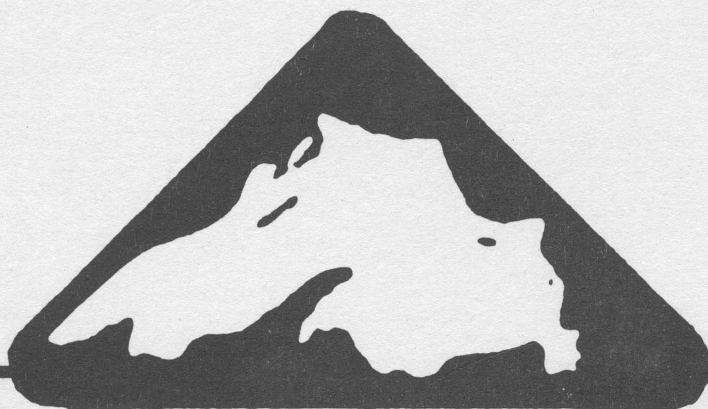


TWENTY-NINTH ANNUAL MEETING

INSTITUTE ON LAKE SUPERIOR GEOLOGY



**May 11-14, 1983
Houghton, Michigan 49931**

Organized by the Department of Geology and Geological Engineering
in cooperation with
the Division of Education and Public Services
Michigan Technological University, Houghton, Michigan 49931

PROCEEDINGS
TWENTY-NINTH ANNUAL
INSTITUTE ON LAKE SUPERIOR
GEOLOGY

held at
Michigan Technological University
Houghton, Michigan 49931
May 11-14, 1983

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Houghton, Michigan 49931

T. J. Bornhorst and J. F. Diehl
Editors

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GENERAL INFORMATION

29th Annual

INSTITUTE ON LAKE SUPERIOR GEOLOGY

Michigan Technological University

Houghton, Michigan

May 11-14, 1983

PURCHASE INFORMATION FOR PROCEEDINGS VOLUME

Volume I & II together for sale at: The Division of Education and
Public Services
Michigan Technological University

Volume II only for sale at: E. R. Lauren Bookstore
Michigan Technological University

INSTITUTE BOARD OF DIRECTORS

T.J. Bornhorst, Department of Geology and Geological Engineering, Michigan
Technological University, Houghton, Michigan (Chairman, 1983)

D.L. Southwick, Minnesota Geological Survey, St. Paul, Minnesota (1982)

W.C. Cambray, Department of Geology, Michigan State University, East Lansing,
Michigan (1981)

P.E. Myers, Department of Geology, University of Wisconsin, Eau Claire, Wisconsin
(1980)

R.C. Reed, Geological Survey Division, Department of Natural Resources, Lansing,
Michigan (Secretary-Treasurer)

LOCAL COMMITTEE

Conference Chairman

T.J. Bornhorst, Department of Geology and Geological Engineering, Michigan Technological University, Houghton, Michigan 49931.

Field Trips

T.J. Bornhorst
J. Kalliokoski
J.B. Paces
W.I. Rose, Jr.
D.M. Rossell

All at the Department of Geology and Geological Engineering, Michigan Technological University, Houghton, Michigan 49931.

Physical Arrangements

Jane Berner, Coordinator
Jean Joffe, Secretary

Division of Education and Public Services
Michigan Technological University, Houghton, Michigan 49931.

Best Student Paper Committee

M.G. Mudrey, Jr., Wisconsin Geological Survey, Madison, Wisconsin 53706.
S.C. Nordeng, Department of Geology and Geological Engineering, Michigan Technological University, Houghton, Michigan 49931.
R. Rowe, Exxon Minerals Company, Rhinelander, Wisconsin 54501.

GOLDICH MEDAL COMMITTEE

G.L. LaBerge, Department of Geology, University of Wisconsin-Oshkosh, Oshkosh, Wisconsin 54901 (Chairman).
R.L. Buchheit, Meridian Land and Mineral Company, Billings, Montana 59103.
W.F. Cannon, U.S. Geological Survey, Reston, Virginia 22092.

SESSION CHAIRMAN

W.S. Cordua, Department of Plant and Earth Sciences, University of Wisconsin-River Falls, River Falls, Wisconsin 54022.
T.B. Holst, Department of Geology, University of Minnesota-Duluth, Duluth, Minnesota 55812.
A.M. Johnson, Institute of Mineral Research, Michigan Technological University, Houghton, Michigan 49931.
J.S. Klasner, Department of Geology, Western Illinois University, Macomb, Illinois 61455.
S.D. McDowell, Department of Geology and Geological Engineering, Michigan Technological University, Houghton, Michigan 49931.

N. Scofield, Department of Geology and Geological Engineering, South Dakota
School of Mines & Technology, Rapid City, South Dakota 57701.
D.L. Southwick, Minnesota Geological Survey, St. Paul, Minnesota 55108.
C.T. Young, Department of Geology and Geological Engineering, Michigan
Technological University, Houghton, Michigan 49931.

ANNUAL BANQUET GUEST SPEAKER

Stephen E. Kesler, Department of Geology, University of Michigan, Ann Arbor,
Michigan 48109.

GOLDICH MEDAL RECIPIENT

Burton H. Boyum, 1740 Glendura Lane, Ishpeming, Michigan 49849.

ACKNOWLEDGEMENTS

The Organizing Committee of the 1983 Institute on Lake Superior Geology
gratefully acknowledge the work of Julene E. Erickson in typing drafts and final
manuscript for the Proceedings Volumes.

REPORT OF THE CHAIRMAN
28th INSTITUTE ON LAKE SUPERIOR GEOLOGY

1982

The 28th Institute on Lake Superior Geology was held May 5-8, 1982 in International Falls, Minnesota under the sponsorship of the Minnesota Geological Survey. Registrants numbered 147, including 121 professional geologists and 26 students. The program included a pre-meeting one-day field trip to examine mineral occurrences in the Fort Frances-Mine Centre area, Ontario, a post-meeting one-day field trip to provide an overview of the Archean geology near International Falls and Kabetogama, Minnesota, and four half-day sessions of technical papers. Seventy seven persons participated in the pre-meeting trip, 51 participated in the post-meeting trip, and 31 papers were accepted for oral presentation at the technical sessions. Background papers for the field trips, field trip road logs, and accepted abstracts were published in the Proceedings volume.

At the Annual Dinner on May 6, 1982 Ralph Marsden was awarded the Institute's Goldich Medal in recognition of his many contributions to the Institute and to the geology of the Lake Superior region. The banquet address was given by Dr. Randolph Koski of the U.S. Geological Survey, who described recent oceanographic research on metal-precipitating hot springs along spreading ridges in the eastern Pacific, and speculated on the role such hydrothermal systems may have played in the production of volcanic-hosted sulfide deposits in Archean greenstone belts.

K. Howard Poulsen, graduate student at Queen's University, received a cash award for presenting the best paper by a student. His paper was entitled "Mineral deposits of the Fort Frances-Mine Centre area."

An open discussion on the organization of the Institute was held on the evening of May 5, 1982 with J. Kalliokoski acting as moderator. About 20 people attended and discussed a range of issues concerning the objectives of the Institute, the pros and cons of formalization, and the manner in which the Institute now manages or should manage its financial affairs. Several informal motions were passed and transmitted to the Board of Directors for consideration at their annual meeting. Many of those attending the discussion were surprised to learn that the Institute indeed does have a formal constitution and a set of by-laws, and also has an I.R.S. number as a tax-exempt, non-profit organization. The constitution and by-laws are appended to this report.

The Board of Directors of the Institute met on May 6, 1982 and took the following action:

1. Accepted with thanks the offer of the Minnesota Geological Survey to maintain the mailing list of the I.L.S.G. The list is now stored on a floppy disk and can be amended easily on the Survey's word processor. The Survey will update the list as instructed by each General Chairman and will supply print-outs of the list and mailing labels to each host organizing committee.

2. Agreed to leave in Canada those I.L.S.G. funds that presently are in Canada, and to appoint M.M. Kehlenbeck, Lakehead University, Thunder Bay, Ontario, as custodian of the Canadian account. The Canadian monies are to be used against I.L.S.G. obligations in Canada to avoid losses on currency exchange. A statement of the Canadian account is appended to this report.
3. Formally moved that henceforth one dollar of each registration fee will be set aside into a special fund to sustain the costs of striking Goldich medals. The Goldich medal fund will be kept separate from I.L.S.G. operating monies and will be maintained in a separate bank account. Under this plan enough money will have accumulated in 7 years to strike a batch of 10 medals, replacing the supply currently on hand. The Board also noted for the record that the first Goldich medal was awarded to S.S. Goldich, the second to Carl Dutton, and the third to Ralph Marsden, leaving 7 for subsequent years from the first striking of 10. The remaining medals are in the custody of G.B. Morey, Minnesota Geological Survey, and are stored in a bank safety deposit box in Minneapolis.
4. Instructed the Secretary - Treasurer to move I.L.S.G. funds from the present non-interest-bearing account to an account that pays the maximum rate obtainable while maintaining liquidity.
5. Noted the desire of Robert C. Reed, Secretary - Treasurer, to retire from his position as of the next Board meeting in Houghton in May 1983. A new Secretary - Treasurer will be elected at the Houghton Meeting.
6. Accepted with thanks the offer of the Geology Department of the University of Wisconsin at Oshkosh to host the 30th I.L.S.G. at Wausau, Wisconsin in 1984.
7. Noted with anticipation the informal offer of Charles Blackburn, Ontario Geological Survey, Kenora Office, to host the 1985 Institute in Kenora. This offer is understood to be tentative, pending final confirmation from Mr. Blackburn.
8. Moved that the summary report of the Chairman be included each year in the next-following Proceedings volume so as to maintain a current and public account of the Institute's affairs.
9. Appointed the following persons to serve on the selection committee for recipients of the Goldich medal:

Gene LaBerge, 1 year term, Chairman (representing academia)
Richard Bucheit, 2 year term, (representing industry)
William Cannon, 3 year term (representing government)

The Board further stipulated that subsequent appointments to fill vacancies on the committee should maintain the equal representation of academia, industry, and government.

10. Moved that the committee to select the best student paper be appointed each year by the host organizing committee. The committee appointed should consist of representatives from academia, industry, and government.

Financially the 28th I.L.S.G. concluded with a net profit of \$2,210.64, and thus pumped some badly needed funds into the general treasury which had been depleted severely by recent deficit meetings and the start-up costs for the Goldich medal program. In my opinion the Institute is in good shape both financially and intellectually, and it is with a sense of satisfaction and relief that I turn over responsibility for 1983 operations to Ted Bornhorst of Michigan Tech.

David L. Southwick

David L. Southwick
General Chairman
28th I.L.S.G.
July 30, 1982

CALENDER OF EVENTS AND PROGRAM

TUESDAY, MAY 10, 1983

7:00 p.m. - 9:00 p.m. EARLY REGISTRATION FOR PARTICIPANTS IN FIELD TRIP 1.

WEDNESDAY, MAY 11, 1983

8:00 a.m. - 6:00 p.m. FIELD TRIP 1. GEOLOGY OF THE KEWEENAW PENINSULA, MICHIGAN - T.J. Bornhorst, W.I. Rose and J.B. Paces, leaders.

4:00 p.m. - 10:00 p.m. REGISTRATION - MEMORIAL UNION BUILDING

7:00 p.m. - 10:00 p.m. SMOKER AND CASH BAR

THURSDAY, MAY 12, 1983

7:30 a.m. - 4:30 p.m. REGISTRATION - MEMORIAL UNION BUILDING

8:20 a.m. - 8:25 a.m. WELCOME TO MICHIGAN TECH, Dr. E.H.T. Whitten, Vice President for Academic Affairs, Michigan Technological University.

8:25 a.m. - 8:30 a.m. WELCOME TO 29TH I.L.S.G., T.J. Bornhorst, Chairman.

8:30 a.m. - 12:00 p.m. TECHNICAL SESSION I, W.S. Cordua and S.D. McDowell, Co-Chairmen.

8:30 a.m. John C. Green -- COMPOSITION, ORIGIN AND EVOLUTION OF KEWEENAWAN MAGMAS - A REVIEW (invited paper).

9:00 a.m. Klaus J. Schulz -- GEOCHEMISTRY OF THE VOLCANIC ROCKS OF NORTHEASTERN WISCONSIN.

9:20 a.m. *James D. Miller, Jr. -- MAJOR ELEMENT CHEMISTRY OF ANORTHOSITES IN THE DULUTH COMPLEX, SNOWBANK LAKE QUADRANGLE, MINNESOTA.

9:40 a.m. A.P. Ruotsala, Paul M. Stadnik and T.J. Bornhorst -- COBALT, NICKEL AND VANADIUM CONTENTS OF PYRITE FROM MICHIGAN SLATE, MICHIGAN.

10:00 a.m. COFFEE

10:20 a.m. *Abelmonem A. EldougDoug -- GEOLOGICAL AND GEOCHEMICAL CHARACTERISTICS OF THE VOLCANO-SEDIMENTARY GLEN TOWNSHIP FORMATION, EAST-CENTRAL MINNESOTA.

10:40 a.m. M.L. Nebel and R.L. Morton -- HYDROTHERMAL ALTERATION
AT THE HELEN MINE, WAWA, ONTARIO.

11:00 a.m. *Sarah J. Mills -- THE RELATIONSHIP BETWEEN THE BASAL
ZONE AND CLOUD ZONE CU-NI SULFIDES, MINNAMAX
DEPOSIT, DULUTH COMPLEX, MINNESOTA.

11:20 a.m. *Warren C. Day -- ULTRAMETAMORPHISM AND MIGMATITE GENER-
ATION IN THE VERMILION GRANITE COMPLEX, NORTHERN
MICHIGAN.

11:40 a.m. *W.I. Petro -- IGNEOUS ROCKS OF THE BARABOO DISTRICT,
WISCONSIN.

12:15 p.m. - 1:45 p.m. GROUP LUNCHEON, Dr. E.H.T. Whitten, Vice President for
Academic Affairs, Michigan Technological University,
Guest Speaker.

 ANNUAL MEETING, I.L.S.G. BOARD

2:00 p.m. - 5:00 p.m. TECHNICAL SESSION II, J.S. Klasner and C.T. Young,
Co-Chairmen.

2:00 p.m. *M.A. Feighner -- THREE-DIMENSIONAL STRUCTURE OF THE
CRUST AND UPPER MANTLE BENEATH THE LAKE SUPERIOR
REGION.

2:20 p.m. C. Patrick Ervin -- LONG-WAVELENGTH GRAVITY ANOMALIES
IN THE GREAT LAKES REGION.

2:40 p.m. Robert J. Ferderer, Val W. Chandler and Judson Mead --
GRAVITY AND MAGNETIC MODEL STUDIES OF THE SOUTHERN
DULUTH COMPLEX, NORTHEASTERN MINNESOTA.

3:00 p.m. Val W. Chandler -- PALEOMAGNETIC AND MAGNETIC ANOMALY
STUDIES OF THE NORTHWESTERN DULUTH COMPLEX, LAKE
COUNTY, MINNESOTA.

3:20 p.m. COFFEE

3:40 p.m. M.E. Bengtson, R.P. Meyer and H.C. Halls -- THE STRUCTURE
OF THE SLATE ISLANDS AREA OF LAKE SUPERIOR.

4:00 p.m. William S. Cordua -- AN ORDOVICIAN CRYPTOEXPLOSION STRUC-
TURE FROM NEAR ROCK ELM, PIERCE COUNTY, WISCONSIN.

4:20 p.m. U.O. Atuanya, D.T.A. Symons and M. Stupavsky -- PALEO-
MAGNETISM OF THE GUNFLINT IRON FORMATION OF NORTH-
WESTERN ONTARIO.

4:40 p.m. Kidjopa Atttoh, Marc Vander Meulen and Daniel Brandsma --
MODELS FOR THE COOLING OF THE PEAVY POND COMPLEX:
IMPLICATIONS FOR THE METAMORPHIC EFFECT IN SURROUNDING
ROCKS.

6:00 p.m. - 7:30 p.m. COCKTAIL PARTY - CASH BAR

7:30 p.m. - 9:30 p.m. ANNUAL BANQUET

Master of Ceremonies - Dr. Albert P. Ruotsala, Michigan Technological University.

Guest Speaker - Dr. Stephen E. Kesler, University of Michigan, "Precious Metal Deposits and Metamorphic Processes".

FRIDAY, MAY 13, 1983

7:30 a.m. - 12:00 p.m. REGISTRATION - MEMORIAL UNION BUILDING

8:30 a.m. - 12:00 p.m. TECHNICAL SESSION III, T.B. Holst and A.M. Johnson, Co-Chairmen.

8:30 a.m. J.K. Greenburg -- RELATIVE AGE AND TECTONIC SIGNIFICANCE OF PROTEROZOIC METASEDIMENTARY ROCKS IN THE UPPER MIDWEST.

8:50 a.m. S.R. Mattson and F.W. Cambray -- THE REANY CREEK FORMATION: A MASS-FLOW DEPOSIT OF POSSIBLE POST MENOMINEE AGE.

9:10 a.m. *Fred S. Pulka -- DEPOSITIONAL AND STRUCTURAL FEATURE OF THE UPPER FREDA SANDSTONE.

9:30 a.m. *Lawrence C. Rosen -- EVIDENCE FOR GLACIAL MARINE SEDIMENTATION IN THE EARLY PROTEROZOIC GOWGANDA FORMATION, NORTHEASTERN ONTARIO, CANADA.

9:50 a.m. COFFEE

10:20 a.m. M.M. Kehlenbach -- SUPERIMPOSED FOLDING AND ITS IMPLICATION ON THE SHEBANDOWAN-QUETICO SUBPROVINCE BOUNDARY, THUNDER BAY, ONTARIO.

10:40 a.m. T.B. Holst -- EVIDENCE FOR NAPPE DEVELOPMENT DURING THE PENOKEAN OROGENY FROM THE EARLY PROTEROZOIC THOMSON FORMATION, MINNESOTA.

11:00 a.m. J.P. Kaszuba, P.A. Schwarzweller and H.H. Woodard -- FOLDED ROCKS IN THE EASTERN CONTACT ZONE OF THE VERMILION BATHOLITH.

11:20 a.m. B.A. Brown and J.G. Greenberg -- GNEISS DOMES AND NOT-SO-GNEISS DOMES IN THE PENOKEAN TERRANES OF NORTHERN WISCONSIN.

12:15 p.m. - 1:15 p.m. GROUP LUNCHEON - REPORT FROM THE CHAIRMAN.

1:30 p.m. - 4:30 p.m. TECHNICAL SESSION IV, D.L. Southwick and N. Scofield,
Co-Chairmen.

1:30 p.m. Gene L. LaBerge -- LASALLE FALLS - AN EXPOSED MASSIVE
SULFIDE DEPOSIT IN FLORENCE COUNTY, WISCONSIN.

1:50 p.m. *David A. Groves -- STRATIGRAPHY OF THE FOOTWALL VOLCANIC
ROCKS BENEATH THE MATLABI MASSIVE SULFIDE DEPOSIT,
STURGEON LAKE, ONTARIO.

2:10 p.m. John C. Green -- PHYSICAL VOLCANOLOGY OF THE KEWEENAWAN
NORTH SHORE VOLCANICS.

2:30 p.m. COFFEE

3:00 p.m. Ted J. Smith, Paul L. Cloke and Stephen J. Kesler --
GEOCHEMISTRY OF FLUID INCLUSIONS FROM ARCHEAN AND
PHANEROZOIC GOLD DEPOSITS.

3:20 p.m. W.A. Bodwell, J.D. Strapko and G.J. Tonkin -- HISTORY,
GEOLOGY, AND RECENT EXPLORATION OF THE ROPES GOLD
MINE, MARQUETTE COUNTY, MICHIGAN (invited paper).

4:10 p.m. *Dean Rossell -- ALTERATION OF THE DEER LAKE PERIDOTITE
IN THE VICINITY OF THE ROPES GOLD MINE, MARQUETTE
COUNTY, MICHIGAN.

4:30 p.m. ANNOUNCEMENT -- BEST STUDENT PAPER AWARD

SATURDAY, MAY 14, 1983

8:00 a.m. - 6:00 p.m. FIELD TRIP II. THE ROPES GOLD MINE AND ITS GEOLOGICAL
SETTING - D. Rossell and J. Kalliokoski, leaders.

1. Underline denotes speaker
2. *student paper

ABSTRACTS

Paleomagnetism of the Gunflint Iron Formation of Northwestern Ontario

U. O. ATUANYA, D.T.A. SYMONS, and M. STUPAVSKY (Department of Geology,
University of Windsor, Windsor, Ontario, Canada N9B 3P4)

The Gunflint Iron Formation outcrops near Thunder Bay, Ontario, as the basal unit of the Animikie Series in the Southern Province of the Canadian Precambrian Shield. Paleomagnetic studies on samples from 47 sites employing alternating field, thermal and chemical demagnetization techniques lead to the isolation of two major magnetization components. The A component yields a pole position of 124°W , 64°N ($\delta_{\text{p}} = 9^{\circ}$, $\delta_{\text{m}} = 10^{\circ}$) which is interpreted to be a primary or diagenetic component acquired at ~ 2300 Ma. A positive conglomerate test supports this conclusion. The B component gives a pole position of 40°W , 7°S ($\delta_{\text{p}} = 8^{\circ}$, $\delta_{\text{m}} = 13^{\circ}$) which indicates the presence of a Hudsonian orogenic metamorphic overprint acquired at ~ 1720 Ma. Taken together the results indicate that the "Penokean" orogeny of the Southern Province in the northcentral United States is equivalent to the Hudsonian orogeny in Canada. A slightly younger ~ 1650 Ma metamorphic component is restricted to a few sites in the Gunflint. Contact tests with a Keweenaw Sill and a lava flow are positive.

Models for the Cooling of the Peavy Pond Complex: Implications for the Metamorphic Effect in Surrounding Rocks

ATTOH, KODJOPA (Department of Geology, Hope College, Holland, MI 49423)
VANDER MEULEN, MARC (Department of Geology, Hope College, Holland,
 MI 49423)

BRANDSMA, DANIEL (Department of Geological Sciences, University of
 Southern California, Los Angeles, CA 90089)

The Peavy Pond Complex (PVC), located $\sim 12\text{km}$ NW from Iron Mountain in northern Michigan, is comprised predominantly of gabbroic and dioritic intrusive rocks exposed in an area 14km^2 . It is interpreted as a sill-like body which is intrusive into the base of the Michigamme Fm and whose base is crudely conformable with the top of the underlying Hemlock Fm.

We have calculated the solidification positions inside, and temperature outside the pluton assuming the temperature of emplacement of the magma is $\sim 1000^\circ\text{C}$ and a latent heat of solidification (ΔH_S) as $\sim 100\text{ cal/gm}$. For a one-dimensional model, in which a 3.2km thick pluton extending infinitely downwards cools by conduction: the 800°C solidification position is $.34\text{km}$ from the contact after $\sim 10 \times 10^3$ yrs during which time the maximum temperature reached at the contact is 678°C . In this model, the PVC is completely solidified 231×10^3 yrs after intrusion. If convection occurs during cooling, the maximum temperature at the contact is 888°C and convection persists for 157×10^3 years. A two-dimensional model for a rectangular pluton ($3.2 \times 4.4\text{km}$) produces maximum contact temperatures of only 497°C .

