evidence of microbial activity, are an important potential biosignature in the search for life on early Earth and in extraterrestrial missions, yet the taphonomic effect of metamorphism is poorly known. While broad regional metamorphism related to convergent tectonics may be largely restricted to post-Hadean Earth, alteration from volcanism, heated and reducing fluids, and impacts is quite common throughout the solar system. The present study describes and quantifies the effect of contact metamorphism on a biogenic stromatolite bed. While the specific conditions of this example may not be widely applicable in studies of current astrobiology targets, the pathways and resultant changes will serve as a valuable analog for developing tools for extraterrestrial stromatolite recognition.

The stromatolites are constrained to two, meter-scale sequences in the Biwabik Iron-Formation of the Mesabi range on the western margin of the Animikie Basin. The Biwabik records shallow marine sedimentation during the Paleoproterozoic before and during a major collision, the Penokean Orogeny (Ojankangas et al., 2001). Deformation related to the Penokean orogeny and subsequent events lasted for nearly 30 million years based on faulting and synorogenic intrusions (see summary in Schulz and Cannon, 2007). However, it is assumed that no major mineralogical effects in the study area resulted from this event.

The next major phase of alteration was related to mid-continental rifting at 1,100 Ma. Though ultimately a failed rift, conspicuous volumes of basalt flows and subjacent gabbro, troctolite, granodiorite and anorthosite formed along the rift. The contact aureole extends for approximately five kilometers in the Mesabi range with temperatures near the contact in excess of 850 degrees C (Hyslop et al., 2008). Mineralogic changes were detailed by French (1968), Loughheed (1983), Floran and Papike (1978), Frost et al. (2007), Hyslop et al. (2008) and others, defining isograds within the contact aureole.

Stromatolites were compared from the each of the two Biwabik beds from both outside and inside the contact aureole. Petrographic thin- and thick-sections were studied with standard transmitted and reflected light microscopy. The unmetamorphosed representative samples came from core at U.S. Steel Minntac (basal stromatolite layer) and Minnesota Geological Survey deep core 2 (upper stromatolite layer from the Upper Cherty member). Samples from within the contact aureole were collected from taconite mine exposures in Polymet (formerly Cliffs-Erie / LTV) Area 5 (basal) and Northshore block 20 (upper stromatolites). Based on isograds presented in French (1968) and modified by Frost et al. (2007), the Area 5 locality is between zones 5 and 6 and Northshore 20 is between zones 7 and 8. Zone 5 records formation of ferrohypersthene with graphite, zone 6 is defined by hedenbergite, zone 7 by fayalite, and zone 8 by orthopyroxene.

Results

Minntac (basal stromatolites, outside aureole)—The stromatolites in this least altered location are composed of sideritic laminae. The laminae are defined by 0.5 mm thick bundles composed of bands averaging 25 μm thick of organics and hematite. Lenses of microquartz occur in shelter porosity. Granules between stromatolite columns are composed of quartz with thin magnetite rims. Filamentous microfossils comparable in size and density to *Gunflintia minuta* from the Gunflint Iron-Formation are rarely preserved in hematite. Early diagenetic features include rare stilpnomelane and ankerite either as late-stage spar or replacing late-stage silica cement.

MGS-2 (upper stromatolites, outside aureole)—These stromatolites are composed of very fine (10-20 μm) laminae and ministromatolites. The thin, dark laminae are defined by organics. Granules are rare and composed of the iron phyllosilicate greenalite. Most grains are ooids rim-replaced by

subhedral magnetite. Early marine cements are preserved by quartz though most of the stromatolites are neomorphosed into mosaic microquartz. Diagenesis is recognized by blocky euhedral ankerite that crosses fabrics.

PolyMet 5 (basal stromatolites, within aureole)—The thin-sections show prevalent destruction of laminae, replaced by microquartz. Secondary removal of microquartz is defined by intrusions of magnetite and calcite. Where preserved, the dark laminae are leached, leaving 1-2 μm thick bands of iron oxides. Veins through the stromatolites are filled with magnetite, calcite, and pumpellyite. Radiating rosettes of either grunerite or minnesotaite are found within laminae and among basal quartz sand grains. Granules of epidote occur at the base of stromatolite columns.