Temperatures at positions outside the pluton, in the Michigamme Fm, were calculated from the one-dimensional models. At 2.6km from the contact, a position corresponding to the mapped staurolite isograd, the maximum temperature reached after 486×10^3 yrs is 302°C , during cooling by conduction. The 500°C isotherm advances to a maximum distance of $\sim .78\text{km}$ from the contact, reaching that position after 76×10^3 years. During cooling involving convection, the maximum advance of the 500°C isotherm is $\sim 1.1\text{km}$ from the contact, arriving 100×10^3 yrs after intrusion, and the maximum temperature reached at the staurolite isograd is 349°C .

The calculated temperatures (T) outside the pluton are much lower than the T-conditions of the observed metamorphic zones. For example, the temperature for the staurolite isograd is estimated from the garnet-biotite geothermometer to be 540°C . Moreover, the T-gradient due to thermal effect of PVC is $\sim 80^\circ\text{C/km}$ whereas the T-gradient inferred from the spacing of metamorphic isograds is $\sim 370^\circ\text{C/km}$.

The Structure of the Slate Islands Area of Lake Superior

M. E. Bengtson and R. P. Meyer (Geophysical and Polar Research Center, Department of Geology and Geophysics, University of Wisconsin-Madison, Madison, WI 53706)

H. C. Halls (Erindale College, Mississauga, Ontario, Canada, and Department of Geology, University of Toronto, Canada)

The origin of the Slate Islands structure of northern Lake Superior is the subject of debate. Some propose the islands are the result of meteoritic impact while others advocate an endogenous origin. A marine magnetic and seismic survey was undertaken to examine this question.

Over 1,500 km of magnetic and 3.5-kHz sonic profiles were taken. The sonic data have been used to construct a bedrock bathymetry map, which is similar to a bottom bathymetry map constructed from data taken by the Canadian research vessel Bayfield. Both show a concentric pattern centered on the islands. However, the bedrock topography exhibits almost 50% greater relief. The sonic data also indicate that the bedrock is more chaotic inside the bathymetric high that surrounds the islands.

A magnetic contour map has also been constructed. A curvilinear north-south trending magnetic gradient east of the islands marks the boundary between the Port Coldwell complex and Archean basement rocks. It appears that the Port Coldwell complex extends at least 25 km into the lake. Short-wavelength anomalies on the east side of the islands have half-widths that indicate source depths 1/2 to 1 km below the lake surface. These may well be feeders for the Port Coldwell complex.

West of the islands, a northwest-trending linear anomaly has been identified. This is most likely due to a basin-bounding fault, with Keweenaw volcanics lying only south of it.

Finally, the islands seem to be surrounded by a magnetic low. This is consistent with an arcuate increase in depth to a coherent magnetic basement centered on the islands.

Over 250 km of explosion seismic reflection and refraction lines were taken. Twenty-five km east of the islands, over 700 m of a 3.5-km/s material overlies about 500 m of a 4.5-km/s material. These velocities have been correlated with the Bayfield-Jacobsville sandstones and the Oronto Group, respectively. These sediments overlie a 5.8-km/s refractor, which is the Port Coldwell complex.

Twelve km west of the islands, the sediments thin to a total thickness of less than 500 m. Here they overlie a 6.1-km/s refractor, which is probably the Archean basement. This thinning suggests that the islands lie on a pre-Keweenaw ridge of Archean basement rocks. All refractors outside the peripheral trough have a southerly dip.

The Structure of the Slate Islands Area of Lake Superior (continued)

In the trough, there is some evidence of minor faulting. Here only small amounts of Bayfield-Jacobsville sandstones remain. However, up to 1 km of a material with apparent velocities of 4.2 to 4.5 km/s exists. This represents either Oronto Group material or some type of crater breccia. Below this material is a refractor with apparent velocities of about 5.5 km/s. This is probably fractured Archean basement.

Minor faulting southwest of the islands has also been observed. The sense of motion is consistent with the interpretation of a basin-bounding fault with the basin to the south.

In summary, the magnetic and seismic data indicate a morphology that supports the impact origin hypothesis, although an endogenous origin cannot be completely ruled out.

Gneiss Domes and Not-So-Gneiss domes in the
Penokean Terranes of Northern Wisconsin

BROWN, B.A. (Wisconsin Geological and Natural History Survey,
1815 University Ave., Madison, WI 53705-4096)
GREENBERG, J.G. (Wisconsin Geological and Natural History Survey,
1815 University Ave., Madison, WI 53705-4096)

The Northern Penokean terrane (NPT) and the Penokean volcanic belt (PVB) of northern Wisconsin are each characterized by a distinct type of major gneissic pluton. The Northern Penokean terrane is intruded by a series of mantled gneiss domes. These bodies are gneiss domes in the true sense, consisting of Archean (up to 3.5 b.y. old) granitic rocks which were remobilized and emplaced at their present crustal level during the Penokean Orogeny (1850 m.y. ago). The domes are mantled by metasedimentary rocks of the Marquette Range Supergroup, and their outlines are clearly delineated by the magnetic expression of the iron formations.

The Penokean volcanic belt contains large foliated granitic bodies of a distinctly different character. The gneisses and granites themselves are superficially similar to those in the NPT, but isotopic evidence suggests ages ranging from 1760 to 2000 m.y. Also, these rocks are intrusive into greenschist facies metavolcanic rocks. The domes in the NPT were formed in a region of amphibolite facies metamorphism. The gneissic rocks of the PVB are complex, multiphase plutonic bodies, probably representing magma emplaced at a deep crustal level, which rose diapirically to form large concordant plutons. It has been suggested by other authors that gneisses in the PVB represent basement to the volcanic sequence. If this is the case, they must be only slightly older or their isotopic systems must have been thoroughly homogenized during the Penokean to account for the apparent lack of Archean ages so common in the NPT gneisses.

We suggest that the gneissic plutons of the PVB are comparable in overall aspect to the large composite batholiths typical of Archean Greenstone belts of the Superior Province. The nature of the plutons, when considered with the localized nature of the metamorphism and the chemical character of the metavolcanic rocks argues for comparison of the PVB with greenstone belts of known Proterozoic age, such as Flin Flon and Lynn Lake in Canada.

The contrast in the character of plutonism further underscores the differences between the NPT and the PVB, and emphasizes the importance of the Niagara tectonic zone as a fundamental boundary separating these terranes.

Paleomagnetic and Magnetic Anomaly Studies of the Northwestern Duluth Complex, Lake County, Minnesota

VAL W. CHANDLER (Minnesota Geological Survey, 1633 Eustis Street, St. Paul, MN 55108)

The effect of remanent magnetization on magnetic anomaly expression was investigated for the Bald Eagle intrusion, a composite body in the northwestern Duluth Complex. Unlike most of the Duluth Complex, this (30 km²) intrusion is well exposed and is known to consist of an outer (11 by 4 km) ring of troctolitic rocks surrounding a gabbroic core. The magnetic anomaly expression in the area does not correspond to either the Bald Eagle intrusion or surrounding features in that individual anomalies appear to be shifted eastward from their probable sources. Broad, large-amplitude (>2000 gammas) minima occur over parts of the Bald Eagle intrusion implying that reversely polarized rocks may be present. However, measured remanent magnetizations for oriented samples from five sites in the troctolitic rocks and two sites in the gabbroic rocks indicate that the Bald Eagle intrusion actually has a remanent magnetization directed essentially along the average normal direction (declination = 290°, inclination = 40°) for Keweenawan rocks in Minnesota. Thus, the large magnetic minima must represent either a deep-seated or a regional-scale anomaly effect.

Remanent magnetization was observed to be generally much stronger than induced magnetization and Q values in excess of 5 were common. To correct for the anomaly effect of the strong remanent magnetization, reduction-to-pole filtering was done on a detailed grid of aeromagnetic data over the intrusion. It was assumed that remanence was everywhere much stronger than induced magnetization and total polarization was therefore directed along a declination of 290° and inclination of 40°. The data reduced to the pole showed a much improved correspondence to the mapped contacts of the Bald Eagle intrusion, as well as to contacts of several surrounding features. Further processing of the reduced data by high-pass filtering revealed intricate structures within individual rock units, and appears to have isolated a previously unreported fault intersecting the Bald Eagle intrusion and extending northwestward at least as far as the basal contact zone of the Duluth Complex. The results of this study demonstrate the power of reduction to the pole in accounting for complications arising from strong remanent magnetization. The procedure should significantly enhance magnetic interpretations over large, poorly exposed parts of the Duluth Complex.

Alternating field demagnetization in a few samples implies several secondary components, including one that appears to be directed westward at a shallow inclination. This component is similar in direction to an overprint reported in Michigan for the Copper Harbor Conglomerate and further investigation is warranted.

An Ordovician Cryptoexplosion Structure
From Near Rock Elm, Pierce County, Wisconsin

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An apparent cryptoexplosion structure centered near Rock Elm, Pierce County, Wisconsin is nearly circular with a diameter of 6.5 kilometers and an area of about 33 km². The structure coincides with a pronounced regional negative gravity anomaly. It is surrounded by Prairie du Chien Group dolomites which are folded, faulted, and brecciated within a few hundred meters of the edge of the structure. This deformation is particularly intense within a large, arcuate, fault-bounded block along the southern edge of the structure. The rocks within the structure consist of an unusual sedimentary section. The exposed base of the section is a conglomeratic quartz arenite containing chert, dolomite, rhyolite, granite and quartzite clasts. This unit forms a domal uplift in the middle of the cryptoexplosion structure. The conglomeratic sandstone is apparently overlain by over 30 meters of interbedded grey pyritiferous shale and bioturbated fine-grained quartz arenite. This in turn is overlain by 7 meters of medium-bedded fine-grained quartz arenite, 5 meters of massive, friable quartz arenite, and at least 2 meters of ferruginous, medium-grained quartz arenite. Lower to middle Ordovician gastropods have reportedly been found in concretions in the shale, suggesting that it is an anomalously thick section of the Readstown Member of the St. Peter Formation. The overlying sands could thus correlate with the Tonti Member of the St. Peter Formation, a conclusion supported by grain size analysis and heavy mineral studies. The shales and other rocks within the cryptoexplosion structure have not been deformed to the extent of the surrounding Prairie du Chien Formation and the conglomeratic sandstones of the central dome.

Diamonds and gold were reportedly found in the 1880's in the gravels from streams draining the structure, suggesting possible erosion of mineralized bedrock. A reconnaissance ground magnetic study has delineated a positive magnetic anomaly associated with the north-western edge of the structure, upstream from the former placer operations. It is possible, however, that the minerals were eroding from a red drift cap that partially covers the structure. So far, heavy mineral studies of the stream sediments have yet to turn up any anomalies that could be related to the erosion of mineralized bedrock or poorly exposed plutons.

Important constraints on the structure's origin include the circular shape, the otherwise undeformed nature of the Paleozoic bedrock in the region, and the post-Shakopee, pre-Readstown timing of the intense deformation. This Ordovician deformation and subsequent erosion produced a deep circular lowland that progressively filled with clay, silt, and sand during St. Peter time. The structure could represent an isolated explosive volcanic feature, however,

the lack of volcanic material anywhere in the region does not support this interpretation. Alternatively, the structure could be an Ordovician astrobleme that later filled with sediment, similar to the Wells Creek and Flynn Creek structures in Tennessee. If plutonism and mineralization occurred in the region, the plutonism could have been triggered by the impact. Alternatively, later plutonism and mineralization could have been controlled by deep-seated fractures produced by the impact. So far, however, no plutonic rocks or features characteristic of impact origin, such as shattercones, suevites, or ejecta blankets have been found in or near the Rock Elm structure. A third alternative is that the structure is related to uplift and differential weathering around a large unexposed pre-Readstown pluton.

Further geologic studies, including drilling, heavy mineral analyses, seismic and other geophysical studies are needed to further elucidate the origin and nature of this interesting structure.

ULTRAMETAMORPHISM AND MIGMATITE GENERATION IN THE
VERMILION GRANITE COMPLEX, NORTHERN MINNESOTA

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ABSTRACT

The 2,700-m.y.-old Vermilion Granitic Complex (VGC) is a granite-migmatite terrane consisting of a supracrustal sequence of biotite schist, tonalite, and granite. The granite is of two types: garnet-bearing two-mica leucogranite (LEUG) and the biotite-bearing Lac La Croix Granite (LLCG). The syntectonic LEUG occurs as stringers and small bodies within the biotite schist, forming the neosome of schist-rich migmatite. The LLCG intrudes the supracrustal country rocks, forming the neosome of granite-rich migmatite and the batholithic part of the VGC. Metamorphic and geochemical studies were undertaken to elucidate the petrogenesis of these granite neosomes along the northern border of the VGC in the Kabetogama Lake area.

Three phases of metamorphism affected the area. M1 was the main regional prograde event, and M2 was a post-tectonic event produced by late-stage deuteritic alteration. M3 was a metamorphic recrystallization event along the major bounding faults. The regional M1 metamorphic conditions were estimated from the mineral assemblages in the biotite schist. Petrographic evidence indicates that M1 exceeded the breakdown reaction $\text{STAR} + \text{MUSCO} + \text{QTZ} = \text{SIL} + \text{BIO} + \text{GAR} + \text{H}_2\text{O}$ and the $\text{AND} = \text{SIL}$ transformation. However, there is no evidence for the breakdown reaction $\text{MUSCO} + \text{QTZ} = \text{SIL} + \text{K-SPAR} + \text{H}_2\text{O}$. The data indicate that peak regional M1 conditions ranged from 650°C to 700°C and 4 to 5 kbar. These conditions overlap minimum melting conditions ($P_{\text{total}} = P_{\text{H}_2\text{O}}$) of the biotite schist, implying an anatexitic origin for the LEUG.

The objective of the geochemical studies was to determine if any compositional gradients in the migmatite can be attributed to anatexis. Millimeter-scale samples were taken normal to foliation across two schist/restite/leucosome transitions to test the hypothesis that the LEUG melted from the biotite schist, leaving the restite margin as a residual phase. One traverse crossed an 8-mm-wide wisp of LEUG neosome, and another transected the interface between a larger vein of LEUG neosome and biotite schist. Small cores (6 mm, 2 g) were drilled and analyzed for major and trace elements. Corresponding modes (obtained using plane polarized light and cathodoluminescence) indicate that quartz and feldspar dominate the leucosome, whereas biotite, apatite, and oxides are concentrated in the restite margin. Of these minerals only apatite would concentrate the rare-earth elements (REE).

The results of the chemical analyses indicate:

- 1) As expected, the major and minor element content reflect modal variations across both traverses. Therefore MgO , FeO_t , K_2O , TiO_2 , Zr , Co , Ni , Sc are concentrated in the biotite-rich margin, whereas Na_2O and SiO_2 are concentrated in the quartz and feldspar neosome. In both traverses, the total REE abundances are greater in the schist and restite margin than in the neosome.
- 2) The two traverses show significant differences in REE profiles. These differences reflect the dynamic behavior of the migmatite generation.
 - a) The narrow 8-mm LEUG wisp formed as a closed system. This is indicated by comparatively enriched REE abundances in the apatite-rich restite margin.
 - b) The larger 5-cm LEUG vein formed as an open system. The expected REE enrichment in the apatite-rich restite margin was not observed.

Although both vein types appear mineralogically similar, they formed under considerably different petrogenetic conditions.

Geological and Geochemical Characteristics of the Volcano-Sedimentary Glen Township Formation, East-Central Minnesota

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Petrographic study of twelve drill cores reveals that the Glen Township Formation consists of the following:

- 1) Pelitic slate, quartzites, and metaconglomerates.
- 2) Oolitic jaspilite.
- 3) Cherty and slaty magnetite-silicate-(minor carbonate and quartz) facies Iron Formation (I.F.).
- 4) Pyrite, pyrite-pyrrohotite, and pyrrhotite bearing graphitic argillite-sulphide facies I.F.
- 5) Massive and banded siderite-(minor silicate, magnetite, and quartz) - carbonate facies I.F.
- 6) Ankerite bearing feldspathic metagreywacke.
- 7) Metavolcanics (metaandesites, metadiorites, and crystal tuff).

The sequence has been assigned to the lower part of the Mille Lacs Group and was metamorphosed and deformed during the Penokean Orogeny (~1,900 to 1,850 m.y. ago).

Massive quartz veinlets containing pyrite, siderite and minor chalcopyrite are present throughout the sequence. The lower part of the graphitic argillite contains pyrite or pyrrhotite mesobands (up to 10 mm thick) and is highly folded. The upper part of this argillite contains a massive pyrite-pyrrhotite horizon. This horizon contains angular fragments of graphitic argillite and in some places appears to be cemented by siderite, chlorite and quartz. Textural evidence indicates that this horizon represents a site of hydrothermal alteration and fracturing.

The occurrence of sulphides as highly folded mesobands in the graphitic argillite indicates that they are of syngenetic origin. This is in accord with the conclusion reached by Han (1968) and contrasts with the epigenetic origin proposed by Theil (1924) and Schwartz (1951).

Data on Au, Ag, Zn, Co, Ni, Cu, and As in the different iron formation facies, pyrite-siderite-quartz veinlets, and associated rocks are presently being collected. The results and preliminary models of the distribution, and mobility of precious metals in this type of geologic terrane will be discussed along with their implications for exploration.

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Long-Wavelength Gravity Anomalies in the Great Lakes Region

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To examine possible relationships between the sources of major gravitational anomalies in central North America, the gravity field was digitized at a 40 km interval to produce a 60 x 40 grid. Using the two-dimensional, power spectrum as a guide, these data were then wavelength-filtered to enhance possible continuities between the regional anomalies. The analysis reaffirms the lack of any direct relationship between the Kapuskasing Anomaly and the anomalies to the south. A deep-seated continuity of the Midcontinent Gravity High through the Michigan and Illinois Basins and into the Mississippi Embayment is implied by the long-wavelength field. Inclusion of intermediate wavelengths degrades this continuity, but suggests the presence of a regional, northwest-trending fracture system.

Three-dimensional structure of the crust and upper
mantle beneath the Lake Superior region

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The structure of the crust and upper mantle was investigated by the use of teleseismic P wave arrival times recorded by the Upper Michigan-Northern Wisconsin (UMNW) Seismic Network. Four methods were used to decipher the structure of the crust beneath the region. They were: travel time residuals, apparent velocity (reciprocal of slowness) and azimuth values calculated for events, ray tracing, and three-dimensional inversion of residuals. The inversion method allowed determination of velocity variations in the mantle to depths of 500 km.

Results show that the Mohorovicic Discontinuity beneath the UMNW Network to be a north-south trending antiform, plunging to the north towards the axis of the Lake Superior syncline. Seismic station MEW (Mellen, Wisconsin), located on the eastern flank of the Midcontinent Gravity High (MGH), had events that arrived 0.7 to 1.0 second earlier than at other stations in the network. Inversion studies indicate that the crust beneath MEW has a six percent higher velocity than at the other stations. From ray tracing, the crust was also found to be thin near this station. Therefore, a high velocity material underlying the MGH is suggested with thinning of the crust of about 5 km.

The nature of the mantle beneath the region as determined by three-dimensional seismic inversion indicate that:

(1) The upper mantle beneath portions of the MGH may be denser than surrounding areas. This is indicated by a zone of velocities faster than the layer average in the 40 to 200 km depth range. The anomaly is present in the gneiss terrane in northwestern Wisconsin but disappears northward into the greenstone terrane. This suggests that the velocity structure in the upper mantle beneath the MGH is dependent upon basement terrane.

(2) An east-west velocity boundary in northern Wisconsin is present in the 200 to 350 km depth range of the mantle. The boundary has a lateral extent of some 300 km and could represent an ancient suture related to the collision of plates during the Penokean orogeny. This also suggests that continental plates have structures that extend to depths of 350 km and are stable for periods of time of 1.8 billion years.

(3) Shorter wavelength velocity anomalies are present in the 350 to 500 km depth range and suggest that heterogeneities exist at these depths in the mantle.

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Gravity and Magnetic Model Studies of the Southern Duluth Complex, Northeastern Minnesota

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Large-amplitude gravity and magnetic anomalies are associated with the dominantly mafic igneous rocks of the middle Proterozoic (Keweenawan Supergroup) Duluth Complex. Two-dimensional gravity and magnetic model studies along three profiles extending across the southern half of the Duluth Complex were performed in order to investigate the structure of the Duluth Complex at depth and the locations of near-surface rock-magnetization contrasts. The three profiles intersect the basal contact of the Duluth Complex near 47°27' N., 92°07' W.; 47°12' N., 92°12' W.; and 46°57' N., 92°16' W. The northernmost profile trends N. 90° E., and the two southern profiles trend N. 105° E. Density, magnetic susceptibility and remanent magnetization data were measured from rocks throughout the southern Duluth Complex.

Gravity model studies were constrained by densities determined from seismic refraction data and field samples. Seismically determined densities and gravity models are mutually supportive for Duluth Complex/country rock density contrasts which extend to a depth of 20 km. Gravity models further imply that the basal contact of the Duluth Complex dips 25° E. near the northernmost profile and 60° E. and 55° E. near the two southern profiles.

Model studies utilizing aeromagnetic data upward continued to a level of 1 km imply that most of the magnetic anomaly expression of the southern Duluth Complex can be accounted for by eastward-dipping sources located within the upper 6 km of crust, polarized near or along the average Keweenawan normal direction (inclination = 40°, declination = 290°). This direction of polarization is consistent with rock magnetization data which imply an average Q of 3. Magnetic models and rock-magnetization data further imply that an increase in rock-magnetization occurs eastward across the southern Duluth Complex. The increase in magnetization, together with its low-dipping normal direction, can account for the regional magnetic low which occurs over the western portion of the complex.

Several large-amplitude magnetic anomalies (<3500 gammas) occur along the northern profile. The westernmost of these, whose maximum occurs at 47°27' N., 91°42' W., is thought to be caused by oxide-rich troctolitic rocks which have been observed in drill core from this area. It is probable that highly magnetized sources, used to model a broader anomaly with a maximum located at 47°27' N., 91°24' W., are related to similar troctolitic rocks, although there are no outcrop or drill core data to verify this possibility. Both of these large magnetic anomalies are bounded to the east by felsic rocks. The pres-

ence of eastward-dipping contacts in the magnetic models implies that the felsic rocks lie stratigraphically above the inferred troctolitic masses. It follows that the troctolitic and felsic rocks may be genetically related and that there may be several troctolite-felsic intrusions along the profile.

Composition, Origin and Evolution of Keweenawan Magmas - a Review

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Keweenawan magma compositions are best approximated by the massive, least-altered parts of the abundant aphyric lavas and dikes. Much more study is necessary to be able to infer with any precision the parent magmas of the major layered intrusive complexes.

Lava analyses show that the most primitive liquids were high-Al olivine tholeiites with $Mg' (= \text{atomic Mg} / (\text{Mg} + \text{Fe}^{+2})) = 0.65\text{--}0.68$, rich in Ni and Cr and low in the incompatible elements such as K, Ti, P, and rare earths. Olivine tholeiites showing a strong Fe - enrichment trend to $Mg' \sim 0.45$ constitute the most abundant lava type. Also very abundant are "transitional" basalts which also tend to be Fe-rich but with increasing amounts of alkalis and other incompatibles. With increasing SiO_2 and alkalis these merge into the considerably less abundant basaltic andesites and andesites and eventually icelandites. Rhyolites form a secondary though low peak of abundance. Minor varieties such as mugearite, tholeiitic hawaiites, and ferroandesite are locally found in the North Shore Volcanic Group (NSVG).