Northshore 20 (upper stromatolites, within aureole)—This location is closest to the gabbro. The stromatolites are still recognizable with laminae defined by single crystals of magnetite preserved within mosaic microquartz. Crystals of microquartz average 40 μm across. Fabric-destructive, larger subhedral magnetite $\sim$ 7-20 μm across, occurs throughout the stromatolite.

Alteration History

- 1) Stromatolites formed under normal marine conditions as alternating thin laminae of sideritic mud and organic-rich, hematite layers. Greenalite granules washed in from deeper waters.
- 2) Early marine silica formed as rim and shelter porosity cements.
- 3) Burial diagenesis led to reduction of hematite, formation of magnetite rims on grains and in stromatolitic laminae. Some destruction of laminae through replacement by microquartz. Ankerite formed as small crystals irregardless of fabric. Growth of stilpnomelane. No increase in crystal sizes.
- 4) Intrusion of gabbro led to further reduction and loss of hematite and remaining iron-carbonate. Laminae now composed of single crystal-thick bands of magnetite. Complete replacement by microquartz. Formation of fabric-destructive calcite, usually in association with magnetite. Pumpellyite formed in veins associated with calcite and magnetite.

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BEDROCK GEOLOGIC MAP OF THE DISAPPOINTMENT AND IMA LAKES AREA, BOUNDARY WATERS CANOE AREA, LAKE COUNTY, NE MINNESOTA

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The “capstone” project for the Precambrian Research Center summer field camp encompasses one week of detailed field mapping in small groups with faculty from the summer field camp. During the fifth and sixth weeks of the 2008 field camp, seven students mapped in the vicinities of Disappointment and Ima Lakes (located within the Boundary Waters Canoe Area Wilderness) under the direction of PRC Faculty Dr. Dean Peterson and Dr. George Hudak. Geological maps of the area were originally published in reports by Van Hise (1901) and Gruner (1941). The purpose of this capstone mapping project was 1) to better understand the nature of the contact between the Mesoproterozoic Duluth Complex and Neoarchean supracrustal strata; 2) to better understand the compositional make up of the Duluth Complex in this area; and 3) to better understand the stratigraphic and structural characteristics of the Neoarchean rocks in this locale. The final map was published at 1:10000 scale and covered an area of approximately 15 square miles.

Prior to mapping, detailed field mapping sheets were constructed. Field mapping sheets were produced at 1:5000 scale. One side of each field mapping sheet consisted of digitized topographic maps, topographic contours and bathymetric contours (digitized in 3D). The second side of each field mapping sheet consisted of an air photo and aeromagnetic data (Chandler, 1991). Mapping was primarily done from canoe, but several difficult traverses through blow-down were also accomplished. For example, there were several traverses completed by faculty and students where our feet never touched the ground for several hundred meters, as we were climbing over dead and fallen trees. Each night, each field party copied their field data on to a master field map, so that by the end of the week, the field map was essentially completed. During the sixth week of the field camp, students digitally produced the field map utilizing a wide variety of software (including ArcView, AutoCad, Surfer, and Adobe Illustrator).

Neoarchean strata (~2.72-2.67Ga) in the study area varied from steeply southwest-dipping to steeply northeast-dipping. The base of the stratigraphic section is interpreted to comprise the Knife Lake Group, and is composed, from oldest to youngest units, of a) massive and pillowed basalt lava flows ; b) interbedded rhyodacitic to dacitic tuff/ lapilli tuff and polymict lapilli tuff/tuff-breccia deposits; c) andesitic lapilli tuff/tuff- breccias; d) interbedded mustone, chert, and Algoma-type oxide-facies banded iron formation; and e) interbedded mustones and greywackes with minor Algoma-type oxide-facies banded iron formation. Subsequent regional D₂ deformation led to the development of west-northwest – east-southeast-trending zones of chlorite schist that are up to 50 meters thick and that can be followed along strike for 500-800 meters. Timiskiming-type metasedimentary strata composed of polymict conglomerates and conglomeratic sandstones occur north of the chlorite schist zones, and are believed to comprise the Ogishke conglomerate (Jirsa and Miller, 2004). Locally, Neoarchean intrusive rocks are locally present and include

synvolcanic diabase dikes, and post-volcanic quartz-feldspar porphyry dikes and diorite stocks.