The most primitive olivine tholeiites were probably derived from 25-30% melting of an undepleted spinel lherzolite mantle at moderate depths (35-55 km), with perhaps only a small amount of olivine fractionated out in transit to the surface. The origin of the Fe-enrichment trend between these and the transitional basalts is uncertain and controversial. Were they derived by partial melting of more Fe-rich mantle than appears in typical peridotite xenoliths in other terranes? If so, they must have resulted from smaller degrees of melting than the primitive tholeiites. Are they the result of fractional crystallization of the primitive composition? Detailed modeling by Brannon with major and trace elements suggests not. Did primitive basalt assimilate ancient sialic crust? Sr and Nd isotopes say no. Did the magmas tend to equilibrate with earlier Keweenawan wall rocks to produce this trend? (Brannon et al, 1981.) Could mixing of two end-members (transitional basalt, primitive olivine tholeiite) be involved?

The origin of the compositional trend between basaltic andesites and rhyolites is almost as uncertain. Although mantle melting can be ruled out, various combinations of fractional crystallization, crustal melting, wallrock reaction, and magma mixing can be entertained. Basic chemical data are accumulating and detailed modeling necessary to narrow the possibilities is in progress.

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PHYSICAL VOLCANOLOGY OF THE KEWEENAWAN NORTH SHORE VOLCANICS

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Although their individual extents are not so well controlled by drilling as the Portage Lake volcanics (e.g. White, 1960), the lavas of the North Shore Volcanic Group (NSVG) are well exposed and many of their original volcanic features are observable. In a study correlating field observations and physical characteristics with chemical type of 198 flows, the following generalizations have emerged.

(a) Explosive activity was very rare except in some icelandite and rhyolite ash flows. Even in interflow sediments, vesicular ash, scoria, and shards are rare.

(b) Many textures as well as structures point to the low viscosity of these lavas on eruption.

(c) 60% of the flows are non-porphyritic and thus were erupted at temperatures at least as high as their liquidus temperatures, thus contributing to their high fluidity.

(d) The tops of some transitional basalts, quartz tholeiites, basaltic andesites and more felsic flows are rubbly, but the surfaces of all of the olivine tholeiites and many of the more evolved flows are smooth or ropy at various scales.

(e) The bases of practically all flows were liquid, unlike the basal rubble zone of typical Hawaiian aa flows.

(f) Pipe amygdules and vesicle cylinders are common in olivine tholeiite flows but are absent in more evolved compositions.

(g) Amygdules in the upper parts of flows are round or amoeboid in the basalts but are commonly elongate, indicating greater viscosity, in andesites, icelandites and rhyolites.

(h) Columnar jointing may occur in all compositions from olivine tholeiite to rhyolite, but many exposures are not good for recognizing it.

Eruptive style was much more like that of Iceland (fissure-fed flood basalts intercalated with more evolved central volcanoes) than Hawaii (all shields).

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Relative Age and Tectonic Significance of Proterozoic
Metasedimentary Rocks in the Upper Midwest

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Four groups of Proterozoic sedimentary rocks are recognized in the Precambrian of the upper Midwest. These are rocks of the northern Penokean terrane (NPT), the Penokean volcanic belt (PVB), the Baraboo interval (BI), and the Keweenawan basins (K). Each of the four groups is characteristic of different tectonic conditions prevailing during the Proterozoic evolution of the southern margin of the Superior Craton.

The oldest group occurs as sequences within the northern Penokean terrane, which developed immediately upon Archean basement about 1900 m.y. ago. These units include the Marquette Range Supergroup in Wisconsin and northern Michigan and the Mille Lacs Group in Minnesota. They were originally deposited on a stable continental shelf which gave way with time to deeper water environments indicative of subsidence. The uppermost units in the succession, which correlate with the Baraga and Paint River Groups, are predominantly turbidites and tholeiitic volcanic rocks. These were deposited in a series of rift basins.

At about the same time or later than deposition in the northern Penokean terrane, sedimentation in the Penokean volcanic belt was taking place to the south in environments similar to island arc, back arc, and interarc basin complexes. Metasedimentary rocks are now poorly preserved and/or exposed in this predominantly volcanic terrane which extends over much of northern Wisconsin. The sedimentary units which were preserved seem to be relatively thin and quite variable. Outcrops and drill-core data suggest that turbidites, graphitic shales, sulfidic and carbonate iron formation, silty dolomite, and various types of volcanogenic sediments were deposited around centers of calc-alkaline volcanism. The observed contrast in lithologies and depositional settings make it unreasonable to correlate units between the two Penokean terranes. Both terranes were apparently deformed together during the Penokean orogeny, about 1850 m.y. ago. At this time, the sinistral arcs and basins (PVB) were accreted to the rifted sial (NPT) along the craton margin to the north.

The third major depositional period, the Baraboo interval is interpreted as a result of subsidence on relatively immature continental crust. This sedimentation immediately followed post-orogenic felsic magmatism 1760 m.y. ago and was both unrelated to rifting and atypical of modern passive margins. Analogues of the Baraboo interval probably occur in the Eocambrian of the Arabian Shield, in the Lower Proterozoic adjacent to the Guiana Shield, and possibly in the Lower Proterozoic of the Athabasca Basin.

Other than the well known red Baraboo, Barron, and Sioux Quartzites, rock units in the Baraboo interval include five other facies: micaceous quartzite, conglomerate, argillite, chert, and iron-rich chemical sediments (including rare dolomite). These sediments may have been deformed about 1630 m.y. ago, as some evidence suggests; however they were definitely deformed and metamorphosed during the intrusion of alkalic plutons 1500 m.y. ago.

Rift-related Keweenawan sedimentary units were deposited in a stable continental environment at least 300 m.y. after the Baraboo interval. The mostly quartzitic Keweenawan rocks are exposed along both shores of Lake Superior and include both pre- and post-volcanic sequences. Keweenawan units were only mildly or locally affected by the heat of rift magmatism. They were not significantly deformed.

The association of depositional and tectonic environments represented by each of the four sedimentary groups is as follows:

<u>GROUP</u>	<u>TIME</u>	<u>DEPOSITIONAL ENVIRONMENT</u>	<u>TECTONIC ENVIRONMENT</u>
NPT	about 1900 m.y. ago	Continental shelf, rift basins	Development of Atlantic- type continental margin
PVB	about 1900- 1850 m.y. ago	Small ocean, arc basins	Early stages of conti- nent-volcanic arc orogeny
BI	about 1760 m.y. ago	Epicontinental basin	Metastable continental crust, subsidence due to thin sial after cratoni- zation
K	about 1300- 900 m.y. ago	Intracontinental rift basins	Tensional reactivation of tectonic weaknesses in mature continental crust

Stratigraphy of the Footwall Volcanic Rocks Beneath the
Mattabi Massive Sulfide Deposit, Sturgeon Lake, Ontario

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The Mattabi massive sulfide deposit, situated in the Wabigoon greenstone belt, is underlain by approximately 2 km of predominantly mafic subaqueous volcanic rocks. The rocks in the study area are terminated by the Beidelman Bay intrusion, a dioritic to trondh-jemitic subvolcanic sill. Detailed geologic mapping and petrographic studies have shown that this previously undifferentiated footwall unit can be divided into several distinct volcanic deposit types on the basis of preserved primary textures, fragment type, and mineralogy.

At the base of the succession, mafic porphyritic flows and flow breccias are intruded by an altered dioritic border phase of the Beidelman Bay intrusion. The mafic flows are intercalated with and overlain by thin felsic lavas and hyaloclastites that grade laterally into heterolithic debris flows. This felsic horizon thickens on both the western and eastern extremities of the study area and, locally, includes coarse block and ash layers. Poorly bedded and graded mafic debris flows overlying this felsic horizon are composed largely of aphyric mafic fragments and scoria and are most common west of Mattabi. These deposits interfinger and mix with felsic lavas and flow breccias east of the ore deposit. The mine footwall horizon, approximately 200 m thick, is comprised of felsic pyroclastic flow deposits composed of coarse, poorly graded tuff breccias and intercalated ash beds. The immediate footwall rock is a poorly graded, lapilli-rich pyroclastic flow.

Thickening of lower felsic flow horizons to the west and east of the ore deposit suggest at least two felsic edifices. Comparisons of felsic pyroclastic units immediately beneath the Mattabi horizon also indicate:

1. An early edifice slightly west of the ore deposit produced coarse basal pyroclastic beds and overlying ash beds that truncate mafic debris flow deposits.
2. Later volcanism east of the ore deposit produced subaqueous pyroclastic flows that grade westward into thinly bedded ash units. These flows form the immediate footwall at Mattabi.

Evidence for nappe development during the Penokean Orogeny from the Early Proterozoic Thomson Formation, Minnesota

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The Penokean orogeny (1,900-1,800 m.y.) was a major tectonic event in the Great Lakes region of North America involving deformation, metamorphism and igneous activity. In Minnesota, the effects of Penokean deformation are most clearly seen in the Thomson Formation of east-central Minnesota. Two major phases of Penokean deformation are now recognized in the Thomson Formation. F_1 folds are isoclinal and recumbent with a well-developed S_1 axial-planar foliation. As hinge regions of F_1 folds are rare, the S_1 foliation is usually observed to be very nearly bedding - parallel in outcrop. F_2 folds are open, upright to steeply inclined, and subhorizontal. There is a foliation that is axial-planar to the F_2 folds. This foliation is a crenulation cleavage where the S_1 foliation is present and a slaty cleavage where the S_1 foliation does not exist. The second deformation affected the entire region of Thomson Formation outcrop, while the effects of the first deformation are found only in the southern two-thirds of Thomson Formation outcrop.

Several lines of evidence indicate that northward-directed nappes developed during the Penokean deformation in Minnesota. This evidence includes petrologic differences between the areas of one and two deformations, the pervasive nature of the S_1 foliation in the area in which it is found, facing direction of F_2 folds, and the refraction pattern of the S_1 foliation in graded greywacke-slate sequences, showing that an area of up to several hundred square km is on the upper limb or limbs of large northward-directed recumbent folds (nappes) of the early phase of deformation.

Recent tectonic models of the Penokean orogeny in Minnesota have suggested that it was an intracratonic event with local compression and metamorphism caused by vertical "remobilization" of basement rocks. The existence of nappes and later upright folds with axial-planar foliation suggests a significant amount of horizontal shortening. These features are quite compatible with the suggestions that Penokean deformation took place in a plate boundary collision environment.

Folded Rocks in the Eastern Contact Zone of the Vermilion Batholith

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Detailed geologic and structural mapping was carried out in a portion of the Jackfish Lake (7½ minute) quadrangle, Minnesota-Ontario during the 1982 field season. This mapping has demonstrated the existence of a major fold sequence, here named the Crooked Lake Fold Sequence. This sequence lies within the southeastern contact zone of the Vermilion Batholith, north of the Vermilion fault zone.

The oldest rocks in the quadrangle are biotite schists, amphibolites, and metabreccias associated with younger leucocratic biotite adamellite and migmatites. The oldest rocks were graywackes and shales, basalts and andesites, and mafic volcanoclastic sediments. Mafic breccias suggest nearby sources of mafic volcanics.

After deposition of the sediments, a major period of deformation occurred to produce the Crooked Lake Fold Sequence. This sequence consists of a series of often overturned synclines and anticlines that plunge gently to the east and northeast. A wide range of orientations of major fold axes and axial planes suggests that the deformational event was characterized by complex disharmonic folding. The changing shape of one of the folds is illustrated in Fig. 1. The fold sequence extends westward across strike through the Friday Bay (7½ minute) quadrangle for approximately 10 kilometers and may extend even farther, into the Iron Lake (7½ minute) quadrangle and the Vermilion Batholith. Southeast of the Jackfish Lake quadrangle the Crooked Lake Folds can be followed across strike into the Basswood Lake West (7½ minute) quadrangle where they may be terminated against a splay of the younger Vermilion fault zone. The minimum total across-strike distance of the fold sequence is approximately 23 kilometers. When followed along strike to the northeast into Canada, individual folds pass into leucocratic biotite adamellite of the Vermilion Batholith. Their position within the batholith can be recognized by systematic changes in foliation orientations.

After the major deformational period, the sediments were metamorphosed to amphibolite grade. Migmatization and formation of leucocratic biotite adamellite occurred after amphibolite grade metamorphism. Regional structural continuity between the older biotite schists and the adamellite suggests that the migmatization which produced the adamellite probably occurred in a younger pile of felsic volcanics which were overlying the more mafic schists. The formation of the migmatites may be the result of a combination of several mechanisms: anatexis, metasomatism, and subsequent intrusion.

Several episodes of faulting and fracturing have taken place. These events produced narrow zones of cataclasis, brecciation, and hydrothermal alteration. As the Vermilion Batholith is approached, the

number of faults increases significantly. Apparent displacement on these faults dies out as the faults pass northward into the more massive rock of the Vermillion Batholith. Most faults when traced over long distances are deflected to the north and west as if they were being controlled by the southeastern margin of the batholith.

The formation of strong joint sets accompanied the faulting events. Many of these joint sets show a strong bimodal distribution which corresponds to the primary layering directions in the opposing limbs of the Crooked Lake Folds. These joints seem to persist into the leucocratic biotite adamellite of the Vermillion Batholith and may represent original planes of weakness in the pre-batholith pile of felsic extrusive rocks.

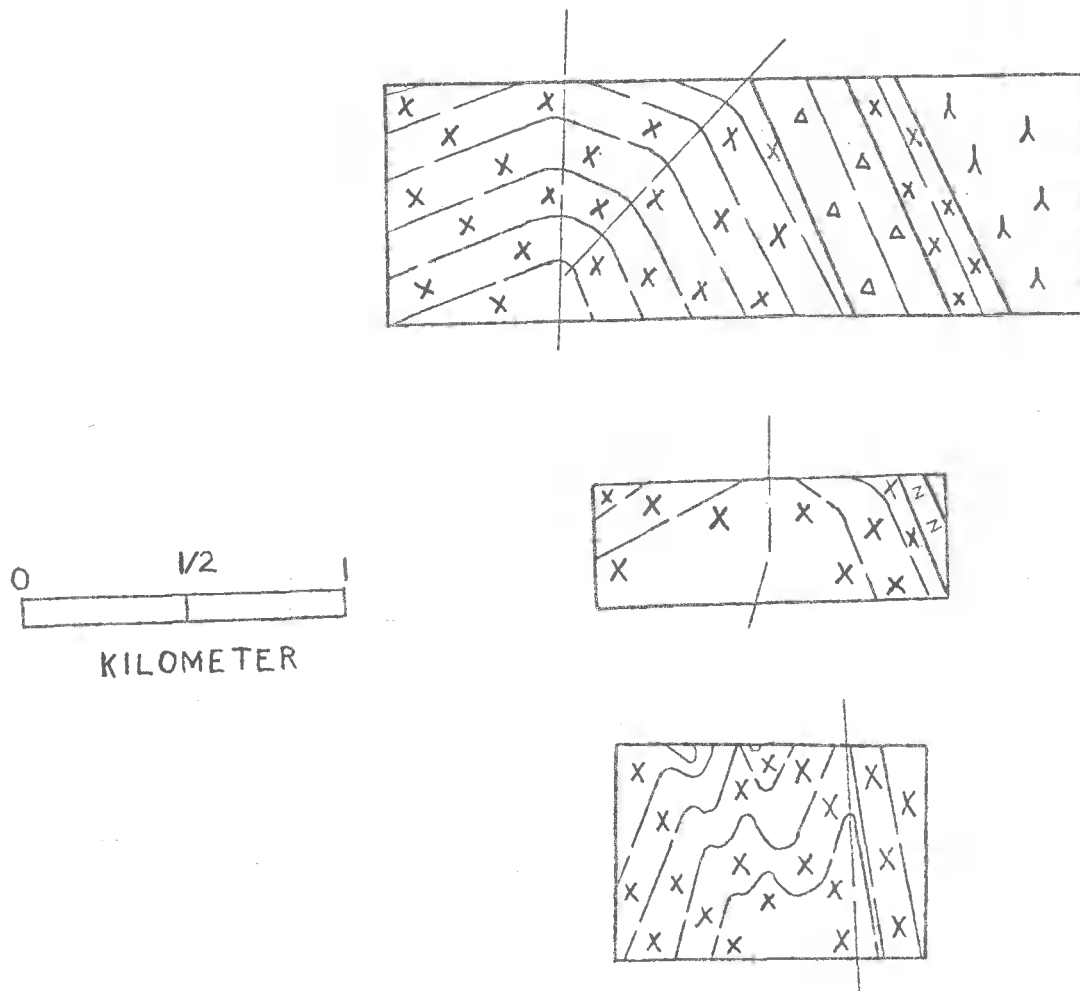


Figure 1. Changing shape of one of the anticlines in the Crooked Lake Fold Sequence. These sections are drawn perpendicular to the strike of a 1.5 kilometer segment of the axial plane of the fold. Vertical scale equals horizontal scale.

SUPERIMPOSED FOLDING AND ITS IMPLICATION ON THE
SHEBANDOWAN-QUETICO SUBPROVINCE BOUNDARY, THUNDER BAY, ONTARIO.

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Detailed structural studies were carried out over a distance of 40 km along an east-west trending zone which is characterized by a lithological transition from a dominantly metavolcanic terrain south of the zone to well stratified metasedimentary rocks exposed north of the zone. This lithologic change from basic flows and intermediate to felsic volcanoclastic rocks to a sequence of greywackes, slates, and turbidites has been defined on published geological survey maps as the boundary between the Shebandowan and Quetico subprovinces in the area north and northwest of Thunder Bay.

The metavolcanic and metasedimentary rocks have been subjected to regional greenschist facies metamorphism and possess a single well defined schistosity or cleavage (S_1). Primary bedding planes (S_0) are well preserved in the metasedimentary rocks as are primary structures such as graded bedding and cross bedding. Pillow structures, although not uncommon, are often too deformed to permit determination of local tops or of primary bedding surfaces in the metavolcanic succession.

Based on cleavage-bedding relationships, the asymmetry of minor folds, and local younging derived from primary structures, a set of folds has been delineated in the metasedimentary sequence. Field observations in a number of fold hinge zones have clearly shown that the subvertical, northeast striking S_1 cleavage parallels the axial surfaces of these folds. Observed S_0/S_1 intersection lineations generally plunge steeply to the northeast and are coaxial with the axes of these folds. Because of their steep plunge, the structural facing of the folds is primarily sideways, and hence they cannot be classified as synforms or antiforms. These folds therefore form a set of vertically plunging, sideways-closing folds.

When tracing one of these folds in the field parallel to the trace of the axial surface, a number of reversals in the structural facing direction of the fold occur. In some portions the structural facing direction is to the northeast, elsewhere to the southwest. Extending such observations over the entire area reveals the existence of distinctive regions in which the stratigraphy as a whole becomes younger toward the northeast, while other parts indicate an overall stratigraphic younging to the southwest. The places where the reversals in the structural facing direction, and therefore in the stratigraphic younging occur, mark the position of the trace of the axial surfaces of an earlier set of folds.

Based on the structural data from this area, it is suggested that the strata were folded about gently plunging axes resulting in a set of isoclinal F_1 folds in which at least some limbs were overturned. A later refolding produced F_2 folds about nearly vertical axes and axial surfaces. The F_2 folding was accompanied by the development of a pervasive axial planar schistosity or cleavage.

Superimposed folding has been documented in the metasedimentary rocks on both sides of the proposed boundary between the Shebandowan and Quetico subprovinces. No evidence has been found to exclude the metavolcanic rocks from the folding demonstrated in the metasedimentary succession.

LaSalle Falls - An Exposed Massive Sulfide Deposit
in Florence County, Wisconsin

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La Salle Falls (Pine Rapids) on the Pine River in Florence County, Wisconsin occurs at the contact between felsic and mafic volcanic rocks of the early Proterozoic Quinnesec Formation. Along the south side of the Pine River the exposed rocks are mainly massive and pillowed (?) greenstones with numerous massive and layered gabbroic dikes. Most exposures have a prominent foliation and mineral associations suggest metamorphism to lower amphibolite facies. At LaSalle Falls and on the north side of the Pine River the dominant lithology of the Quinnesec Formation is felsic volcanic rocks that appear to be coarsely fragmental. Significant pyrite, pyrrhotite and chalcopyrite are disseminated in the felsic rocks at LaSalle Falls. To the north the Quinnesec is in fault contact with the Michigamme Formation along the Niagara Fault. To the south the volcanics are in contact with, and intruded by, granitic rocks of the Dunbar gneiss dome.

The sulfide deposit, a graphitic, sulfide-rich sediment zone about fifty feet thick, occurs at the contact between the mafic and felsic rocks. The sedimentary unit is mainly a finely laminated chloritic and sericitic slate with discontinuous pyrite lenses 1 - 2 mm thick. Cherty layers are relatively common within the zone. Garnets are abundant in some of the pelitic rocks. Although only iron sulfides were observed in the sediments, drilling by mining companies indicate the presence of base metal sulfides. The main sulfide deposit apparently underlies the river channel below the falls and has been largely removed by erosion.

In addition to this occurrence along the Pine River, a base metal sulfide deposit in felsic tuffs has been drilled approximately one mile to the south. Massive sulfide deposits have also been reported in the Quinnesec Formation in Marinette County. The exposure would make an excellent field trip stop.

The Reany Creek Formation: a Mass-Flow Deposit of Possible Post Menominee Age

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The Reany Creek Formation (RCF) crops out in a narrow east-west trending belt to the north of the Dead River storage basin in Marquette County, Michigan. Lithologies of the formation are meta-mudstones with both round and angular, matrix supported clasts (some up to 3 m in diameter); meta-arkosic-wackes; meta-feldspathic wackes; and minor lithic greywackes which also have matrix supported clasts. The RCF has been previously interpreted as being of glacial origin and stratigraphically the lowest formation in the Marquette Supergroup (Puffet, 1969; Ojakangas, 1982). This interpretation has largely been supported by the presence of matrix supported clasts which were interpreted as glacial drop stones. In this report the RCF is interpreted as a proximal mass-flow deposit. The RCF has similar lithologies and structural trends to the Michigamme slate.

In general, two sets of mafic dikes occur in the Marquette area; Keweenawan dikes and older sets of dikes which are Pre-Baraga in age. The base of the RCF lies unconformably on Archean age greenstones. In places this contact is obscured by the intrusion of Keweenawan dikes. Keweenawan age dikes also occur within the RCF. No dikes of an older age appear to cut the RCF. Regional mapping (Puffet, 1974) indicates that all older dikes are truncated by the RCF. Detailed mapping of the RCF (this study) has found no actual case of this truncation; however, many dikes have been observed to intrude the Menominee Group, but not the RCF.

Bedding-cleavage intersections and minor folds axes appear to indicate a shallow, doubly plunging synform with an axial plane dipping slightly to the southwest. The presence of kink-bands in cleavage indicates a F_2 deformation. Bedding typically strikes to the northwest and dips to the southwest or northeast ($40-80^\circ$). Cleavage strikes northwest and dips to the southwest ($55-80^\circ$). Measurements on flow directional indicators (e.g., flute casts, scour channels, and tool marks) suggest north-south transport directions (mean N17E or S17W, $N = 24$) and are similar to the current directions found in the Michigamme slate (Trow, personal communication).

All of the sedimentary structures of the RCF can be explained by a mass-flow mechanism. Depositional models which involve a glacial environment or glacial marine environment are unsupported by any direct evidence (e.g., glacial striations on clasts). A Post-Menominee depositional age for the RCF is supported by the absence of Menominee age dikes and the apparent truncation of these dikes by the RCF. Correlation of the Huronian tillites and the RCF would thus seem unjustified.

Major Element Chemistry of Anorthosites from the Duluth Complex
Snowbank Lake Quadrangle, Minnesota

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Field and petrographic studies (1) indicate that at least three stages (early, main and late) of anorthosite emplacement may be distinguished in the Duluth Complex in the Snowbank Lake quadrangle. Preliminary evaluation of new microprobe data on 18 anorthositic gabbro and 2 troctolite samples from the study area defines a number of distinct chemical relationships within and between the anorthositic gabbro series and the younger troctolitic series. Major and minor element abundances in plagioclase (Pl), olivine (Ol), clinopyroxene (Cpx), orthopyroxene (Opx), and oxide minerals (Ox) were analyzed. We report here the general characteristics of the major element data.

1) As a group, the anorthositic suite has a broad but constant range in Pl composition (Fig. 1). When compared to the troctolites from the study area and the nearby South Kawishiwi Intrusion (SKI-Fig. 1, 2), the anorthositic rocks are higher in An ($\text{Ca}/\text{Ca}+\text{Na}+\text{K}$) over the same range of Fo ($\text{Mg}/\text{Mg}+\text{Fe} = \text{mg, mole\%}$). This relationship is also found between gabbroic and anorthositic rocks of the Stillwater Complex (3).

2) The mg ratio of the mafic phases in the troctolitic anorthosites of all stages (TAE, TAM, RAL) is higher than in the main stage olivine ophitic anorthosites (LSA) and the main stage anorthosite (ANM) (Figs. 1-4, Table 1). Gabbroic anorthosite (GAM) Cpx has intermediate mg ratios (Table 1).

3) The mg ratios of the mafic phases indicate varying degrees of equilibrium over a cm scale. -- The mg relationship of Opx rims on Ol in all anorthosites, indicates that the two phases are in disequilibrium (Fig. 2); adjacent mineral pairs plot below the Fo-En equilibrium partitioning curve (4). Ol-Opx pairs in troctolite are near equilibrium. Over the mg range considered, the equilibrium curve may be considered linear and simplified to: $\text{Fo} = -18.9 + 1.187 \text{ En}_{\text{Opx}}$. Opx rims are compositionally similar to that in Opx-Ox symplectites which partially replace Ol in all anorthosites investigated, but is rare in the troctolites. These symplectites are thought to form by low temperature (600-700°C), late magmatic to subsolidus oxidation reactions, possibly involving some mass transfer (5). The result is an mg enrichment of the Opx above that in equilibrium with the core Ol. The rim Opx could have formed before or contemporaneously with the symplectite. If before, it reequilibrated during symplectite formation. Textural evidence supports this interpretation. -- The En ratios of Opx-Cpx intergrown mineral pairs (Fig. 3, P), commonly as Ol rims, and of Opx exsolution lamellae in a Cpx host (E) define a linear trend: $\text{En}_{\text{Opx}} = -19.5 + 1.2 \text{ En}_{\text{Cpx}}$. The mg relationship of intercumulus Cpx, commonly ophitic, and rim Opx, which are separated by plagioclase over a mm scale, plot above the linear array (S) indicating that most Cpx formed before the Opx or before it reequilibrated during symplectite formation. -- The Fo- En_{Cpx} compositions of the various units (Fig. 4) show a single, broad positive trend. From the equilibrium equations derived above, an Fo- En_{Cpx}

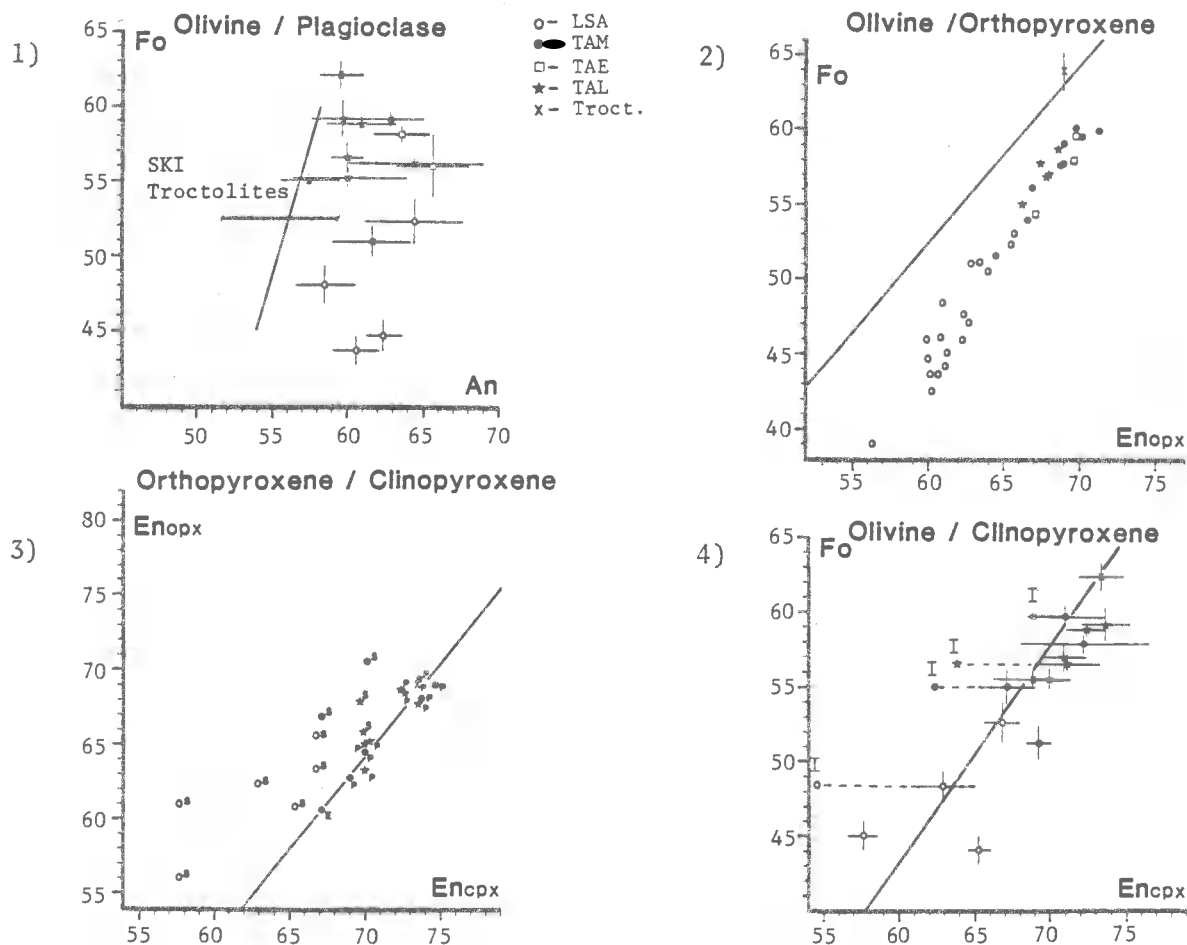
hypothetical equilibrium equation was independently calculated:
 $Fo = -42.1 + 1.425 \text{ En}_{\text{Cpx}}$. Agreement of this calculated curve and the data is very good.

4) Cpx in inclusions in plagioclase have lower En ratios than nearby intercumulus Cpx (Fig. 4, I). The form and composition of these inclusions, which also contain ilmenite and often sodic plagioclase, suggests that they represent crystallized melt inclusions.

References: 1) Miller, J.D. and Weiblen, P.W., 1982, Proceedings, 28th ILSG, 26-28. 2) Weiblen, P.W., 1982, Geol. Am. Mem. 156, 57-82. 3) Raedke, L.D. and McCallum, I.S., 1980, Geochim. Cosmochim. Acta, Suppl. 12, 133-153. 4) Medaris, L.G., 1969, Am. J. Sci. 255, 241-253. 5) Zeck, H.P., et al., 1982, Lithos 15, 173-182.

Table 1: Compositional range of mineral phases

Stage	Rock Type(1)	An	Fo	En _{opx}	En _{Cpx}	# samples
Early	TAE	59-70	54-60	67-70		2
	LSA	55-72	38-59	56-66	57-67	4
	SSA	60-66				1
Main	GAM	54-64			65-71	1
	ANM	52-66			57-60	1
	TAM	57-66	49-60	64-72	65-74	4
Late	TAL	50-70	54-59	63-69	69-75	5
	Troctolite	55-63	54-65	70-72	69-75	2



The Relationship Between the Basal Zone and Cloud Zone Cu-Ni
Sulfides, Minnamax Deposit, Duluth Complex, Minnesota

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The copper-nickel sulfides of the Minnamax deposit, Babbitt, Minnesota, are located within two zones of the Duluth Complex; these are the basal and cloud zones. Sulfide minerals in each consist of chalcopyrite, cubanite, pentlandite, and pyrrhotite.

Rock units identified in drill core include a thick (~150 meters) sulfide-poor anorthositic troctolite which is both overlain and underlain by irregularly mineralized mixed zones. These mixed units are composed of varying proportions of anorthosite, troctolite, and picrite, with grain size ranging from fine to pegmatitic ($\geq 15\text{mm}$). A highly mixed unit lies at the base (lower 50 meters) of the Duluth Complex and exhibits the greatest number of mafic pegmatites, rock inclusions, and the highest abundance of Cu-Ni sulfides ("basal zone" sulfides).

Sulfide mineralization is most abundant in the highly mixed basal unit of each core. Smaller intervals of mineralization also occur in the mixed unit several hundred meters above the base in what have been termed "cloud zones." Characteristics common to both the basal zone and cloud zone sulfides are: 1) sulfides occur in the mixed or highly mixed units, but are absent from the large, consistent anorthositic troctolitic units, 2) sulfide abundances change abruptly and are generally accompanied by a corresponding change in rock type, 3) the most abundant sulfides are associated with mafic pegmatites in both the cloud and basal zones, and 4) the Cu/Cu+Ni ratios are approximately 0.8 in each.

This study suggests that there is a strong correlation between mafic pegmatites and sulfide occurrence in both the basal and cloud zones. The sulfides (and pegmatites) which occur in the mixed units are considered in this study to be magmatic and to form discontinuous pods of relatively small dimension.

Hydrothermal Alteration at the Helen Mine,
Wawa, Ontario

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Felsic volcanic rocks underlying the Archean Helen Iron Formation include lava flows and domes, massive and bedded pyroclastic rocks, block and ash flows, and hyalotuffs. They have been variably altered by hydrothermal solutions to five chemically and/or mineralogically distinct alteration facies: 1) least altered, 2) sericite, 3) chlorite, 4) chloritoid, and 5) ankerite.

Least altered rocks have perhaps undergone spilitization, but have been affected primarily by regional greenschist facies metamorphism, and are the freshest rocks to be found in the study area. The other alteration facies are named for the dominant alteration mineral present.

Sericite facies alteration forms a widespread (6x2 km) semi-conformable zone beneath the iron formation. A less extensive (2x1 km) pipe-like body, consisting of chlorite, chloritoid, and ankerite facies alteration zones, cross-cuts the sericite zone.

Based on mineralogy and chemistry of the alteration, and on the geometry of the alteration zones, the following sequence of events for the development of the alteration is proposed. Shallow circulating sea water (1-3 km), heated by a subvolcanic intrusion (possibly the Jubilee Stock), encountered rocks of felsic composition within the volcanic succession. Sea water-rock reactions evolved an acidic, K-rich solution that migrated upward, reacting with overlying felsic rocks, converting plagioclase to sericite and quartz by the addition of K and the removal of Na. The porosity in the altered rocks was decreased, forming a widespread, relatively impermeable, semi-conformable sericitic alteration zone over the hydrothermal system.

Deeper-circulating sea water reacted with basaltic rock at depths greater than 3 km and became enriched in Fe, Mg, Mn, and Ca relative to the felsic rocks. This second hydrothermal solution moved upward where it encountered the previously altered, relatively impermeable cap rock. Fracture and fault systems were developed or reactivated in the cap rock, allowing reaction of this solution with sericite facies rocks. This involved the addition of Fe, Mg, and Mn and the removal of K to form chlorite $\pm$ pyrophyllite at the expense of sericite.

During greenschist facies metamorphism, the assemblage chlorite + pyrophyllite was converted to chloritoid + quartz, whereas chlorite in the absence of an aluminum silicate phase remained stable.

Near the sea floor, a sudden release of pressure on the solution, coupled with mixing of cool sea water, rapidly decreased carbon dioxide solubility, causing mass precipitation of iron carbonate and formation of the ankerite facies assemblage. Precipitation of siderite occurred on the sea floor.

The absence of base metals and sulfur in the Helen deposit suggests a low temperature and a high water/rock ratio for the hydrothermal system.

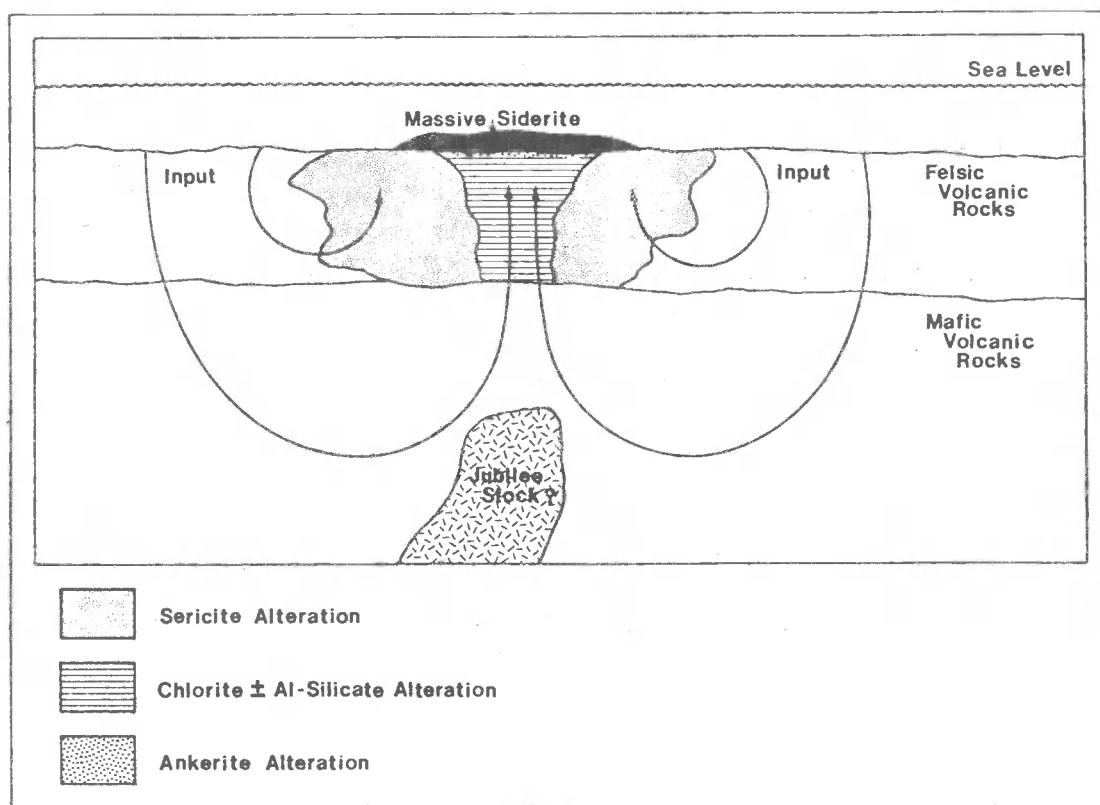


Figure 1. Alteration Model

Igneous Rocks of the Baraboo District, Wisconsin

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Volcanic rocks, granitic rocks and mafic dikes occur in the Baraboo district of south-central Wisconsin. Recent field work has established the age relations among these igneous rocks and the associated Baraboo quartzite, yielding important information on the geologic evolution of this part of the southern Lake Superior region.

The volcanic rocks are exposed along the outer margins of the quartzite ridges that outline the Baraboo synclinorium, and are probably the basement upon which the meta-sedimentary sequence was deposited. These rocks consist of porphyritic rhyolite flows, tuffs and agglomerates.

The Baxter Hollow granite contains sparse xenoliths of volcanic rocks and banded iron formation. Where exposed at the base of the quartzite, the chilled margin has been disrupted by granitic dikes. Mafic dikes also intrude the Baxter Hollow granite. All these rocks have been metamorphosed to low-grade assemblages.

The relationship between the quartzite and granite has long been a point of controversy. From this new information, it is concluded that the quartzite was deposited upon the volcanic rocks, and intruded by the Baxter Hollow granite.

Depositional and Structural Feature of the Upper Freda Sandstone

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The Freda Sandstone is part of the Upper Keweenawan Oronto Group. The upper beds of the Freda exposed at the type locality at Freda, MI are mostly thin, red, alternating planar laminated and microtrough cross-laminated beds. The planar laminated beds are claystone or very fine- to medium-grained sandstone. The claystone and sandstone are distinct and non-gradational. The planar laminated sandstones have mica flakes parallel to the bedding and often have parting lineation on bedding planes. They occasionally have small scale straight to sinuous current ripple marks on the bedding surface causing an undulating lamination within the horizontally laminated beds due to ripple migration.

The microtrough cross-laminated beds usually have small lunate ripple marks on the bedding planes. Migration of the lunate ripples probably caused the microtrough cross-lamination. Raindrop imprints can be seen on some lunate ripples in close association with dessication features.

The claystone planar laminated beds are alternating greenish and red in color. They commonly have distorted or convolute bedding. One individual bed, eight inches thick was traced over half a mile.

The two distinct grain size facies and the bedding succession imply a transitional environment, possibly between fluvial and lacustrine conditions. The sandstone mineralogy suggests a mixed silicic and mafic volcanic source area. The silicic fraction has a high proportion of strained quartz suggesting a subsidiary metamorphic source.

The Freda Sandstone in this area has a well developed extensional joint system striking approximately N50E. The Freda is cut by numerous normal faults either perpendicular to or parallel to the joint system. The faults have vertical displacements of from one to 30 feet. Normal faults parallel to the master joint system occasionally have drag folds. They are downthrown to the west and mineralization is lacking along the faults. The faults nearly at right angles to the master joint system are the most abundant and are frequently mineralized with calcite. The faulting and folding probably developed late in the subsidence history of the Lake Superior Syncline.

Evidence for Glacial Marine Sedimentation in the Early Proterozoic
Gowganda Formation, Northeastern Ontario, Canada

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Evidence for glacial marine sedimentation in the Gowganda Formation (Huronian Supergroup) in the Gowganda-Elk Lake area of northeastern Ontario changes the previously known regional distribution of continental glacial and glacial marine sedimentary facies. Lindsey (1969) interpreted the Gowganda to be a marine deposit in the south (Espanola-Whitefish Falls) and a continental deposit in the north (Cobalt area) which includes the area under discussion here.

In the study area, the Gowganda rests unconformably upon the Archean basement. The subhorizontal formation is from 0 to >1700 m thick (based on drill hole data) and no complete sections are present. It is a heterogeneous assemblage of diamictites, orthoconglomerates, graywackes, arkoses, siltstones, argillites, pebbly argillites, and breccias. Lateral and vertical facies changes can be rapid, however the graywacke-argillite association is abundant, widespread, and constitutes the dominant facies. Orthoconglomerates and massive to thick bedded arkoses, occasionally cross-bedded, are most common at the base of the section and again near the top. Diamictite is a prominent lithology and varies from massive to weakly stratified with clasts up to 1.2 m in apparent diameter; units vary from a decimeter to as much as 20 m in thickness. Wisps and deformed pieces of sandy material are often present within the diamictites. Contacts with other units can be sharp, irregular, or transitional. The diamictite is restricted to the lower two-thirds of the formation.

Interbedded graywackes, siltstones, and argillites commonly constitute fining-upward sequences from 2 cm to 4 m thick in the lower portion of the section and both fining-upward and coarsening-upward sequences in the upper part of the section. Internal stratification includes graded beds, ripple marks, laminations, and convolute bedding. In addition, features such as ripped-up clasts, flame structures, and other loading phenomena are present. Thinly laminated siltstone and argillite sequences with lonestones as large as 30 cm are present throughout the lower two-thirds of the section. They are more common in the central and western portions of the study area. Lonestone sequences are as much as 40 m thick, while individual units vary from 1 to 5 m thick. Breccias and units with soft sediment deformation structures are fairly widespread but constitute a minor part of the section; units vary from .5 to approximately 4 m thick.

The following depositional history of the Gowganda in this area is indicated. Paleovalleys, probably largely tectonic in origin with perhaps as much as 1000 m relief, were partially filled by fluvial processes which deposited the orthoconglomerates and arkoses prior to the arrival of glacial ice in the vicinity. The lonestones in the laminated units are interpreted to be dropstones released from melting icebergs or a floating ice shelf. The paucity of unequivocal

varved bedding and the widespread occurrence of dropstone-bearing sequences is suggestive of a glacial marine rather than a glacial lacustrine environment. The weakly stratified diamictites, in view of their distribution and transitional contacts with dropstone units, are interpreted to be the products of rapid fallout of abundant debris released beneath an ice shelf. The generally thinner, massive diamictites are attributed to submarine gravity flow mechanisms beneath an ice shelf or near the margin of a melting land-based glacier. The fining-upward and coarsening-upward sequences reflect the changing conditions within the basin as increases and decreases in both energy and sediment supply occurred and may represent submarine outwash. The graywackes resulted from the interaction of various types of sediment gravity flows, dominantly turbidity currents with subordinate fluidized/liquidized flows and possibly grain flows. The more well sorted and laminated sandstones, siltstones, and argillites may represent more normal marine sedimentation. The breccias and deformed units represent either resedimentation from unstable depositional sites or minor tectonic instability. The distribution of the rock types within the thick stratigraphic column suggests changing conditions probably associated with advances and retreats of glaciers located to the north. Basin subsidence continued throughout Gowganda time, allowing the great thickness of sediments to accumulate and be preserved. In late Gowganda time, amelioration of the climate occurred, indicated by the lack of glacial features in the deposits. Sedimentation appears to have been largely fluvial-deltaic, as also evidenced in the overlying Lorrain Formation.

Alteration of the Deer Lake Peridotite in the Vicinity
of the Ropes Gold Mine, Marquette County, Michigan

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Gold mineralization at the Ropes Mine is contained entirely in an east-west striking septum of highly altered felsic rock within the serpentinitized Deer Lake Peridotite. Near the Ropes Mine the serpentinite consist of two principal textural varieties: Type A, with well preserved relict igneous textures, and Type B, showing recrystallized and foliated textures, probably produced by shearing. A prominent zone of Type B serpentinite along the north shore of Deer Lake may represent an extension of a shear zone along the felsic septum.

Compositionally, the serpentinites represent altered harzburgite and lherzolite (Rossell and Kalliokoski, this volume). An original compositional zoning or layering may be reflected by wide variations in the olivine to pyroxene ratios determined from calculated mineral modes, but the scale of these variations has not been established.

Serpentinite has been extensively altered to a talc + dolomite $\pm$ magnesite $\pm$ chlorite assemblage in a zone adjacent to the Ropes ore body. Major and trace element compositions, including gold, were determined for a suite of talc-carbonate rocks from the northern alteration zone. From this data relative additions and losses of chemical components were computed by two methods: The first assuming that alteration occurred at constant volume, and the second assuming that Al and Sc are immobile during alteration while volume is allowed to change. Changes calculated using the first method appear to be more consistent with observed mineralogical changes than those calculated by the latter method.