The Mesoproterozoic (~1.1 Ga) Duluth Complex in the vicinity of Ima Lake is composed of early Anorthositic Series rocks (anorthosite and anorthositic gabbro) that were subsequently intruded by the new, informally named Ima Lake Intrusion. The Ima Lake Intrusion is broadly layered, and comprises a) a basal unit composed primarily of oxide- and sulfide-bearing gabbros with local zones comprising sulfide-bearing norite; b) an extensive unit of augite troctolite; c) and an upper zone composed of anorthositic troctolite. The sulfide-bearing gabbroic base of this intrusion is akin to Early Gabbro Series intrusions to the east-northeast and differs markedly to the classic sulfide-bearing troctolitic intrusions of the Troctolite Series to the southwest (ie., the South Kawishiwi and Partridge River intrusions). A two kilometer long by up to 500 meter thick zone of pyroxene hornfels occurs along the southwestern margin of the Ima Lake Intrusion, suggesting that Neoarchean supracrustal strata were thermally metamorphosed during the emplacement of the Duluth Complex.

This detailed mapping project, combined with analysis of aeromagnetic data, has resulted in the relocation of the contact between the Duluth Complex and the adjacent Neoarchean supracrustal strata approximately 1.6 kilometers from previous mapping (Miller et al., 2001).

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METAMORPHISM AND DEFORMATION AT MUSSELWHITE MINE

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Musselwhite Mine is a shear-zone-hosted orogenic gold deposit located within the Superior Province in Northwestern Ontario, 480 km north of Thunder Bay. An Archean metamorphosed and deformed banded iron formation is host to the economic gold mineralization.

Metamorphism and deformation are contemporaneous with gold mineralization at Musselwhite Mine. Most of the gold mineralization is within garnet-grunerite-biotite schist. Associated garnet-staurolite-biotite schist and sillimanite-garnet-staurolite-biotite schist indicate metamorphism within the staurolite or sillimanite zone of the amphibolite facies. True amphibolites are absent within the mine due to dominance of metasedimentary lithologies. Grunerite schist and biotite-grunerite schist, often logged as mafic volcanics, are interpreted as metasedimentary.

As expected at amphibolite facies metamorphic conditions the rocks have mainly undergone ductile deformation. At the microscopic scale, strain is heterogeneous across compositional bands within the metamorphosed banded iron formation. Quartz bands have relatively larger grains with undulose extinction and irregular grain shapes typical of grain boundary migration recrystallization. Adjacent to grunerite, quartz is finer grained, implying some difference in strain rate or deformation mechanisms along phase boundaries. Within iron-rich bands, grunerite, biotite, and garnet are products of metamorphic reaction. Fine-grained biotite and grunerite define the foliation. Strain partitioning between these iron-rich bands and the quartz bands is likely.

Although most minerals exhibit evidence of ductile deformation mechanisms at these metamorphic conditions, garnet does not. The garnet crystals have undergone brittle deformation. This small amount of brittle deformation in otherwise ductile conditions may create temporary porosity in a region which otherwise has none. This seems to be important to gold mineralization because gold is found in and around areas where both brittle and ductile deformation structures are present.

OPTIONS FOR GEOLOGIC SEQUESTRATION OF CARBON IN THE UPPER MIDWEST: MINERAL CARBONATION AND DEEP INJECTION

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Increasing concern about climate change has necessitated assessment of ways to reduce emissions, while increasing our preparedness to adapt. Emissions reductions can be achieved by reducing combustion of fossil fuels, by reducing other activity that generates greenhouse gases, and by increasing carbon storage in vegetation and soils. In addition, the technology to capture CO₂ from sources such as electrical generating stations and ethanol plants is available, allowing geologic sequestration through methods such as deep injection or mineral carbonation to return carbon to the geosphere. Options within Minnesota therefore are being assessed, as an alternative to eventual transportation of CO₂ by pipeline to a jurisdiction such as North Dakota or Illinois.