Talc-carbonate alteration at the Ropes Mine appears to have resulted in the addition of CO₂, Ca and Al, and the removal of H₂O and Mg from the serpentinite. Au abundance in the serpentinite samples analyzed were found to be near crustal averages. Talc-carbonate samples showed greater variation, but generally had Au concentrations equal to or greater than those found in serpentinites.

Gold may have been transported as a carbonyl or carbonate complex in a CO₂ rich fluid from some outside source to the ore host rock. Subsequent carbonate forming reactions in the ultramafic rock surrounding the ore host rock sufficiently lowered the P_{CO₂} and/or decreased the acidity to allow for deposition of gold in suitable structures in the ore host rock.

Cobalt, Nickel, and Vanadium Contents of
Pyrite from Michigamme Slate, Michigan

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The Michigamme Slate is an organic-rich metasedimentary rock in central Upper Peninsula of Michigan. The Michigan Geological Survey, with funding from the Department of Energy tested the uranium potential of the Michigamme in Marquette, Baraga and Iron Counties with six diamond drill holes (Trow, 1979). In this study, pyrites were separated from core material and analyzed for cobalt, nickel, and vanadium with the objective of determining its mode of origin. Most pyrites fall into the syngenetic field of Price (1972), in terms of Co/Ni ratios; however, a number of high Co/Ni ratios were found which fall into the volcanic-exhalative massive sulfide field.

References

- Trow, J., 1979, Final report diamond-drilling for geologic information in the Middle Precambrian basins in the western portion of northern Michigan: Geol. Surv. Div., Michigan Dept. Nat. Resources, Lansing, Open-File Report UDOE OFR GJBX-162(79), 44 p.
- Price, B.G., 1972, Minor elements in pyrites from the Smithers map area, B.C. and exploration applications of minor element studies (M.S. Thesis): Univ. of British Columbia, Vancouver, 270 p.

Geochemistry of the Volcanic Rocks of Northeastern Wisconsin

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The early Proterozoic volcanic-plutonic belt of north-central Wisconsin is well exposed in the northern half of Marinette County. In this area, the volcanic sequence has been informally divided into four formations (Jenkins, 1973): the Quinnesec Formation, the McAllister Formation, the Beecher Formation, and the Pemene Formation. Although stratigraphic relationships between these are still not fully resolved, it appears that the overall section represents a progression from mafic through felsic volcanics.

Although a general calc-alkaline affinity has been recognized for the more felsic portions of this volcanic section, uncertainty still remains as to the geochemical affinities of the basaltic rocks and their possible petrologic relationship to the more felsic volcanics. For the present study, a suite of samples was collected for analysis (major elements, rare earth, and other trace elements) with emphasis on the mafic Quinnesec Formation.

The Quinnesec pillowed flows and associated diabbases range from basalt through andesite and show little evidence of a trend in iron enrichment. They have variable, though generally high, Al_2O_3 and low TiO_2 contents. The rare earth elements (REE) show a wide range in both total abundance and chondrite normalized slopes. Most basalts show extreme light (L)REE depletion with $[\text{La}/\text{Sm}]_n = .14-.38$ (total range .14-.76). Two gabbro samples from the Sturgeon Falls sill, one of several large gabbroic sills within the Quinnesec Formation, also show significant LREE depletion suggesting possible consanguinity with the basalts. The andesites have enriched LREE ($[\text{La}/\text{Sm}]_n = 1.23-1.47$), but relatively low total REE abundances.

Samples from the Beecher Formation are andesitic whereas those from the Pemene Formation are rhyolitic. The rhyolites have higher REE abundances and larger negative Eu anomalies than the andesites, but show similar shaped, LREE-enriched patterns. The rhyolites also have lower Sr (55-133 ppm) and higher Rb/Sr ratios than the andesites ($\text{Sr} \approx 360$ ppm).

The data suggest the following conclusions:

1. The Quinnesec Formation basalts and related diabbases are compositionally distinct from the other early Proterozoic basalts in upper Michigan (i.e. Hemlock, Badwater, etc.) and were derived from mantle which was highly depleted in large ion lithophile elements.
2. The basalts and andesites of northeastern Wisconsin are not related by crystal fractionation but represent separate melts from compositionally distinct sources.
3. The overall chemical characteristics of the Quinnesec basalts

suggest affinities with basalts in recent island-arcs and back-arc basins rather than those of the ocean floor or continental regions. The appearance of andesites and more felsic units with these basalts also supports such an island-arc to back-arc basin environment.

Reference

Jenkins, R. A., 1973, Institute on Lake Superior Geology, 19th, p. 15-16.

Geochemistry of Fluid Inclusions from Archean and Phanerozoic Gold Deposits

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Fluid inclusions from various Archean and Phanerozoic gold deposits in metamorphic terrains were examined using a specially designed gas chromatographic analytical system and conventional heating/freezing techniques. The inclusion analyses indicate that, in most cases, the fluids are $\text{H}_2\text{O}-\text{CO}_2$ or $\text{H}_2\text{O}-\text{CH}_4-\text{CO}_2$ mixtures, with trace amounts of CO and N_2 . Heating and freezing measurements indicate the presence of low salinity (<2 equiv. wt%NaCl), $\text{H}_2\text{O}-\text{CO}_2$ and $\text{H}_2\text{O}-\text{CH}_4-\text{CO}_2$ fluid inclusions, confirming our analyses. Homogenization of the inclusions occurred at temperatures of 220°C to 380°C . Temperature and f_{O_2} determinations were made by plotting reaction lines on a_{O_2} -temperature diagrams utilizing a recently developed equation of state for supercritical $\text{H}_2\text{O}-\text{CO}_2-\text{CH}_4$ fluids. Our results indicate that the fluids obtained equilibrium at temperatures of 340°C to 500°C and f_{O_2} 's near the QFM buffer. Isochores, also calculated from the equation of state, indicate high pressures of 2000 to 4000 bars.

Jacobsville Sandstone Ridge in Keweenaw Bay

R. L. Wunderman and M. Rausch

There is a north-northeast trending lake bottom ridge of Jacobsville Sandstone in Keweenaw Bay (Fig. 1). A recent scuba dive confirms the presence of subhorizontal Jacobsville Sandstone 20 m under water at a point 7 Km southeast of Portage Entry ($88^{\circ}22'W$, $46^{\circ}56'N$) cropping out as a detritus-free north-west facing scarp. At this locality, the Jacobsville Sandstone is lithologically similar to nearby shore exposures. Warren (1981, Figs. 46 and 47) shows that this ridge forms the southeastern margin of a steep-sided valley so that similar excellent exposures of bedrock are likely to be found on the northwest ridge face as well. Being sheltered from the lake, the ridge face more probably is related to the formation of the steep-sided valley than being the result of wave erosion on a lake cliff.

Reference

Warren, E.J., 1981, The bedrock topography of the Keweenaw Peninsula, Michigan (Ph.D. dissertation), Michigan Technological University, Houghton, 169 p.

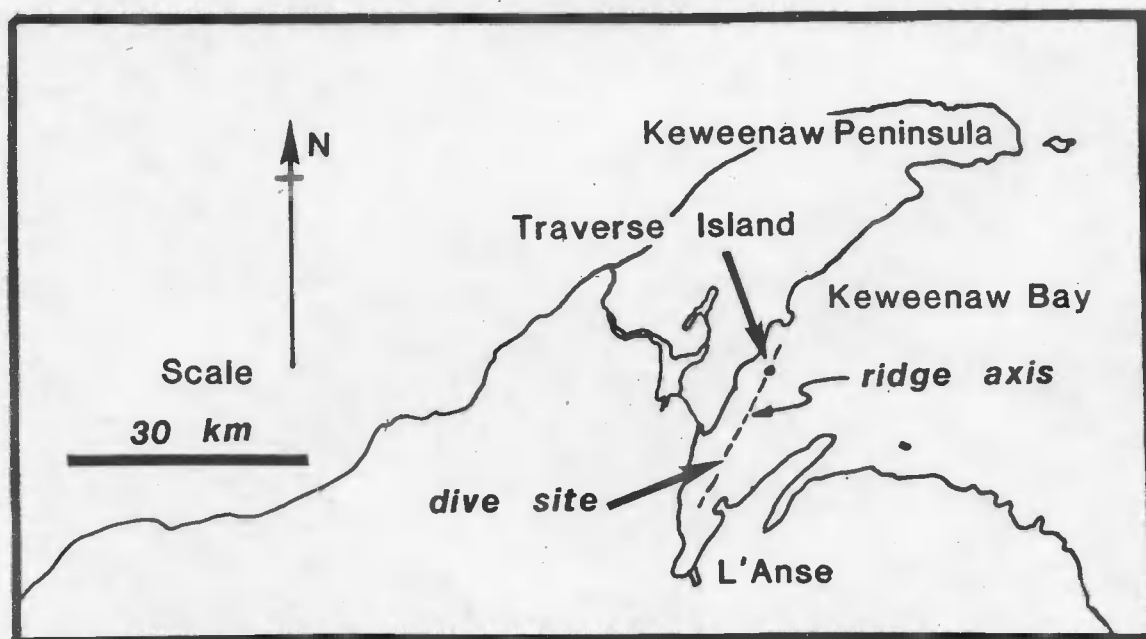


Figure 1: Location Map.

ROPES GOLD MINE AND ITS GEOLOGICAL SETTING

Dean Rossell and J. Kalliokoski

THE ROPES GOLD MINE AND ITS GEOLOGICAL SETTING

Dean Rossell and J. Kalliokoski

INTRODUCTION

Location

The Ropes Gold Mine is located in Section 29, T48N-R27W, Marquette County, Michigan, about three miles north of Ishpeming and a quarter mile west of Deer Lake (Figs. 1, 2). The Ropes Mine is the most extensively developed of the 20 or more gold prospects and mines that comprise the Michigan gold belt.

History

Most of the following history is summarized from Broderick (1945). The Ropes ore body was discovered in 1880 by Julius Ropes while he was prospecting for asbestos among the outcrops of the Deer Lake Peridotite. Mining operations at the Ropes began in 1882 and continued until 1897 when the mine was closed by creditors. At the time of closing, 15 levels had been developed to the east and west of the Curry shaft, that reached a depth of 244 meters. During the 15 years that the mine was in operation it produced 1250 kg of gold and 6200 kg of silver from 145,000 tons of ore, averaging 5.96 g/ton gold and 28.05 g/ton silver (Morgan and DeCristoforo, 1980). Around 1901 some 30,000 tons of tailings were cyanided.

In 1933 the Ropes property was acquired by the Ishpeming Mining Co., which continued surface exploration in the area. Calumet and Hecla Mining Co. bought a majority interest in the Ishpeming Mining Co. in 1934. From 1934 to 1942 they conducted an extensive exploration program of diamond drilling, drifting on the 15th level, and resampling of the old workings in an attempt to find an extension of the Ropes ore body (Fig. 3). Although this work found no major extensions of the ore body, it did disclose over a million tons of lower grade ore in the ore host rock surrounding the old workings. These zones, located between the 1st and 15th levels, average 0.13 oz/ton gold and 0.7 oz/ton silver. In 1942 war time restrictions on precious metal mining stopped operations at the mine, preventing further exploration below the 15th level.

In 1974 Callahan Mining Corp., the present owner of the Ropes Mine, began a new exploration program to confirm and try to expand the low grade ore reserves established by the Calumet and Hecla Mining Co. To date this work has included rehabilitation of the old mine workings, an extensive surface and underground diamond drilling campaign, extraction of bulk samples for metallurgical tests, resampling of old workings, and remapping of the surface and underground geology (Skillings, 1981).

Previous Geological Studies

The only detailed geological work on the Ropes Mine is by Broderick, who was the mine geologist for Calumet and Hecla Mining Co. In 1945 Broderick published a detailed description of the Ropes ore body and the surrounding peridotite. Subsequent published work on the geology of the surrounding area has been by Boyum (1964, 1970, 1975), Puffett (1966, 1974), Clark and others (1975), Cannon and Klasner (1975), and Morgan and DeCristoforo (1980). The latter provide the most recent data on the overall geology of the Ishpeming greenstone belt. Information on the ore host rock comes from an unpublished mine report by Creasy (1981).

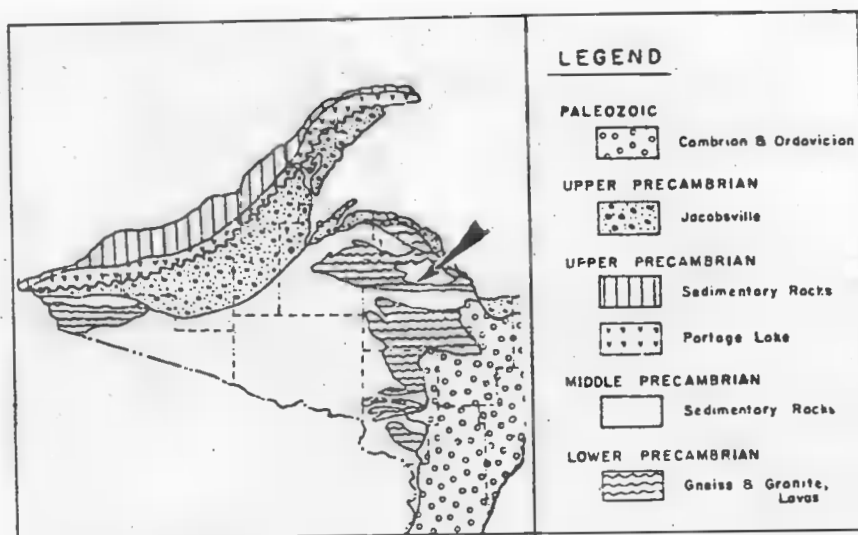
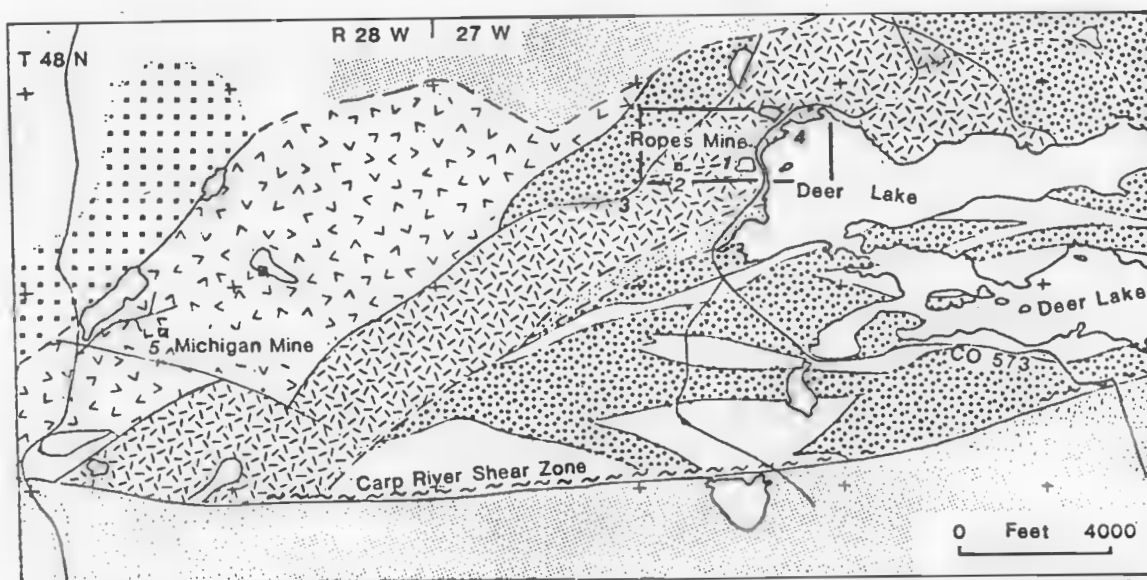
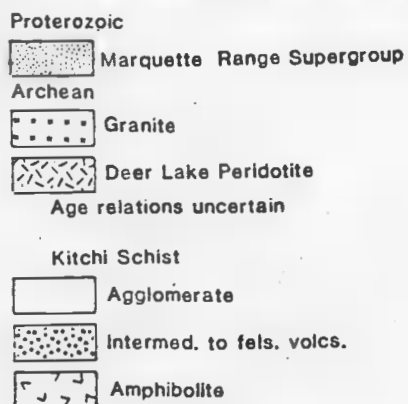


Figure 1. Location of the Ropes Gold Mine.



(Cannon and Klasner, 1975; Clark and others, 1975)



*5 Field trip stops

GEOLOGY OF THE AREA AROUND THE ROPES AND MICHIGAN GOLD MINES

Figure 2. Regional geology of the Ropes Mine and Michigan Mine area.

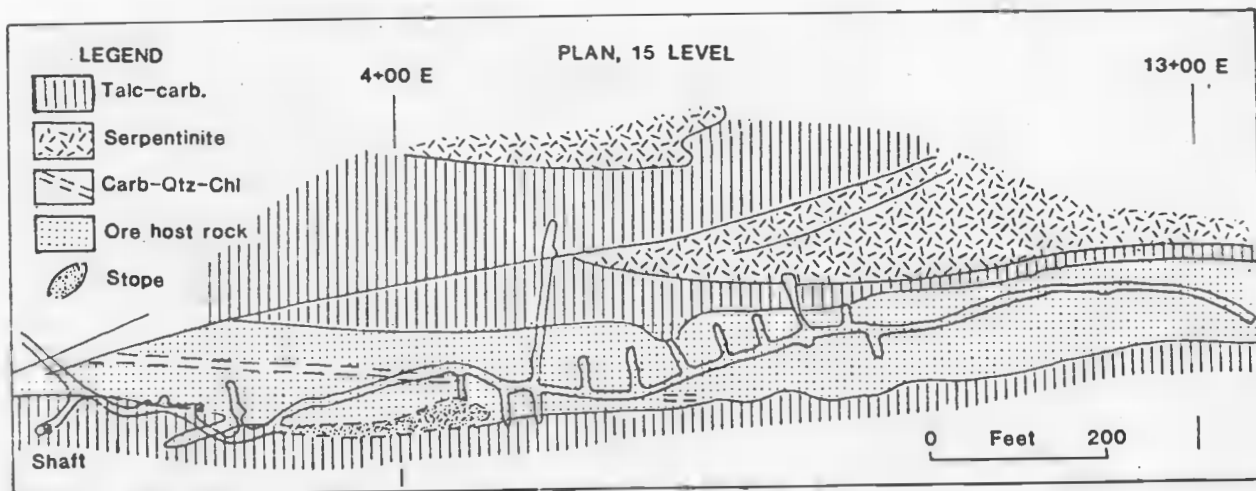


Figure 3a. Geologic plan of the east half of the 15th level.

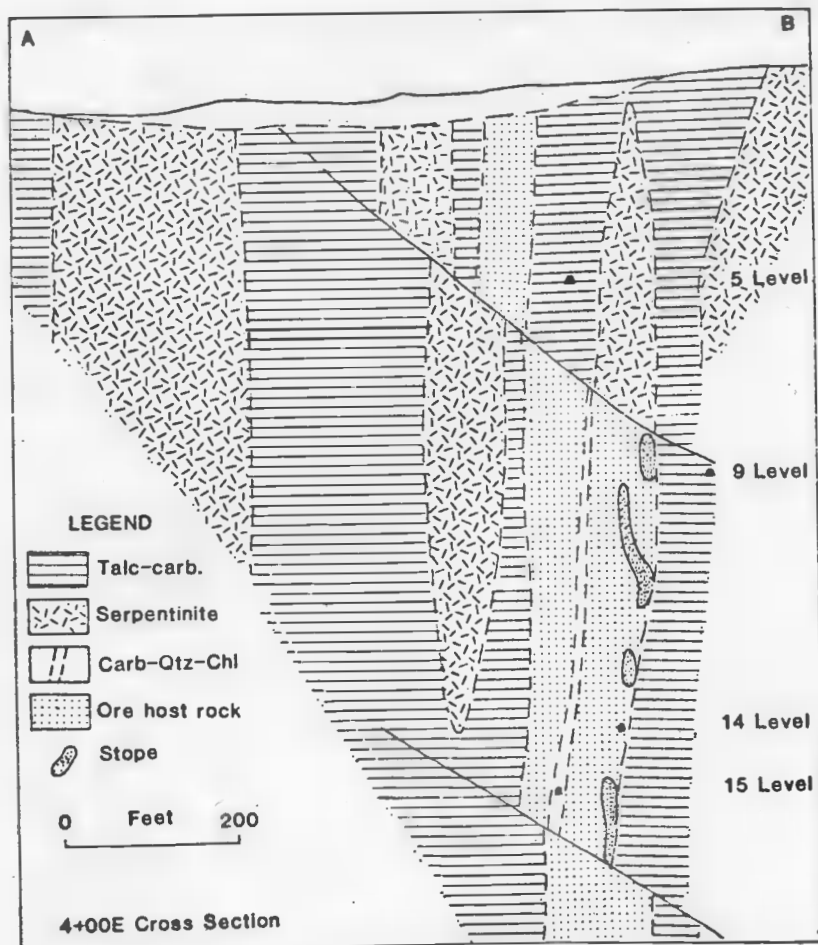


Figure 3b. 4 + 00E cross-section through the Ropes ore body. Darker lines in 3a and 3b represent reverse faults dipping 30° to 40° to the south. (Figures 3a and 3b modified from unpublished maps and cross-sections prepared for Callahan Mining Corp. by Resource Exploration Inc., 1982).

A large part of the report that follows is taken from an M.S. thesis under preparation by the senior author, on the alteration of the Deer Lake Peridotite in the vicinity of the Ropes Gold Mine.

Regional Geology

The Ropes Gold Mine is situated within the Ishpeming greenstone belt, part of which is shown in Figure 2. This belt is Archean in age, and geologically similar to the other greenstone belts that occur in the main part of the Superior Geological Province, north of Lake Superior. It represents the easternmost part of the granite-greenstone terrane in Michigan (Sims, 1976).

On the west, the greenstone belt is cut by younger granites, and on the east it is covered by Lake Superior and probably the Jacobsville Sandstone. On the north and south the Archean rocks form the basement for the mildly metamorphosed sedimentary rocks of the Marquette Range Supergroup that outcrop in the Dead River Basin and are in fault contact with the Kitchi schists along the Carp River Falls shear, possibly a reactivated Archean fault (Sims and others, 1980).

The greenstone belt consists of several thousand feet of felsic to mafic volcanic rocks, with an abundant pyroclastic component, that are intruded by Archean peridotites and granitic plutons (Table 1). Northwest of Deer Lake a gray granite in amphibolite Kitchi Schist gave a Rb/Sr age of 2490 m.y. (Van Schmus, 1974, in Morgan and DeCristoforo, 1980). The volcanic rocks are assigned to the Mona and Kitchi Schist formation (Van Hise and Bayley, 1895), and Morgan and DeCristoforo (1980) note that both formations represent volcanic cycles, beginning with mafic and ending with more felsic volcanic units.

The Kitchi Schist is the host for the Deer Lake Peridotite (also referred to as DLP). In the vicinity of Deer Lake, the Kitchi Schist consists of a lower mafic member that is composed of basaltic flows, diabases, and gabbros, all of which generally are metamorphosed to the amphibolite grade. The upper part contains andesite flows, coarse grained dacitic pyroclastic units, flow top breccias, and fine grained pyroclastic or crystal tuffs (Morgan and DeCristoforo, 1980).