In relation to deep injection, the most prospective rocks in Minnesota at the 1 km depth required to maintain CO₂ in a liquid-like state are sedimentary basins of the Midcontinent Rift, present in two north-south belts on either side of the Twin Cities, running from Pine County and Washington County, south to Iowa. Currently available data, however, indicate that there is a very low probability of success in confirming suitable geologic conditions in these rocks, due to likely lack of adequate porosity and permeability, as well as inadequate seal integrity - while at the same time, it is recognized that drilling may be required to adequately clarify options prior to major expenditures on other options (Thorleifson, 2008).

Another geologic technique is mineral carbonation, in which CO₂ is reacted with olivine-rich material from mining, producing mineral products for disposal or use in construction (Metz et al., 2005). A clear advantage of this method is the lack of risk due to leakage. Minnesota may eventually be well positioned to utilize the mineral carbonation method of geologic carbon sequestration, given the presence of large tonnages of appropriate rock material near Duluth that may be mined for copper, nickel, and platinum group elements, in proximity to well developed infrastructure. In this method, CO₂ is reacted with minerals such as olivine, yielding carbonate and quartz. Should these deposits go into production, it is possible that the slurry of minerals produced as a waste product from the mines could be suitable for mineral carbonation of CO₂, and in a future carbon-trading scenario, these mines could obtain significant revenue by selling carbon credits. The principal constraint to mineral carbonation at present, however, appears to be cost. According to the Intergovernmental Panel on Climate Change (IPCC), costs for deep injection of CO₂ into saline formations are estimated at 0.5 to 8 US\$/tCO₂, while their estimate for mineral carbonation is 50 to 100 US\$/tCO₂ (Metz et al., 2007). Furthermore, although the process has been demonstrated experimentally, it has not been tested at a scale that approximates field conditions. Nevertheless, there could be developments in the method, and there could be circumstances in which a particularly favorable mineral carbonation opportunity could coincide with constraints to other sequestration options, such as transportation, thus possibly making mineral carbonation a conceivable option.

Minnesota agencies therefore are preparing to conduct an analysis of the mineral carbonation option, to place available information into a Minnesota context, largely by modeling a scenario related to Duluth-region mining in order to evaluate the magnitude of this potential opportunity. A needed aspect of the analysis will be an approximation of the foreseen waste rock composition and production rates at the proposed and contemplated mines, based on literature, analogy to mines elsewhere, and data made available by the project proponents. The analysis will seek to identify the amount of CO₂ that could be stored, given well-outlined assumptions, resulting in an estimate of the potential that can readily be updated as needed information is enhanced. This information will enable

Minnesota public and private agencies to be aware of the likelihood that mineral carbonation could be an option for the state, the approximate magnitude of the potential in terms of the amount of carbon that could be sequestered at what rate and cost, and the factors that will govern whether implementation can be anticipated. By doing so, an activity that could possibly bring significant economic benefits to the state in association with anticipated climate change policy initiatives will be clarified. Should the literature review phase be encouraging, further analysis of mineral processing considerations would be called for, to be conducted by parties with the required expertise.

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MINE WATER QUALITY PREDICTION AND ENVIRONMENTALLY-RESPONSIBLE MINING – YES WE CAN!

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Minnesota is entering a new era of mine development as economic prospects associated with the Duluth Complex are being pursued with considerable vigor. Equally vigorous has been the opposition to such developments, fueled in large part by the concerns related to potential environmental impacts. Coupled with the notion that prediction of such impacts is considered by some to be exceedingly difficult and frequently flawed, it would seem that exploitation of the Duluth Complex faces an uphill battle.

In reality, prediction and prevention of environmental impacts has made significant strides in the last decade. Current available guidance on sample collection, geochemical characterization methods, interpretation of results, water quality prediction, and evaluation of potential environmental impacts is based on best practices that have met with demonstrated success. In particular, the most recent guidance, the Global Acid Rock Drainage Guide (GARD Guide), developed by the International Network for Acid Prevention (INAP, 2009), a consortium of mining companies dedicated to reducing liabilities associated with sulfide mine materials, contains a wealth of information in this regard, and presents a roadmap to evaluate and manage environmental issues related to generation of acid rock drainage and metal leaching (ARD/ML).

Our general understanding of geologic materials, mine wastes, and hydrogeochemical factors that govern mine water quality continues to advance through the implementation of laboratory and field experiments. Similarly, ongoing characterization and monitoring of mine facilities allows for development of improved scaling factors needed to extrapolate results from smaller-scale tests to an operational level. Further, the necessary tools required for geochemical, hydrological, and hydrogeological modeling in support of water quality prediction exist.

It should further be noted that the use of more sophisticated tools does not necessarily equate to more accurate and precise water quality predictions. The nature and sophistication of a prediction effort should vary depending on the desired outcome. For instance, a prediction exercise aimed at answering a “yes/no” question (for example: will the water quality criterion for constituent X be exceeded?) requires less *a priori* understanding of the system being evaluated, in which case the use of a relatively basic prediction approach may suffice. In contrast, when a more quantitative answer is required (for example: what is the expected concentration of constituent X), the complexity of the prediction effort may be quite significant, requiring both a detailed conceptualization of the system being modeled as well as use of advanced modeling codes.

Therefore, tools should be selected that suit the need of a particular application and are compatible with the range and quality of the input data. Also regulatory expectations with respect to water quality prediction should become more realistic. It should be recognized that massive sampling and testing sampling campaigns coupled with extensive, expensive, and frequently impenetrable water quality modeling are not always a guarantee for more precise and accurate water quality predictions, but in fact may provide a false sense of security. Instead, use of simpler and more robust approaches, that take into account accumulated knowledge complemented by a targeted verification campaign, may be just as reliable and useful for decision making.

A good example of such a robust approach is the use of geo-environmental models. Geo-environmental models provide a very useful way to interpret and summarize the environmental signatures of mining and mineral deposits in a systematic geologic context (Plumlee, 1999), and can, therefore be used to anticipate water qualities and potential environmental problems at future mines, operating mines, and orphan sites.

Figure 1 shows ranges of pH and trace metals concentrations for mine water discharging from two types of ores of interest to Minnesota: banded iron formation ores (i.e., the taconite ores), and magmatic sulfide deposits such as the Duluth Complex. Without having collected a single sample, stakeholders can readily identify potential water quality issues associated with the two different ore types. Through a limited sampling and characterization program, these water quality ranges can be refined and verified.

Information presented in Figure 1 can also be used to identify and evaluate prevention and mitigation alternatives. Although some site-specific testing will be needed, such a program can focus from the outset on appropriate and relevant methods, bounded by pragmatic constraints.

Figure 1 identifies that exploitation of the Duluth Complex may generate mine water that is of different quality than the taconite operations have traditionally produced. However, the modern mining industry is committed to and capable of minimizing environmental impacts. Kennecott's Flambeau Mine in Wisconsin is a good example of such an approach. Although, due to the nature of the ore deposit, potential water qualities at this site were predicted to be much poorer than expected from the Duluth Complex, proper waste management and reclamation have lead to successful prevention of water quality impacts while the site has been restored to beneficial use

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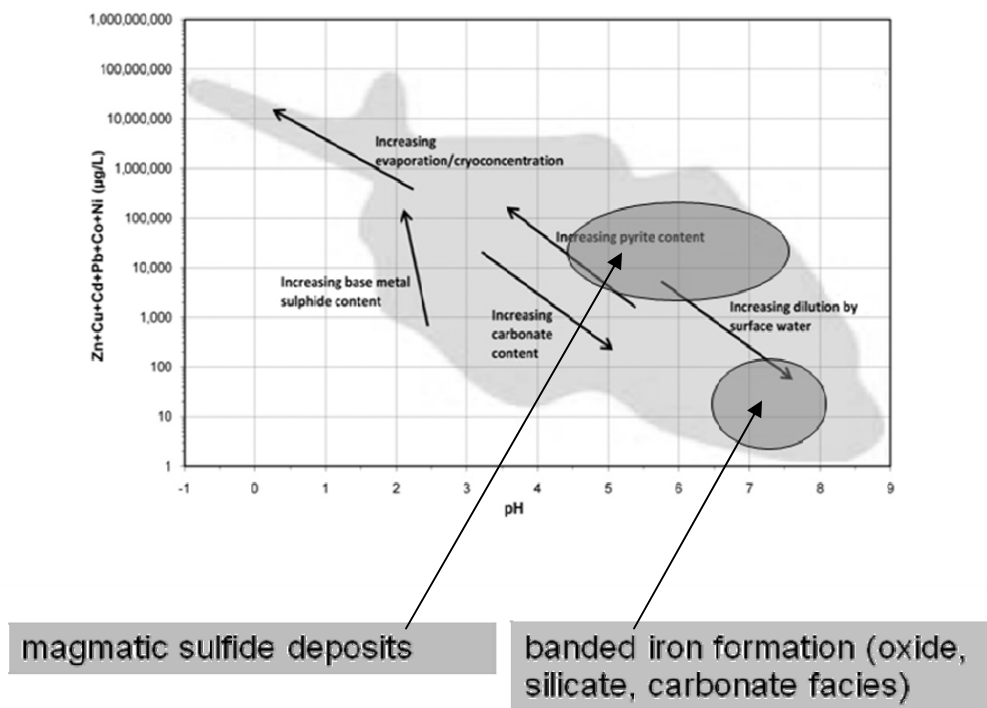