Overlying the Kitchi Schist is the Mona Schist, consisting of pillow basalts and of felsic pyroclastic rocks, some now schistose. Puffett described the contact between the Mona and Kitchi Schists as conformable (Puffett, 1974) whereas Morgan and DeCristoforo interpret it to be an unconformity, based on the higher metamorphic grade of some units in the Kitchi Schist near the contact (Morgan and DeCristoforo, 1980). The Mona Schist has been dated as at least 2750 m.y. old (Van Schmus, 1974, in Morgan and DeCristoforo, 1980).

The Kitchi Schist is transected by a northeast-trending body of serpentized ultramafic referred to as the Deer Lake Peridotite. The peridotite stretches 6.5 Km from the Carp River Falls Shear to Deer Lake. The DLP is discordant to most contacts within the Kitchi Schist, and for this reason is thought to be younger.

Other ultramafic bodies in the region are the Presque Isle Peridotite, northwest of the city of Marquette (Lewan, 1972; Puffett, 1974) and the Yellow Dog Peridotite of Lower Keweenaw age, situated about 20 miles north-northwest of the Ropes Gold Mine (Klasner and others, 1977; Morris and Wilband, 1977).

Table of Formations
Ishpeming Greenstone Belt

PROTEROZOIC

Keweenawan

Diabase dikes, Yellow Dog Peridotite

----- Intrusive Contact -----

Marquette Range Supergroup

Quartzite, dolomite, slate, conglomerant
banded iron formation, and minor meta-
volcanic rocks

----- -Unconformity- -----

ARCHEAN

Dead River Pluton and
Compeau Creek Gneiss

Massive and foliated, medium and coarse
grained, intermediate to felsic plutonic
rocks

----- -Intrusive Contact -----

Mona Schist

Volcanic-plutonic cycle of pillowed ba-
salts, sericitic-chloritic schist, rhy-
olite tuff, interlayered amphibolite and
exhalites.

----- Contact Relationship Uncertain -----

Deer Lake Peridotite
Presque Isle Peridotite

Serpentinized harzburgite and lherzolite

----- Contact Relationship Uncertain -----

Kitchi Schist

Volcanic-plutonic cycle of gabbro, dia-
bases and basalts (all now generally
amphibolites), intermediate and felsic
agglomerates, tuffs and flows

----- ??? -----

Basement Unknown

ORE HOST ROCK

Occurrence

Ore grade mineralization at the Ropes Mine is confined entirely within a narrow body of rock that will be referred to as the ore host rock or the OHR. The OHR is a nearvertical, tabular body of silicic rock that strikes N70°E along its surface exposure. The OHR is bounded on the north and south by talc-carbonate rock which grades laterally into the serpentinite of the Deer Lake Peridotite. The OHR is about 16 meters wide at the surface, near the Curry shaft, and gradually increases in width to over 30 meters along the 15th level (Fig. 3). Laterally, the OHR extends over 1400 feet to the east of the Curry shaft, pinching out before it reaches the shore of Deer Lake (Fig. 4).

The origin of the OHR and its relationship to the surrounding serpentinite and talc-carbonate rocks of the Deer Lake Peridotite remains problematic. The early miners referred to the OHR as the mineral dike. Broderick described the OHR as a segment of Keewatin basic lavas and fragmentals, equivalent to the volcanic rocks of the Kitchi Schist to the immediate west, and proposed that faulting probably played a major role in emplacing the OHR within the peridotite (Broderick, 1945).

Recent workers generally support Broderick's contention that the OHR is principally volcanic, but disagree on its mode of emplacement within the peridotite. Morgan and DeCristoforo suggest that the Deer Lake Peridotite may represent at least in part a series of komatiitic lava flows or subvolcanic intrusions (Morgan and DeCristoforo, 1980). If this were the case, the OHR could represent a conformable sequence of more felsic volcanics, extruded during a hiatus in komatiitic volcanism. Nevertheless, emphasizing the sheared nature of the OHR, Morgan and DeCristoforo (1980) consider the OHR a faulted-in portion of the older Kitchi Schist.

Creasy (1981) also supports a volcanic origin for the OHR and suggests that the juxtaposition of the OHR and peridotite is the result of magmatic intrusion of the Deer Lake Peridotite around the OHR (Creasy, 1981). Evidence collected by the senior author from the serpentinite and talc-carbonate rocks surrounding the OHR, leads him to favor the view that the juxtaposition of the contrasting rock types is largely the result of tectonism. Figure 5 shows a possible analog where a sliver of metasedimentary rock, similar in dimensions to the OHR, has been sheared into an Alpine-type ultramafic body in Ludlow Township, Vermont (Gregg, 1975). These points will be addressed further in later sections.

Petrography of the OHR

Based on examination of core, thin section work, and chemical analysis of selected rock from the OHR, Creasy interprets the OHR to be a sequence of intermediate to felsic fragmental rock of varying particle size and composition, minor intermediate flows and possibly volcanically derived sediments and exhalites (Creasy, 1981). He also has found a preservation of relict volcanic textures, primarily in thin section, in spite of the intense, pervasive alteration throughout the OHR. Relict textures recognized by Creasy include pseudomorphs of pyroxenes, amphiboles and feldspars, hydration fractures of originally glassy rocks, and a general fragmental aspect of many of the rocks (Creasy, 1981).

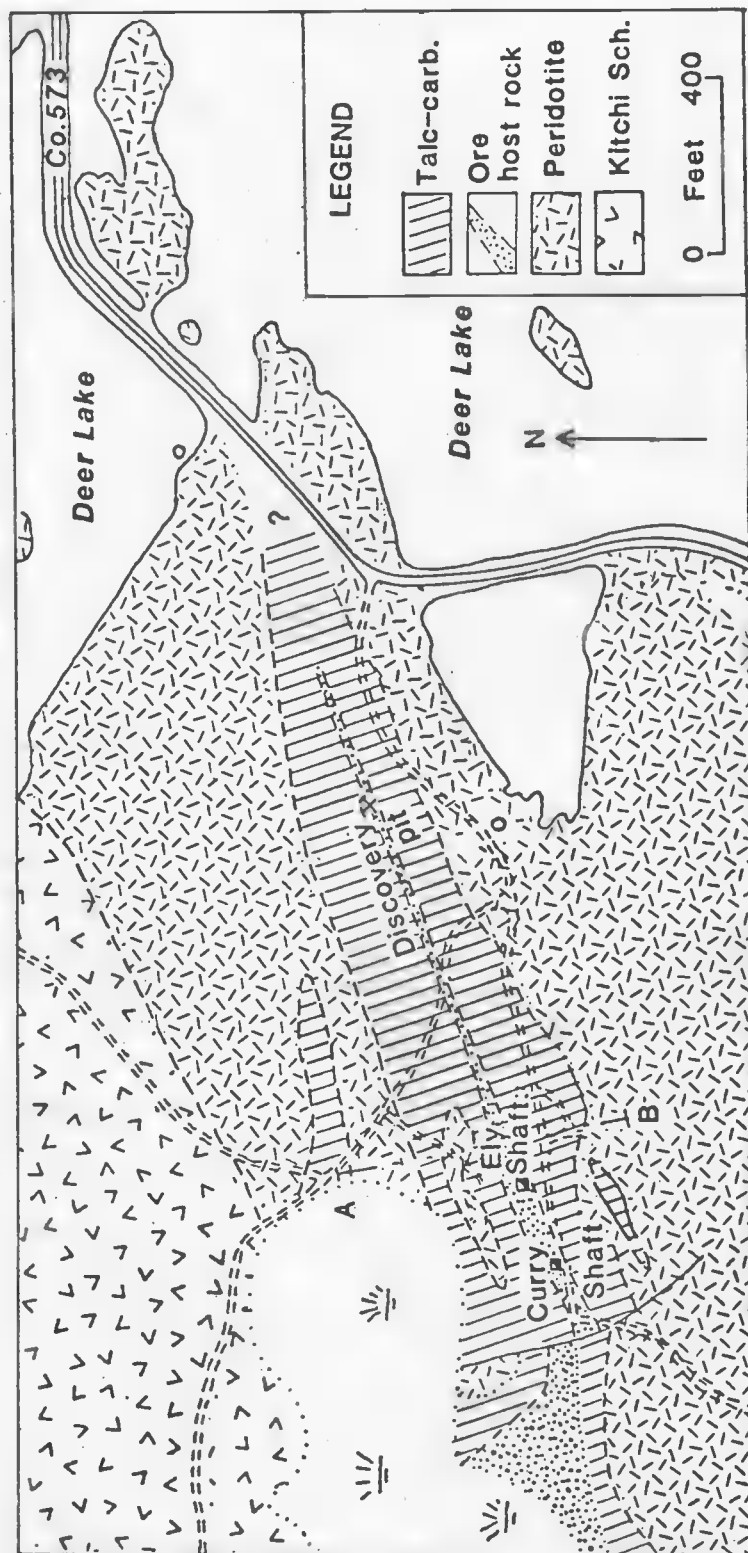


Figure 4. Map of the surface geology in the vicinity of the Ropes Mine. Surface projection of the east end of the 15th level denoted by (o). (Map compiled using information from unpublished company maps prepared for Callahan Mining Corp. by Resource Exploration, Inc., 1982).

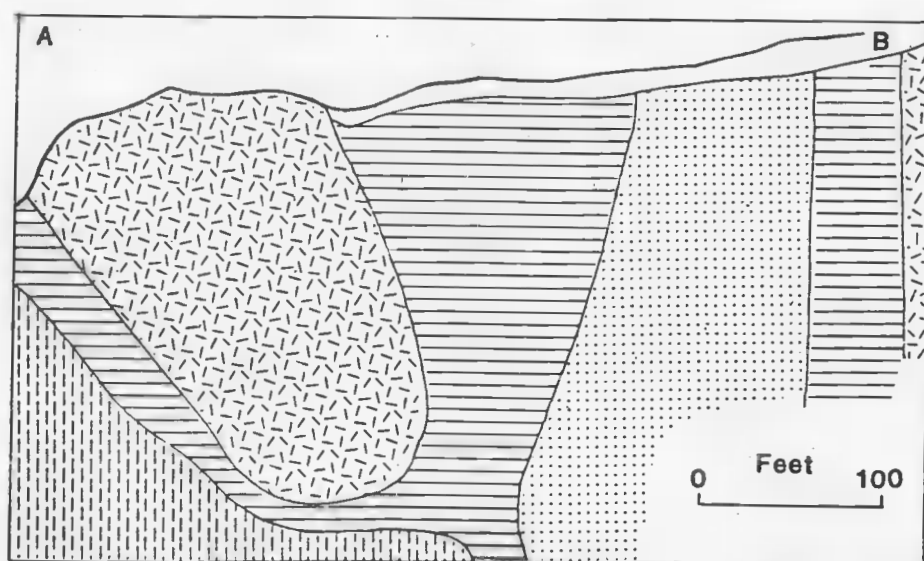
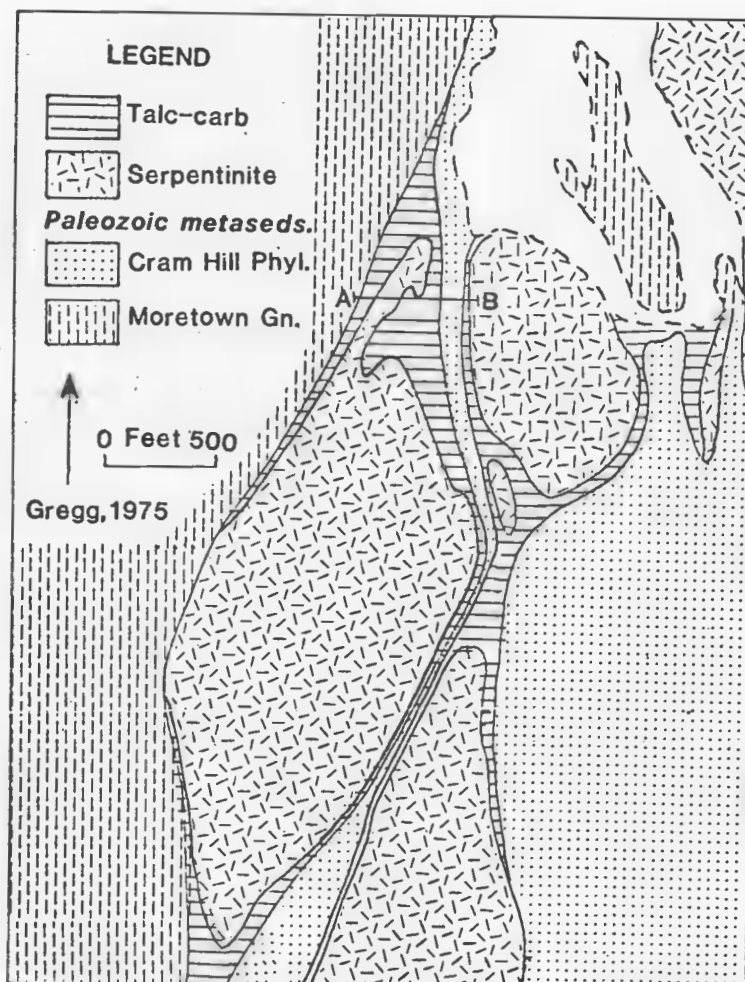


Figure 5. Surface map (upper) and cross-section (lower) of an alpine type serpentinite body from southeastern Ludlow Township, Vermont. The serpentinite is crossed by a sliver of Cram Hill Phyllite (thought to be tectonically emplaced) similar in dimensions to the Ropes Gold Mine ore host rock. (Modified from Gregg, 1975).

At the discovery pit (Fig. 1, Stop 1) the rock is a quartz-chlorite-sericite schist with abundant 0.1 to 0.3 mm grains of quartz. To the north, six feet south of the contact with the talc-carbonate-altered peridotite, the rock displays in thin section a micro-breccia texture consisting of angular fragments of darker quartz-chlorite material (0.2 to 0.5 mm in maximum dimension) in a lighter colored quartz-sericite matrix. There are also a few 1 mm quartz grains. At the talc-carbonate contact the ore host rock is a fine-grained, highly fractured, quartz-sericite schist, sporadically replaced by coarser grained sericite and by younger veinlets of chlorite and carbonate.

Broderick describes four types of alteration from the OHR within the mine: sericitization, chloritization, silicification, and pyritization, and notes that sericitization is more prevalent than chloritization (Broderick, 1945).

Carbonatization, generally considered to be confined to the talc-carbonate rocks surrounding the OHR, has been noted by the senior author to overlap into the OHR. Although carbonatization is not pervasive throughout the OHR, it is intensely developed locally, replacing matrix, forming small veinlets, and rimming quartz and sericitic fragments. Carbonate alteration of the OHR is most prevalent along the south contact and has produced a zone of carbonate-quartz-chlorite rock that will be described further in the section on talc-carbonate alteration.

Chemistry of the Ore Host Rock

Chemical analyses of various rock types from the OHR are listed in Table 2. Analyses 1, 2, 3 and 4 are from Creasy (1981); analyses 5, 6 and 7 are new analyses, from a series of samples collected from the chloritic OHR along the north edge of the discovery pit (Fig. 4), and analysed for this paper by Drs. T. Bornhorst and W.I. Rose, Jr. by X-ray fluorescence analysis.

Creasy (1981) notes that based on comparison with less altered rocks of similar silica content, the Ropes Mine rocks are characterized at a given silica content by greater than average values of MgO, very low CaO, low to very low Na₂O, and K₂O in two ranges, very low or moderately high. Creasy attributes these variations to the pervasive alteration that has affected the OHR, and concludes that on both chemical and textural grounds, portions of the OHR resemble lithologies found in the Kitchi and Mona Schists (Creasy, 1981).

The lighter major oxides, MgO and SiO₂, in the new analyses (5, 6, 7, Table 2) may be significantly in error due to matrix effects resulting from a suspected high volatile content. Nevertheless, the values of the heavier minor and trace elements, like TiO₂ and Zr₂O₃, which are unlikely to be significantly in error, suggest a parent composition of an intermediate igneous rock, possibly an andesite, of alkaline affinity.

Mineralization

The gold mineralization of the Ropes ore body (Figs. 3, 4) can be subdivided into two types following the work of Broderick (1945): 1) higher grade mineralization associated with quartz-tetrahedrite veins; and 2) lower grade, disseminated mineralization that surrounds the quartz-tetrahedrite veins.

ANALYSES OF ORE HOST ROCK SAMPLES

	1	2	3	4	5	6	7
SiO ₂	37.70	55.40	61.30	72.00	48.39	50.05	49.57
Al ₂ O ₃	23.80	12.80	16.30	13.20	15.07	15.68	17.85
Fe ₂ O ₃	11.20	1.40	.64	3.10	10.28	8.27	7.67
FeO	.00	5.50	4.60	.24	.00	.00	.00
MgO	10.60	17.50	6.10	1.90	16.57	14.33	11.67
CaO	.40	.60	.38	.26	.60	1.23	.35
Na ₂ O	.52	.02	4.70	.07	.18	.19	.20
K ₂ O	5.70	.01	1.30	4.20	3.01	3.55	4.54
TiO ₂	1.10	.59	.64	.48	1.01	.98	.77
P ₂ O ₅	.29	.17	.18	.02	.08	.07	.17
MnO	.03	.03	.11	.01	.05	.05	.03
CO ₂		.50	.05	.20			
TOTAL	91.34	94.52	96.30	95.68	95.24	94.40	92.82

Table 2. Selected analyses of ore host rocks. Samples 1-4 taken from Creasy, 1981. Samples 5-7 are new analyses for this paper. Analyses in wt. percent. No. 5, contact with talc-carbonate rock; b, 6 feet south of contact; 7, discovery pit.

The quartz-tetrahedrite veins still remaining in the old workings range in thickness from several inches to several feet, and Broderick reports thicknesses of up to 38 feet for veins that had already been mined. Ore veins typically strike north-east, oblique to the general strike of the OHR, and have a near-vertical dip. Eight major veins or vein systems were exploited during the early mining operations, all of which pinched out along strike and with depth. None of the quartz-tetrahedrite veins cross the OHR contact into the surrounding talc-carbonate rocks. These veins are composed mainly of white, splintery quartz with minor tetrahedrite, chalcopyrite, galena, pyrite and rare native gold. Broderick (1945) also mentions the presence of sphalerite, native silver, and rare molybdenite and tourmaline. One small vein near the 1070 cross-cut on the 15th level consists primarily of massive chalcopyrite, with galena, tetrahedrite, pyrite, quartz and possible ruby silver widely scattered along thin carbonate-filled fractures in the vein. Several other large quartz veins within the OHR with similar orientation, contain large pods of pyrite but no significant gold.

The lower grade disseminated ore generally is confined to the hydrothermally altered and pyritized rock surrounding the quartz-tetrahedrite veins. No free gold has been reported from these zones, and apparently most of the gold and silver is contained within the abundant pyrite. However, Broderick (1945) has noted that abundant pyrite in the OHR does not necessarily indicate ore grade material, in that some pyritic zones have very low gold values.

Gold and silver mineralization is not evenly distributed throughout the OHR. The clustering of old stopes shows that the majority of the higher grade ore was found along the south contact of the OHR (Fig. 3). Smaller discontinuous lenses of ore occur sporadically along the north contact, but generally do not extend across to the south contact, leaving an interior zone of the OHR with very low grades. Skillings (1981) reports grades of 0.15 oz/ton for portions of the Ropes ore body.

Veins and Evidence for Faulting in the OHR

The OHR has undergone obvious deformation shown locally by pronounced foliations, intense fracturing and vein development, boudinaged quartz veins, and faults. However, the ore host rock shows a wide variety of secondary alteration effects so pervasive that, in most cases, it has not been possible to establish sufficiently distinctive and persistent map units to work out structural relationships.

Similarly, a number of veins are exposed within the mine, but only a few, none of them mineralized, show cross cutting relationships to provide data on relative ages. Thus, although the available data is insufficient for determining the complete structural and vein emplacement history, several features concerning vein relationships have been noted. For example, many small quartz veins scattered throughout the OHR show cross-cutting relationships, demonstrating multiple periods of quartz vein formations. Veins of banded carbonate which have a sporadic distribution throughout the OHR, are everywhere younger than quartz veins, where cross-cutting relationships can be observed.

The entire sequence of ore host rocks and the surrounding peridotite are offset by several large reverse faults, which strike to the northeast and dip between 25° and 35° to the south (Fig. 3; 4 + 00 E cross cut). The lower blocks are rotated clockwise along these faults, changing the strike from $N70^{\circ}E$ at the surface to $N80^{\circ}E$ at the 15th level. The larger reverse faults are commonly marked by one to two feet of breccia, but the smaller ones commonly contain prismatic, terminated dolomite crystals, with minor chalcopyrite and pyrite. Sprays of millerite are also common where reverse faults cut the surrounding talc-carbonate and serpentinite.

A number of older, high angle faults are also seen in the mine workings, but most appear to have had only limited movement along them. A larger, apparently high angle, north-striking fault offsets the OHR to the west of the Curry shaft (Fig. 2).

DEER LAKE PERIDOTITE

Occurrence

The Deer Lake Peridotite is a linear, near-vertical (Morgan and DeCristoforo, 1980), tabular ultramafic body, now predominantly composed of serpentinite. The serpentinites form prominent ridges in the area, providing good exposures. Good outcrops are also found along the north shore of Deer Lake.

In general, the contacts between the Deer Lake Peridotite and the surrounding Kitchi Schist are very poorly exposed, typically denoted by narrow depressions. This contact does outcrop at two locations west of the spillway on the north side of Deer Lake. There the contact is marked by a 3 to 6 foot wide zone of soft actinolite-chlorite schist, possibly similar to the tremolite-chlorite zones described by Chidester and others (1978) at the contacts of the Belvidere ultramafic body in Vermont. Serpentinite near the actinolite-chlorite schist contains abundant carbonate and talc, which diminish abruptly away from the contact. The Kitchi Schist near this contact is strongly chloritized and contains numerous quartz veins.

The origin of the Deer Lake Peridotite is still unclear. Broderick (1945), Clark and others (1975), and most recently Creasy (1981) suggest, based largely on the discordant nature with the surrounding Kitchi Schist, and locally well preserved cumulate olivine textures, that the Deer Lake Peridotite is a magmatic intrusion. On the basis of chemical similarities and pillow-like structures found near Deer Lake, Morgan and DeCristoforo (1980) propose that all, or part, of the Deer Lake Peridotite may be komatiitic flows. As previously mentioned, the present authors have noted structural and textural similarities between the Deer Lake Peridotite and Alpine type ultramafics, and thus there is the added possibility that the Deer Lake Peridotite may have crystallized elsewhere and subsequently was emplaced as a solid or semi-solid body, in a manner similar to that proposed for alpine-type ultramafic bodies.

Petrography of Serpentinites

Two distinct types of serpentinites are seen in the Deer Lake Peridotite. Type A, the most common variety in surface exposures, is dark gray on fresh surfaces, with fine to medium grained serpentine, giving the rock a slightly greasy luster. These serpentinites generally have no obvious foliation, and commonly have readily identifiable 1-5 mm serpentine pseudomorphs after olivine or pyroxene outlined by thin selvages of white carbonate and talc. No spinifex olivine or pyroxene, considered indicative of komatiitic flows, were recognized anywhere.