Figure 1. Water quality ranges for magmatic sulfide deposits and banded iron formation

HYDROSTRATIGRAPHY OF THE BIWABIK IRON FORMATION – IMPLICATIONS FOR CURRENT GROUNDWATER FLOW PATTERNS AND PAST GENESIS OF NATURAL ORE BODIES

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Recent well logging studies conducted by the Minnesota Geological Survey and the Minnesota Department of Health on the west-central Mesabi Iron Range suggest that groundwater flow within the Biwabik Iron Formation is influenced by internal stratigraphic contacts. Groundwater flow appears to be focused in distinct zones within the Upper and Lower Cherty members. The strongest evidence for flow appears near the top of these members, close to the contact with overlying slaty strata. The Upper Cherty flow zone is characterized by groundwater that is young in recharge age, warm and high in total dissolved solids relative to the Lower Cherty flow zone.

These findings have several implications regarding mine dewatering and other environmental considerations. In addition, they may reflect on the origins of the natural ore bodies that were exploited in the early years of mining on the Mesabi Range. These data support a model whereby vertical movement of oxidizing fluids along faults and fractures was accompanied by lateral flow along contacts between slaty and cherty strata.

MAGMA CONDUIT HOSTED PLATINUM-PALLADIUM-COPPER-NICKEL MINERALIZATION AT THE THUNDER BAY NORTH PROJECT, NORTHWEST ONTARIO: DISCOVERY, EXPLORATION, GEOLOGY AND RESOURCE POTENTIAL

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Glacially transported Pt-Pd-Cu-Ni mineralized peridotite boulders were found on the west shore of Current Lake, approximately 50 km northeast of Thunder Bay, by two geologists prospecting through the area in 2001. Magma Metals Limited optioned the claims in 2005 and found a larger occurrence of mineralized boulders on the east shore of the lake in mid-2006. Magma drilled its first hole, TBND001, under these boulders in December 2006 and intersected 10.5 m @ 2.69g/t Pt+Pd, 0.45% Cu & 0.34% Ni from 72 m down-hole.

Subsequent geophysical surveys and over 45,000 m of drilling have delineated a large mineralized intrusive complex within a 50 km² area. The complex forms a network of mafic-ultramafic magma conduits associated with the Keweenawan-age Midcontinent Rift. The mafic-ultramafic magmas were emplaced within late-Archean granitoids and metasediments of the Quetico subprovince of the Superior craton. Most of the exploration work has focused on the Current Lake Intrusive Complex (CLIC), the 5 km-long easternmost conduit, which is described here.

Several intrusive phases have been identified and there are strong structural controls on the emplacement of the conduits. The earliest intrusive phase in the CLIC is a minor pegmatoid unit which intrudes flat structures. This is followed by gabbro phases which have assimilated much country rock and show a variety of textures and compositions; these intrude flat and steep structures. Finally, several pulses of sulphide-rich melagabbro to peridotite intrude the earlier phases and form the main conduits.

The dominant style of mineralization is disseminated sulphide, principally pyrrhotite and chalcopyrite. Thick zones have been intersected in systematic drilling over a strike length of 3 km in the CLIC, some of these zones are relatively high-grade, e.g. 61.7 m @ 2.87g/t Pt, 2.74g/t Pd, 0.66% Cu & 0.38% Ni from 29.3 m down-hole, including 35.5 m @ 4.52g/t Pt, 4.31g/t Pd, 1.04% Cu & 0.57% Ni in drill-hole TBND061. Zones of net-textured (semi-massive) sulphide also occur. Some narrow intervals of high-grade massive sulphide mineralization have also been intersected near the base of the conduit, including 0.4 m @ 13.80g/t Pt, 10.75g/t Pd, 3.70% Cu & 2.91% Ni from 315.15 m down-hole in drill-hole BL08-61. There is generally good correlation between pyrrhotite-chalcopyrite abundance and grade of mineralization. Sulphide tenors (estimated grades in 100% sulphide) are consistently in the ranges 3-4% Ni, 6-8% Cu, 24-38g/t Pt and 22-37g/t Pd.

There is excellent correlation between Pt, Pd, Cu and Ni in the melagabbro-peridotite indicating a pristine magmatic system with little alteration or re-distribution of metals. Preliminary petrochemical analysis indicates the mineralized melagabbro-peridotite had a tholeiitic parent magma (~6% MgO) and there is evidence of homogenized crustal contamination in addition to localized marginal contamination.

Recent reconnaissance drilling in other parts of the magma conduit network to the west of the CLIC has confirmed the potential for further mineralization outside of the area currently being systematically drilled. There is potential for an aggregate multi-million ounce resource of platinum-group metals with substantial copper and nickel credits within the magma conduit network. There is also potential for associated Ni-Cu massive sulphide deposits. A major drilling program is in progress to define initial resources within the northwestern and central parts of the CLIC over a strike-length of 3 km.

DIAMONDIFEROUS MASS-FLOW AND PLACER DEPOSITS FORMING A NEOARCHEAN FAN DELTA, WAWA AREA, SUPERIOR PROVINCE

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Diamond bearing Neoproterozoic metaconglomerates are present in the Michipicoten Greenstone Belt, Wawa-Abitibi Subprovince, near Wawa, Ontario. They form a portion of the Dore Metasediments in the Arliss Lake Subbasin, and unconformably overlie a succession of mafic metabasalts. The conglomerates are transitional to the south into argillite and are overlain by argillite. This in turn is conformably overlain by metabasalts. The conglomeratic succession under study here has a maximum thickness of 454 meters and is confined in what appears to be a deformed paleovalley at the base of the sedimentary succession. It pinches out against basement on its northern margin and is terminated by a fault on its southern margin, where it is 200 meters thick. Both matrix supported and clast supported beds characterize the unit.

Dominant clast types include basalt, rhyolite, gabbro, diorite and sandstone. Clasts are generally angular to sub-rounded, and more rarely rounded to well-rounded. Matrix compositions and textures are variable from mud- and silt-sized material dominating within the matrix-supported, cobble to boulder conglomerates, to fine-grained to very coarse-grained feldspathic, quartz-rich and mafic sands within the clast-supported, cobble to pebble conglomerates. Boulder conglomerates are poorly sorted, while cobble to pebble conglomerates are poorly to moderately-well sorted with a decrease in clast size generally corresponding to better sorting. The unit can be divided into two main lithofacies associations. The dominant lithofacies within Association 1 is massive, matrix-supported cobble to boulder conglomerate, characterized by an abundance of mud-sized matrix material that is disorganized to swirly. This is interbedded with massive to crudely horizontally layered, and more rarely trough cross-stratified, cobble to pebble conglomerate and minor horizontally layered coarse-grained sandstone. Contacts between these lithofacies are commonly planar and rarely erosive. This facies association is most prevalent near the base of the succession in the center of the apparent paleovalley. Many of the features of the mud-rich conglomerates suggest weakly sheared and highly viscous debris-flows. The poor-sorting, high mud matrix content, angularity of clasts and lack of sedimentary structures implies that few grain-to-grain bedload collisions occurred (weakly sheared) and the transportation mechanism was incapable of winnowing fine sediments and sorting the clasts. Highly viscous debris-flows are characterized by a muddy matrix and often occur in the proximal reaches of alluvial fans, whereas sandy matrix is typical of less viscous, distal-fan debris-flows. Some units containing disorganized clast fabrics may have formed from non-sheared (high strength) plug flow, or only weakly sheared, high viscosity flow on the upper fan. The trough cross-stratified and horizontally layered conglomerates interlayered with the massive conglomerates are the product of active bedload traction transport that was more efficient at winnowing fine sediment and sorting clasts. The sporadically developed erosive bases exhibited by these units and their upward fining is typical of turbulent fluidal flow or heavily sediment laden stream flow following a debris-flow event. Where the stratified conglomerates exhibit more extensive erosional bases they probably represent later erosive reworking of debris-flow material by stream activity. The horizontally stratified sandstones present capping the layered conglomerates were deposited by waning flow resulting in cessation of movement of clasts, falling of sand from the saltation and suspension populations into the traction population, and its deposition. Composite units with thick, crude to distinct internal layering or with the presence of thin, discontinuous sandy zones may result from rapidly surging flows.