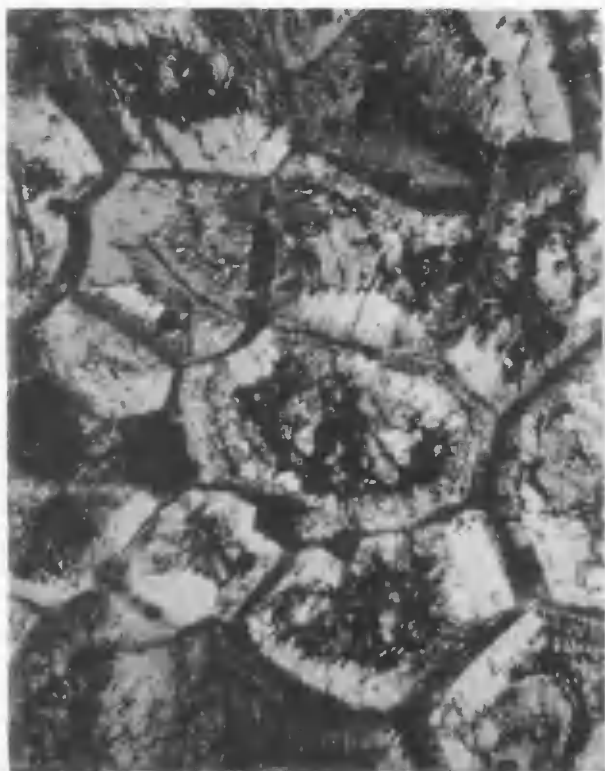
In thin section, Type A serpentinite frequently shows well developed serpentine pseudomorphs after olivine and pyroxene. The pseudomorphed olivine commonly shows serpentine mesh textures, similar to those described by Wicks and Whittaker (1977), with subparallel, length-slow, serpentine fibers growing toward the grain centers from original olivine grain boundaries and fractures. In some sections accumulate textures are well preserved, outlined by thin rims of dusty magnetite, carbonate and talc (Fig. 6). The central portions of the above pseudomorphed olivine are replaced by carbonate and talc, which are generally minor but ubiquitous, mineral phases.

Serpentine pseudomorphs after pyroxene, called bastite (Wicks and Whittaker 1977) appear as 1-3 mm patches of parallel serpentine fibers which mimic one of the pyroxene cleavage directions. A second relict cleavage is commonly outlined by subparallel lines of fine-grained magnetite, perpendicular to the serpentine orientation. Bastite-rich samples also contain scattered 1-3 mm wispy flakes of pleochroic chlorite with anomalous "Berlin Blue" birefringence, thought to be penninite. The Type A serpentinite textures correspond to the "Type 3" serpentine textures of Wicks and Whittaker (1977).

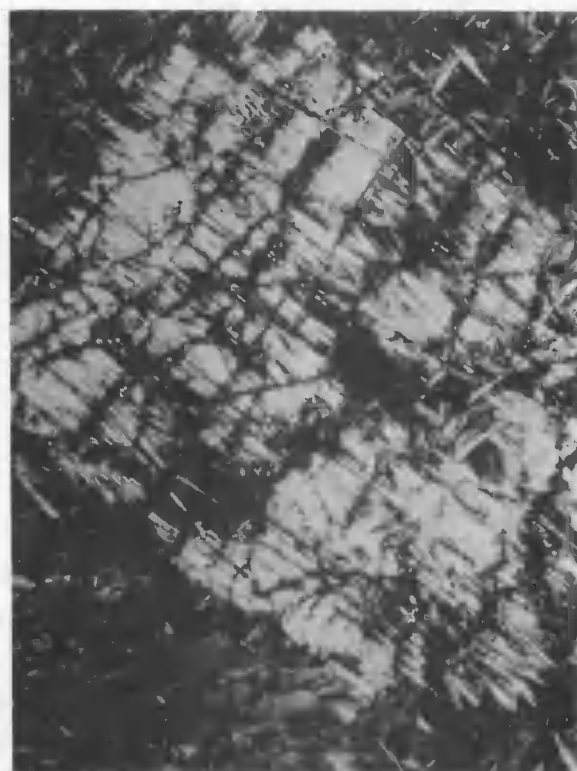
Type B serpentinite, which corresponds to Wicks and Whittaker's (1977) "Type 8" serpentine texture, outcrops rarely but is common as 10-40 foot layers in drill core from the serpentinites south of the Ropes ore body. The best surface exposures are along the shore of Deer Lake (Fig. 4). Type B serpentinite ranges in color from pale green to yellowish white on fresh surface, is extremely fine grained, and has no recognizable relict igneous textures. Commonly these serpentinites have a strong, often contorted foliation, best seen on weathered surfaces. Coarse grained magnetite forms prominent, irregular veinlets and streaks along foliations in most Type B serpentinites.

In thin section, Type B serpentinite differs from Type A in that no pseudomorphic textures are preserved. Instead, serpentine occurs either as a uniform, interlocking felted texture (Fig. 6c) or as strongly foliated (Fig. 6d). Nearly white, Type B serpentinite from drill core, contains abundant, very fine grained, secondary dolomite. Wicks and Whittaker (1977) have correlated non-pseudomorphic serpentine textures similar to those in Type B serpentinites with shearing processes and prograde metamorphic environments.

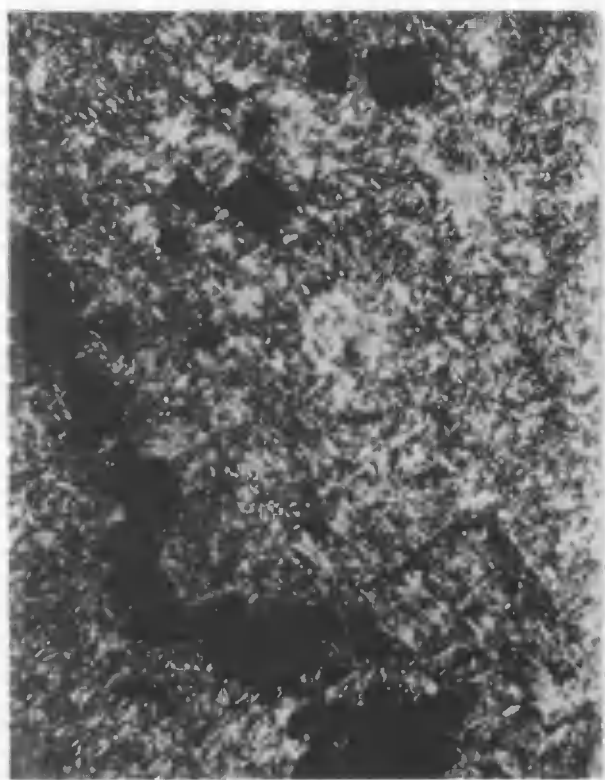
Whole-rock X-ray diffraction patterns of a number of samples of Type A and Type B serpentinites suggest a difference in the prevalent serpentine structural variety in the two types. Generally Type A serpentinite contains a mixture of cryptotile and/or lizardite with lesser amounts of antigorite. Type B serpentinite contains substantially more antigorite. The presence of antigorite rather than cryptotile or lizardite is thought to be indicative of prograde metamorphism, or serpentinitization in a higher pressure-temperature regime (Moody, 1976).



6a



6b



6c



6d

Figure 6: Photomicrographs of serpentine textures from the Deer Lake Peridotite: a) Type A serpentinite, serpentine pseudomorphs after olivine; b) Type A serpentinites, serpentine pseudomorph after pyroxene (bastite); c) Type B serpentinite, recrystallized felted texture; d) Type B serpentinite, foliated texture. All crossed polars. Scale on all photos, 1 cm = 0.66 mm.

Alteration of the Deer Lake Peridotite in the Vicinity
of the Ropes Gold Mine, Marquette County, Michigan

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Gold mineralization at the Ropes Mine is contained entirely in an east-west striking septum of highly altered felsic rock within the serpentinitized Deer Lake Peridotite. Near the Ropes Mine the serpentinite consist of two principal textural varieties: Type A, with well preserved relict igneous textures, and Type B, showing recrystallized and foliated textures, probably produced by shearing. A prominent zone of Type B serpentinite along the north shore of Deer Lake may represent an extension of a shear zone along the felsic septum.

Compositionally, the serpentinites represent altered harzburgite and lherzolite (Rossell and Kalliokoski, this volume). An original compositional zoning or layering may be reflected by wide variations in the olivine to pyroxene ratios determined from calculated mineral modes, but the scale of these variations has not been established.

Serpentinite has been extensively altered to a talc + dolomite $\pm$ magnesite $\pm$ chlorite assemblage in a zone adjacent to the Ropes ore body. Major and trace element compositions, including gold, were determined for a suite of talc-carbonate rocks from the northern alteration zone. From this data relative additions and losses of chemical components were computed by two methods: The first assuming that alteration occurred at constant volume, and the second assuming that Al and Sc are immobile during alteration while volume is allowed to change. Changes calculated using the first method appear to be more consistent with observed mineralogical changes than those calculated by the latter method.

Talc-carbonate alteration at the Ropes Mine appears to have resulted in the addition of CO_2 , Ca and Al, and the removal of H_2O and Mg from the serpentinite. Au abundance in the serpentinite samples analyzed were found to be near crustal averages. Talc-carbonate samples showed greater variation, but generally had Au concentrations equal to or greater than those found in serpentinites.

Gold may have been transported as a carbonyl or carbonate complex in a CO_2 rich fluid from some outside source to the ore host rock. Subsequent carbonate forming reactions in the ultramafic rock surrounding the ore host rock sufficiently lowered the P_{CO_2} and/or decreased the acidity to allow for deposition of gold in suitable structures in the ore host rock.

Cobalt, Nickel, and Vanadium Contents of
Pyrite from Michigamme Slate, Michigan

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The Michigamme Slate is an organic-rich metasedimentary rock in central Upper Peninsula of Michigan. The Michigan Geological Survey, with funding from the Department of Energy tested the uranium potential of the Michigamme in Marquette, Baraga and Iron Counties with six diamond drill holes (Trow, 1979). In this study, pyrites were separated from core material and analyzed for cobalt, nickel, and vanadium with the objective of determining its mode of origin. Most pyrites fall into the syngenetic field of Price (1972), in terms of Co/Ni ratios; however, a number of high Co/Ni ratios were found which fall into the volcanic-exhalative massive sulfide field.

References

- Trow, J., 1979, Final report diamond-drilling for geologic information in the Middle Precambrian basins in the western portion of northern Michigan: Geol. Surv. Div., Michigan Dept. Nat. Resources, Lansing, Open-File Report UDOE OFR GJBX-162(79), 44 p.
- Price, B.G., 1972, Minor elements in pyrites from the Smithers map area, B.C. and exploration applications of minor element studies (M.S. Thesis): Univ. of British Columbia, Vancouver, 270 p.

Geochemistry of the Volcanic Rocks of Northeastern Wisconsin

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The early Proterozoic volcanic-plutonic belt of north-central Wisconsin is well exposed in the northern half of Marinette County. In this area, the volcanic sequence has been informally divided into four formations (Jenkins, 1973): the Quinnesec Formation, the McAllister Formation, the Beecher Formation, and the Pemene Formation. Although stratigraphic relationships between these are still not fully resolved, it appears that the overall section represents a progression from mafic through felsic volcanics.

Although a general calc-alkaline affinity has been recognized for the more felsic portions of this volcanic section, uncertainty still remains as to the geochemical affinities of the basaltic rocks and their possible petrologic relationship to the more felsic volcanics. For the present study, a suite of samples was collected for analysis (major elements, rare earth, and other trace elements) with emphasis on the mafic Quinnesec Formation.

The Quinnesec pillowed flows and associated diabases range from basalt through andesite and show little evidence of a trend in iron enrichment. They have variable, though generally high, Al_2O_3 and low TiO_2 contents. The rare earth elements (REE) show a wide range in both total abundance and chondrite normalized slopes. Most basalts show extreme light (L)REE depletion with $[La/Sm]_n = .14-.38$ (total range .14-.76). Two gabbro samples from the Sturgeon Falls sill, one of several large gabbroic sills within the Quinnesec Formation, also show significant LREE depletion suggesting possible consanguinity with the basalts. The andesites have enriched LREE ($[La/Sm]_n = 1.23-1.47$), but relatively low total REE abundances.

Samples from the Beecher Formation are andesitic whereas those from the Pemene Formation are rhyolitic. The rhyolites have higher REE abundances and larger negative Eu anomalies than the andesites, but show similar shaped, LREE-enriched patterns. The rhyolites also have lower Sr (55-133 ppm) and higher Rb/Sr ratios than the andesites ($Sr \approx 360$ ppm).

The data suggest the following conclusions:

1. The Quinnesec Formation basalts and related diabases are compositionally distinct from the other early Proterozoic basalts in upper Michigan (i.e. Hemlock, Badwater, etc.) and were derived from mantle which was highly depleted in large ion lithophile elements.
2. The basalts and andesites of northeastern Wisconsin are not related by crystal fractionation but represent separate melts from compositionally distinct sources.
3. The overall chemical characteristics of the Quinnesec basalts

suggest affinities with basalts in recent island-arcs and back-arc basins rather than those of the ocean floor or continental regions. The appearance of andesites and more felsic units with these basalts also supports such an island-arc to back-arc basin environment.

Reference

Jenkins, R. A., 1973, Institute on Lake Superior Geology, 19th, p. 15-16.

Geochemistry of Fluid Inclusions from Archean and Phanerozoic Gold Deposits

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Fluid inclusions from various Archean and Phanerozoic gold deposits in metamorphic terrains were examined using a specially designed gas chromatographic analytical system and conventional heating/freezing techniques. The inclusion analyses indicate that, in most cases, the fluids are $\text{H}_2\text{O}-\text{CO}_2$ or $\text{H}_2\text{O}-\text{CH}_4-\text{CO}_2$ mixtures, with trace amounts of CO and N_2 . Heating and freezing measurements indicate the presence of low salinity (<2 equiv. wt%NaCl), $\text{H}_2\text{O}-\text{CO}_2$ and $\text{H}_2\text{O}-\text{CH}_4-\text{CO}_2$ fluid inclusions, confirming our analyses. Homogenization of the inclusions occurred at temperatures of 220°C to 380°C . Temperature and f_{O_2} determinations were made by plotting reaction lines on a_{O_2} -temperature diagrams utilizing a recently developed equation of state for supercritical $\text{H}_2\text{O}-\text{CO}_2-\text{CH}_4$ fluids. Our results indicate that the fluids obtained equilibrium at temperatures of 340°C to 500°C and f_{O_2} 's near the QFM buffer. Isochores, also calculated from the equation of state, indicate high pressures of 2000 to 4000 bars.

Jacobsville Sandstone Ridge in Keweenaw Bay

R. L. Wunderman and M. Rausch

There is a north-northeast trending lake bottom ridge of Jacobsville Sandstone in Keweenaw Bay (Fig. 1). A recent scuba dive confirms the presence of subhorizontal Jacobsville Sandstone 20 m under water at a point 7 Km southeast of Portage Entry ($88^{\circ}22'W$, $46^{\circ}56'N$) cropping out as a detritus-free north-west facing scarp. At this locality, the Jacobsville Sandstone is lithologically similar to nearby shore exposures. Warren (1981, Figs. 46 and 47) shows that this ridge forms the southeastern margin of a steep-sided valley so that similar excellent exposures of bedrock are likely to be found on the northwest ridge face as well. Being sheltered from the lake, the ridge face more probably is related to the formation of the steep-sided valley than being the result of wave erosion on a lake cliff.

Reference

Warren, E.J., 1981, The bedrock topography of the Keweenaw Peninsula, Michigan (Ph.D. dissertation), Michigan Technological University, Houghton, 169 p.

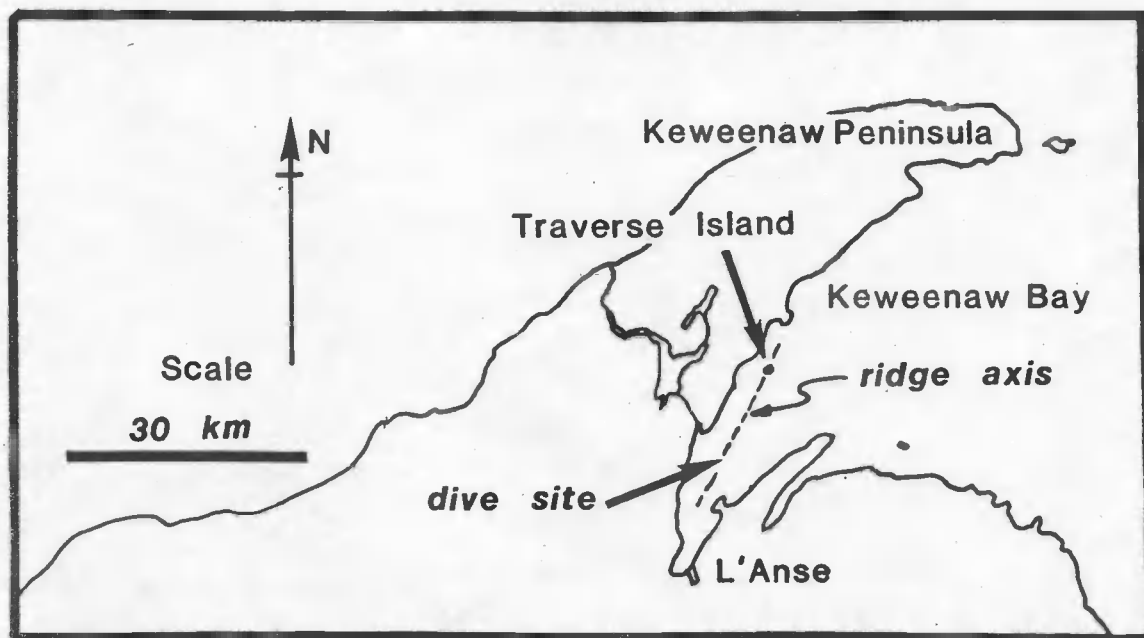


Figure 1: Location Map.

ROPES GOLD MINE AND ITS GEOLOGICAL SETTING

Dean Rossell and J. Kalliokoski

THE ROPES GOLD MINE AND ITS GEOLOGICAL SETTING

Dean Rossell and J. Kalliokoski

INTRODUCTION

Location

The Ropes Gold Mine is located in Section 29, T48N-R27W, Marquette County, Michigan, about three miles north of Ishpeming and a quarter mile west of Deer Lake (Figs. 1, 2). The Ropes Mine is the most extensively developed of the 20 or more gold prospects and mines that comprise the Michigan gold belt.

History

Most of the following history is summarized from Broderick (1945). The Ropes ore body was discovered in 1880 by Julius Ropes while he was prospecting for asbestos among the outcrops of the Deer Lake Peridotite. Mining operations at the Ropes began in 1882 and continued until 1897 when the mine was closed by creditors. At the time of closing, 15 levels had been developed to the east and west of the Curry shaft, that reached a depth of 244 meters. During the 15 years that the mine was in operation it produced 1250 kg of gold and 6200 kg of silver from 145,000 tons of ore, averaging 5.96 g/ton gold and 28.05 g/ton silver (Morgan and DeCristoforo, 1980). Around 1901 some 30,000 tons of tailings were cyanided.

In 1933 the Ropes property was acquired by the Ishpeming Mining Co., which continued surface exploration in the area. Calumet and Hecla Mining Co. bought a majority interest in the Ishpeming Mining Co. in 1934. From 1934 to 1942 they conducted an extensive exploration program of diamond drilling, drifting on the 15th level, and resampling of the old workings in an attempt to find an extension of the Ropes ore body (Fig. 3). Although this work found no major extensions of the ore body, it did disclose over a million tons of lower grade ore in the ore host rock surrounding the old workings. These zones, located between the 1st and 15th levels, average 0.13 oz/ton gold and 0.7 oz/ton silver. In 1942 war time restrictions on precious metal mining stopped operations at the mine, preventing further exploration below the 15th level.

In 1974 Callahan Mining Corp., the present owner of the Ropes Mine, began a new exploration program to confirm and try to expand the low grade ore reserves established by the Calumet and Hecla Mining Co. To date this work has included rehabilitation of the old mine workings, an extensive surface and underground diamond drilling campaign, extraction of bulk samples for metallurgical tests, resampling of old workings, and remapping of the surface and underground geology (Skillings, 1981).

Previous Geological Studies

The only detailed geological work on the Ropes Mine is by Broderick, who was the mine geologist for Calumet and Hecla Mining Co. In 1945 Broderick published a detailed description of the Ropes ore body and the surrounding peridotite. Subsequent published work on the geology of the surrounding area has been by Boyum (1964, 1970, 1975), Puffett (1966, 1974), Clark and others (1975), Cannon and Klasner (1975), and Morgan and DeCristoforo (1980). The latter provide the most recent data on the overall geology of the Ishpeming greenstone belt. Information on the ore host rock comes from an unpublished mine report by Creasy (1981).

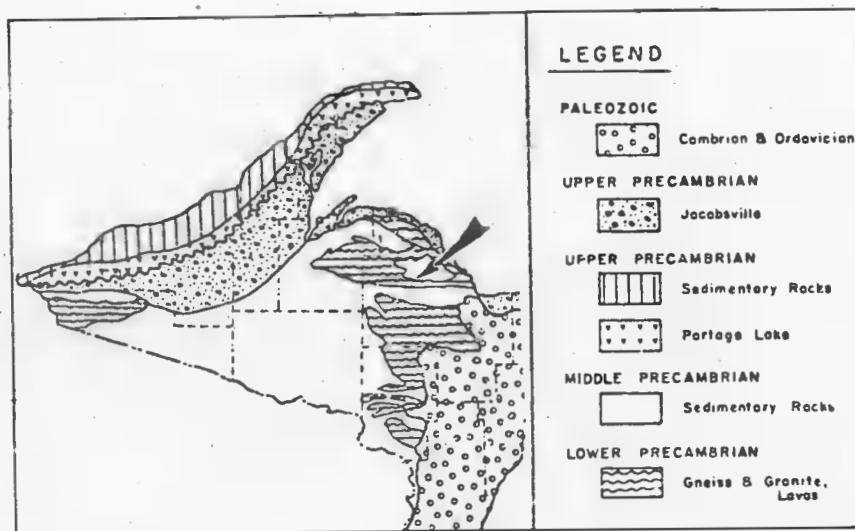
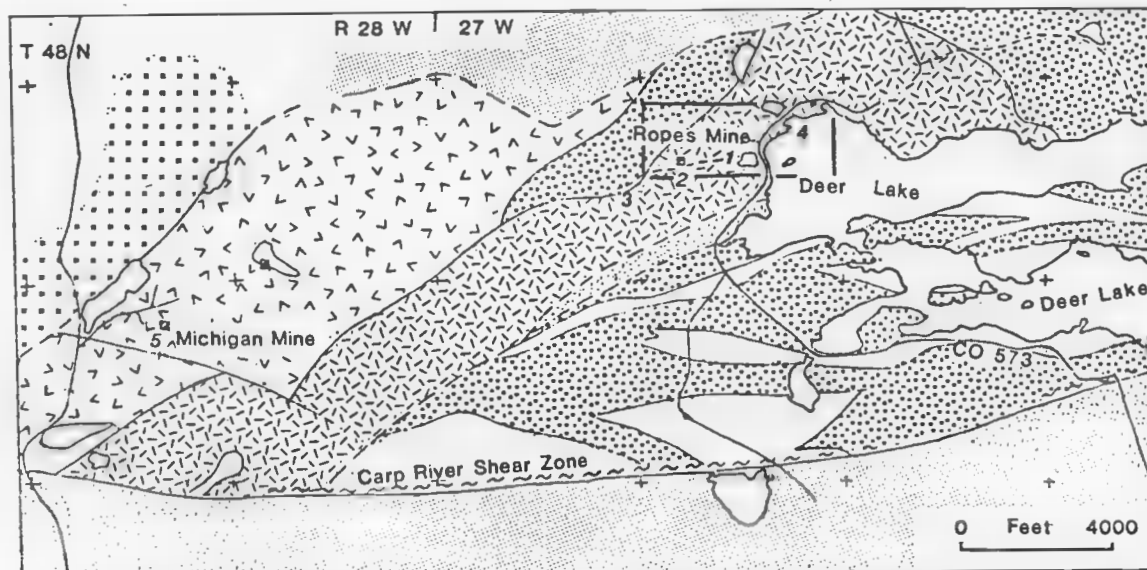
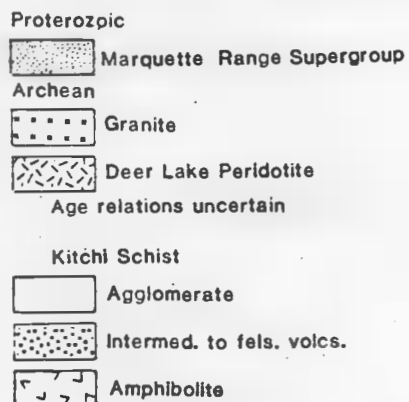


Figure 1. Location of the Ropes Gold Mine.