Lithofacies Association 2 occurs in the middle and upper portions of the unit. It is composed of interbedding of massive, clast-supported conglomerate and horizontally laminated and trough cross-stratified sandstone. Other minor lithofacies that occur locally are horizontally layered and trough

cross-stratified conglomerate; planar cross-stratified, ripple laminated and scour-fill sandstones; and horizontally laminated and massive mudstones. The major difference between the massive conglomerates of this Association and Association 1 is that the former is generally finer-grained, dominated by cobbles and pebbles, is clast supported and has a coarse-grained sand to granule matrix. This association was deposited by traction currents in braided fluvial channels of the Scott type. These channels were dominated by gravel longitudinal bars with sandy lenses formed by the infilling of chute channels and scour hollows during falling stage and low water. Sand and gravel bar edge sand wedges were also present in the system and major channels were probably mostly dominated by gravel, as more extensive sandstone successions, typical of sandy large channels, are rare.

Association 1 was the product of proximal alluvial fan debris-flows that would have occurred on a fairly steep gradient allowing for such rapidly surging flows to result in an increase in sediment instability causing the coarse-grained sediment and mud-charged debris-flows to move down the alluvial fan-delta. As the gradient decreased the highly viscous debris-flows would deposit almost instantaneously resulting in the immature nature of the fabric and large boulder sized clasts being left in suspension in the muddy, swirly textured matrix. Once the initial surge of the debris-flow had been deposited the fluvial activity that remained would, on occasion, be strong enough to actively transport bedload material depositing stratified gravels and sands as the stage fell. Further down fan was subjected to less debris-flow activity and it developed an extensive network of gravelly braided channels and gravel bars. It is likely that the upper fan-delta was dominated by off channel processes, whereas in the mid-fan-delta, where the main channel was no longer entrenched, water and sediment was delivered to the fan's surface on a more consistent basis leading to a better developed fluvial network. A transgressive event resulted in a rapid drowning of the fan delta and deposition of fine-grained sediment.

Whole-rock geochemistry was conducted on samples of metasedimentary rock from the unit. Ratio plots utilizing immobile elements clearly indicate that the sediment was mostly derived from mafic rock mixed with an ultramafic igneous source. A minor number of samples had a significant felsic source component. The CIA values for the sandstones indicate most samples have undergone a moderate amount of weathering with some reflecting fairly intense weathering. Elements typically contained in heavy minerals, and therefore enriched in placer deposits, (i.e. Zr, Ti, Nb, Y, REEs, Cr and Ni) do not show any systematic enrichment in the sandstones sampled that cannot be accounted for by the composition of the source rocks. This strongly implies that preferential heavy mineral enrichment did not occur in the sandstones. The conglomerates are still under investigation. Diamond concentrations are correlated with increased amounts of Ni, Cr, Co, Ti, Fe and Mg in the samples. When the sandstone samples were plotted on a TiO_2/Zr , Nb/Y diagram they defined a more alkalic trend than the felsic to mafic volcanic rocks in the area. This is in agreement with an alkalic ultramafic source rock for the diamonds. The source could either be ultramafic, diamond-bearing lamprophyre dikes present in the area or as yet undiscovered or eroded kimberlites. Whatever the source, a prolific amount of it must have been exposed on surface during formation of the fan delta.