(Cannon and Klasner, 1975; Clark and others, 1975)



*5 Field trip stops

GEOLOGY OF THE AREA AROUND THE ROPES AND MICHIGAN GOLD MINES

Figure 2. Regional geology of the Ropes Mine and Michigan Mine area.

Composition of Serpentinities

Because of difficulty in field recognition, no attempt was made during mapping to distinguish pyroxene-rich and olivine-rich portions of the peridotite. In general, olivine-rich ultramafics produce more magnetite when serpentinized than do the pyroxene-rich varieties. A large scale zonation of magnetic properties in the Deer Lake Peridotite, showing a highly magnetic core and less intensely magnetic margins (Morgan and DeCristoforo, 1980), suggests an olivine-rich core and pyroxene-rich margins.

The chemical compositions of 10 representative serpentinites from the Deer Lake Peridotite are given in Table 3. The MgO values reported in this study are significantly higher than those reported by Morgan and DeCristoforo (1980), but correlate well with those reported by Creasy (1981). After recalculating the chemical data to exclude volatiles, mineral modes were calculated for the serpentinite samples using a computer program. The dominant mineral phases in the calculated modes are olivine and orthopyroxene, with lesser amounts of diopside, magnetite, chromite and, in pyroxene rich samples, of anorthite. In the following paragraph references to olivine and pyroxene also are to their calculated modes. The modal olivine to pyroxene ratios range from 0.28 to 1.93. The 10 samples in Table 3 are plotted on an olivine-orthopyroxene-clinopyroxene ternary diagram in Figure 7.

All of the analyzed samples from the Deer Lake Peridotite fall in or near the hartzburgite field. Ashely (1974), Coleman and Keith (1970), and Page (1967) report losses of Ca during serpentinization of primary ultramafic rocks. If substantial Ca has been lost from the Deer Lake Peridotite during serpentinization, the original ultramafic rock may have had more diopside than shown in the calculated modes.

Comparison of trace element abundances with calculated mineral modes reveals some general trends. In the samples analyzed in this study, Al_2O_3 , TiO_2 and Sc are enriched in pyroxene-rich serpentinites relative to the olivine-rich ones. Increases in these abundances correlate with increasing chlorite in the serpentinite. NiO content appears to decrease with decreasing olivine content. Cr_2O_3 and FeO show no consistent trends between olivine- and pyroxene-rich samples. The consistent variation in the ratios of $\text{TiO}_2/\text{Al}_2\text{O}_3$, $\text{Sc}/\text{Al}_2\text{O}_3$ for these samples imply that these serpentinites were originally derived from a single parent magma.

Comparison of Serpentine Compositions With Those of Other Ultramafics

The determination of the origin of the Deer Lake Peridotite could have exploration significance. Morgan and DeCristoforo (1980) noted that, based on their analyses, the composition of the Deer Lake Peridotite is close the komatiite field of Naldrett and Cabri (1976). It follows that if the Deer Lake Peridotite represents komatiitic volcanic rocks, the OHR might be an interflow tuff sequence, possibly with an associated, laterally extensive exhalite component.

Many chemical criteria have been proposed to distinguish komatiitic rocks since the recognition of ultramafic lavas in the late 1960's. There now seems to be a consensus (Basaltic Volcanism Special Project, 1981) that komatiites are characterized by: 1) MgO values greater than 18 and less than 40 weight percent, but typically between 20 and 30 weight percent; 2) TiO_2 less than 1%; 3) Ni greater than 100 ppm; 4) Cr greater than 140 ppm; 5) $\text{CaO}/\text{Al}_2\text{O}_3$ 0.8 to 1.1. In the serpentinite samples analyzed for this study (with values recalculated to exclude volatiles; Table 2):

ANALYSES OF SERPENTINITE SAMPLES

	1	2	3	4	5	6	7	8	9	10
SiO ₂	43.20	42.55	42.18	39.88	41.88	42.03	41.10	40.21	38.30	44.46
Al ₂ O ₃	1.96	.03	.98	1.71	5.34	5.53	.00	3.82	.00	2.07
Fe ₂ O ₃	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
FeO	8.99	5.67	9.69	5.58	10.00	10.59	6.33	9.48	12.21	5.43
MgO	36.77	35.07	36.12	34.29	26.60	27.69	35.53	29.57	31.85	37.73
CaO	.27	2.30	1.48	4.36	2.08	1.89	4.01	1.60	3.14	.35
Na ₂ O	.03	.03	.03	.03	.04	.06	.03	.05	.03	.04
K ₂ O	.00	.00	.00	.01	.02	.02	.00	.01	.00	.00
H ₂ O+	9.70	6.70	6.20	8.20	6.80	7.20	9.90	7.50	6.50	6.50
TiO ₂	.11	.02	.05	.07	.27	.24	.01	.21	.01	.06
P ₂ O ₅	.01	.02	.02	.02	.03	.03	.03	.02	.02	.01
CO ₂	.00	7.80	2.15	5.08	6.06	3.75	2.12	.00	6.87	1.22
TOTAL	102.25	101.06	100.01	100.00	100.00	99.99	100.01	93.47	99.97	97.87
SC	11	6	7	12	19	19	8	15	7	6
V	85	39	52	49	126	123	17	82	43	70
CR	5172	1988	4667	1582	2918	3343	2274	3423	3940	2163
CU	25	27	17	26	38	34	20	22	13	62
ZN	59	49	37	21	60	66	64	50	60	98
AU		1	4		3					4

Table 3. Selected analyses of serpentinites from the Deer Lake Peridotite. Elements listed as oxides in wt. percent, others in ppm.

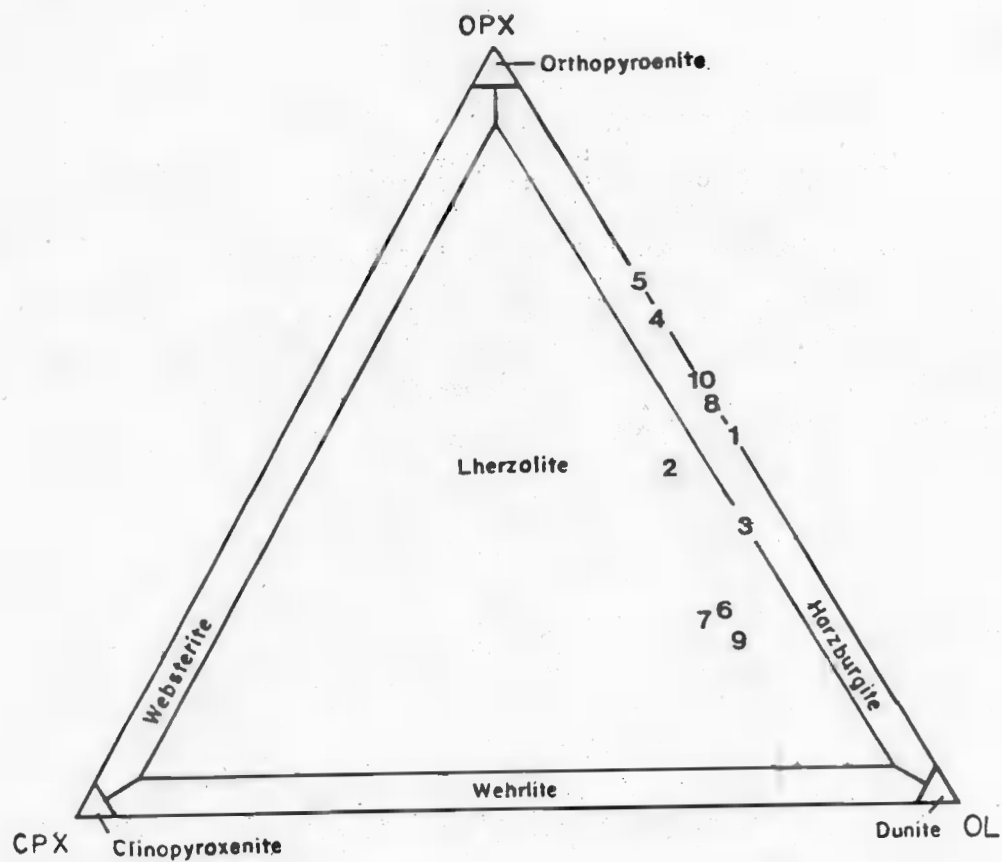


Figure 7. Compositions of serpentinites from Table 3 plotted on nomenclature ternary diagram. (Modified from Coleman and Keith, 1971).

1) the MgO content, in every sample, is greater than 30 weight percent, and several are more than 40 weight percent; 2) TiO₂ in all samples is less than 1% and in most samples is less than 0.1%; 3) for all samples both Cr and Ni are greater than 1000 ppm; and 4) CaO/Al₂O₃ ratios range from 0.17 to 75.74. The wide variation of this ratio probably reflects the mobility of Ca during serpentinization and carbonatization. From this comparison it can be seen that TiO₂, Cr and Ni fit the requirements for komatiite, but all would be marginal values. Only some of the MgO values fit the criteria, and those that do, also are near the limit.

A commonly used plot for distinguishing komatiitic rocks from tholeiitic rocks is the Al₂O₃ vs. FeO/(FeO+MgO) plot of Naldrett and Cabri (1976) shown in Figure 8. The diagonal line in Figure 8 separates plots of African and Canadian komatiites (x) from those of tholeiitic Canadian synvolcanic dikes and flows (o). All serpentinite of the Deer Lake Peridotite (listed in Table 3 and plotted as solid dots on Figure 8) fall in or near the komatiitic side of the diagram. However, a number of samples of Alpine-type ultramafics (plotted as stars (*)) also fall well within the komatiite side of the diagram. This lack of discrimination is noted by Naldrett who points out that many other ultramafic and mafic rocks that are not related to komatiites will plot on the komatiitic side of the diagram (Naldrett, 1980).

On the basis of the plot in Figure 8 the Deer Lake Peridotite is komatiitic. However, the very high values of MgO for many of the serpentinite samples do not correspond with one of the diagnostic features of komatiites (Basaltic Volcanism, Special Project, 1981). These high MgO values are considered by the senior author to be typical of intrusive and alpine type ultramafics. Moreover, most recent classifications of ultramafic rock types have been based on tectonic setting rather than chemistry alone (Naldrett, 1980), implying that both compositional and field evidence should be considered for a valid designation.

Talc-Carbonate Alteration

Serpentine, olivine, and pyroxene, the primary constituents of serpentinites and peridotites, are unstable in the presence of fluids rich in CO₂ and break down according to the following reaction:



(Deere, et al., 1965).

The serpentinites of the Deer Lake Peridotite have been altered extensively to talc and carbonate in the vicinity of the Ropes Mine. Here zones of talc-carbonate rock extend over 400 feet to the north of the ore host rock, and over 200 feet to the south (Fig. 4). Both zones apparently pinch out eastward, but persist downward, at least to the present levels of exploration. In general the distribution of talc-carbonate alteration appears to be largely controlled by the distribution of the OHR. Due to the difficulty of recognizing low to moderate abundances of talc and carbonate in hand sample, talc-carbonate zones, shown in Figure 4, refer only to zones in which talc and carbonate constitute the majority of the rock. This criterion has undoubtedly led to an underestimation of the extent of talc-carbonate alteration.

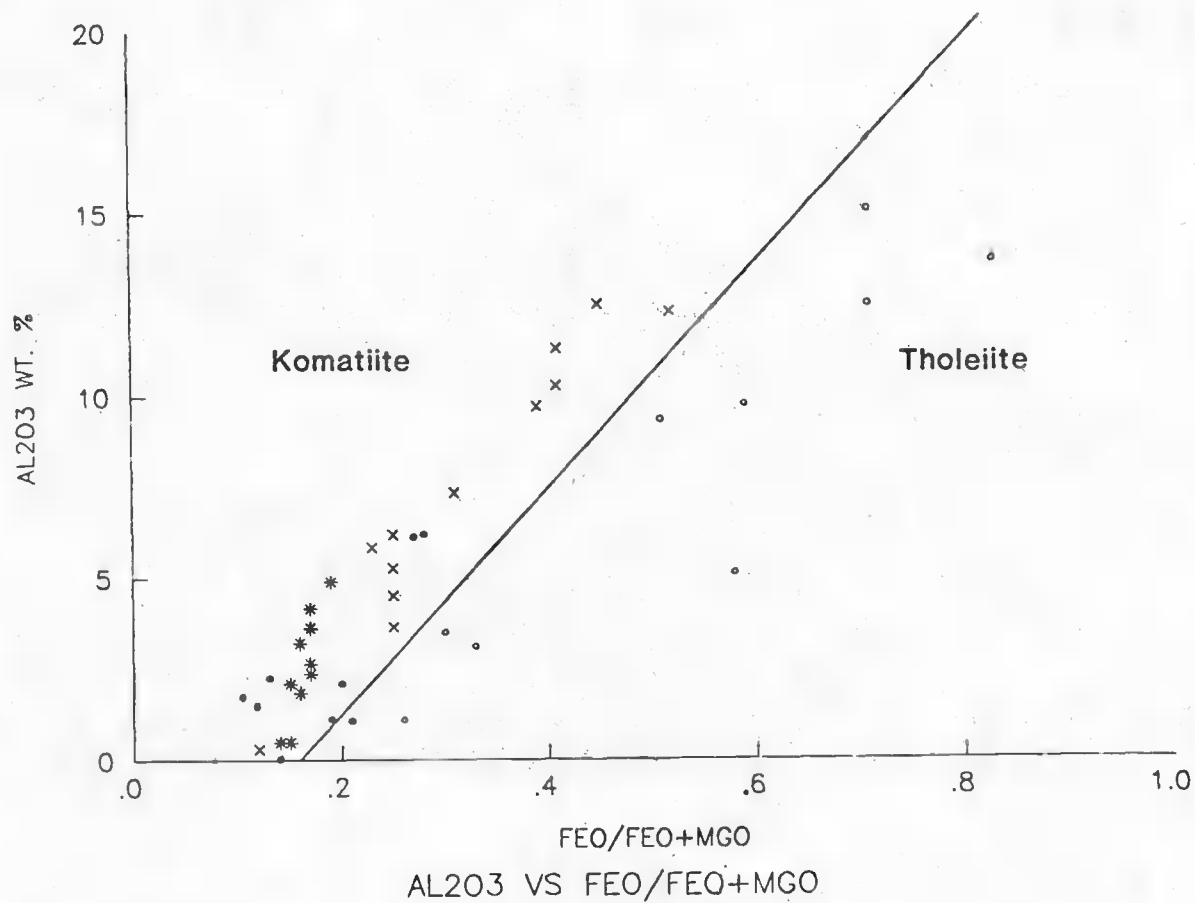


Figure 8. Variation of Al_2O_3 with $\text{FeO}/(\text{FeO} + \text{MgO})$ wt. percent ratio: (•)= serpentinites of the Deer Lake Peridotite, (x)= komatiites (data from Naldrett and Cabri, 1976), (o)= tholeiites from Dundonald Sill and Theo's Flow (Data from Naldrett and Cabri, 1976), (*)= Alpine type lherzolites and harzburgites (data from Menzies, 1977). Total Fe is calculated as FeO and all analyses are calculated to exclude volatiles. (Figure modified from Naldrett and Cabri, 1976).

Peripheral to the talc-carbonate zones, carbonate alteration in the serpentinite occurs as pseudomorphic replacements of serpentine veins by carbonate. Veins generally increase in abundance near the margins of the talc-carbonate zones, so that a single hand sample may contain several generations of veins. In these areas, younger sets of veins, composed of coarse-grain carbonate, typically cross-cut older veins of serpentine replaced by carbonate.

The contact between serpentinite and talc-carbonate rock is typically gradational, marked only by a gradual lightening in color of the rock, as talc and carbonate increase at the expense of the serpentine matrix. Serpentinite features, such as vein patterns and serpentine pseudomorphs after olivine, are commonly preserved for some distance into the talc-carbonate zone. However, serpentinite features are obliterated in more intensely altered rock, which commonly contain 3 mm clots and thin contorted seams of chlorite. The degree of alteration varies widely throughout the north and south alteration zones, with pods of relatively fresh serpentinite preserved within the mapped boundaries of the alteration zones. The ratio of talc to carbonate generally varies from about 2.0 to 0.5, but several small zones of almost pure talc (steatite) have been found in the mine. Both dolomite and magnesite have been formed during alteration of the serpentinite, dolomite being the most abundant, particularly near the OHR.

Near the contact with the OHR, the talc-carbonate rock changes composition, so that quartz and chlorite become significant mineral phases and talc becomes a minor phase. Chidester and others (1978) have proposed that similar carbonate-quartz zones in the Belvidere Mountains ultramafic body represent the final stage of talc-carbonate alteration, occurring along zones where CO₂-rich fluids travelled most freely. The locally gradational nature of the south wall contact between carbonate-quartz-chlorite rock and the OHR, suggest that talc-carbonate alteration has also affected the OHR. This is supported by large differences between trace element abundances in samples near the contact, which reflect the composition of OHR, and those in talc-carbonate rocks further from the contact. A similar overlap of alteration from talc-carbonate rocks to more felsic rocks has been reported at the Campbell Red Lake and Dickenson gold mines in Canada (MacGeehan and Hodgson, 1980). A more complete discussion of petrographic changes in the talc-carbonate zone is under preparation by Rossell (M.S. thesis, in preparation).

Relationship of Talc-Carbonate Alteration to Gold Mineralization

It has been proposed by writers such as Pyke (1976) that ultramafic rocks may be the "source bed" from which the gold in many deposits has been derived. Pyke based his arguments largely on the close spatial association between ultramafic rocks and the gold deposits at Timmins, Ontario and in other large Precambrian gold camps. Additional support for this point of view came from Gottfried and others (1972), who presented evidence suggesting that primary gold abundances in ultramafic rocks are higher than in most other rock types. Anhaeusser and others (1975), and Sager and others (1982) dispute this conclusion, and show that, on a worldwide basis, the primary gold content of ultramafic rocks is no higher, and in many cases is lower, than crustal averages.

Pyke (1976) proposes that one reason for the relationship of ultramafic bodies to gold mineralization is that substantial amounts of gold were released from the ultramafic rocks during carbonatization. The senior writer has tested the hypothesis by obtaining neutron activation gold analyses for a suite of samples from the north talc-carbonate zone at the Ropes Mine, and for serpentinites from the

surrounding Deer Lake Peridotite. This data should permit an evaluation of the degree of redistribution of gold and other elements during carbonate alteration.

The direct comparison of chemical data expressed as weight percent is not satisfactory for determining chemical changes associated with metasomatic alterations (Kerrick and Fyfe, 1981). This is particularly true when substantial changes in specific gravity accompany alteration, as is the case when serpentinite (sp. gr. 2.60) alters to talc-carbonate (sp. gr. 2.70-2.90).

Chidester (1962), Naldrett (1966), and Barnes (1973) have concluded that talc-carbonate alteration is a constant volume process. For this and other reasons discussed by Rossell (Thesis in prep.) constant volume was assumed when calculating relative changes in chemistry, using a method outlined by Chidester (1972). Relative additions and subtractions have been calculated from the data in Table 4 and listed in Table 5. The composition of the initial parent rock is assumed to be that of serpentinite sample No. 3 (Table 3). Reasons for choosing this parent rock composition are given by Rossell (Thesis in prep.). Samples in Table 5 are listed from left to right according to decreasing distance from the OHR contact. Mineral modes visually estimated from thin section are listed below each sample. Variations in abundance of C, H, Ca, Mg, Al and Au with distance from OHR contact are shown graphically in Figure 9.

The large increases in C and Ca shown in Figure 9a and 9b correspond to increasing abundances of dolomite. Losses in hydrogen throughout the zone (Fig. 9) correspond to the loss of serpentine, and are consistent with the partial dehydration nature of the reaction given on an earlier page. Major gains in Al (Figure 9c) correspond with the increasing abundance of chlorite near the OHR contact.

All of the altered serpentinite samples listed in Table 3 and shown graphically in Figure 9d show significant losses of Mg. As noted before, many of the analyses of ore host rock show apparent increases in Mg, suggesting that Mg, and possibly Fe, have migrated from the talc-carbonate zones into the ore host rock.

In five samples of relatively uncarbonatized serpentinite from the Deer Lake Peridotite, gold has an average abundance of 2.8 ppb (range 1-4 ppb) which is certainly not greater than abundances in other types of igneous rocks. However, these values may not represent the initial gold content of the peridotite if substantial gold were removed during serpentinization. Gold values in carbonatized serpentinite samples showed greater variation, with an average abundance of 3.4 ppb and a range from trace to 11 ppb. As shown in Figure 9e gold values increase significantly in the most intensely altered rocks near the ore host rock contact. From the data available, it appears that gold values increase with increasing alteration suggesting that gold is being added, not removed, during talc-carbonate alteration of the Deer Lake Peridotite.

Kerrick and Fyfe (1981) have suggested that ultramafic rocks may play an important role in localizing the precipitation of gold from hydrothermal solutions. They propose that gold may be transported as carbonyl or carbonate complexes in CO₂-rich hydrothermal fluids. Subsequent carbonate forming reactions involving ultramafic rocks may trigger gold precipitation by reducing the partial pressure of CO₂ and/or decreasing acidity (Kerrick and Fyfe, 1981).

ANALYSES OF TALC CARBONATE ROCKS

	1	2	3	4	5	6	7	8	9	10
SiO ₂	46.21	54.32	26.83	47.86	42.04	39.77	45.56	39.30	46.12	52.74
Al ₂ O ₃	1.65	4.59	5.62	2.01	1.94	2.06	1.03	1.17	1.13	1.29
FeO	7.06	4.78	5.28	4.20	4.51	5.55	5.38	7.14	5.39	6.06
MgO	26.55	22.78	20.55	24.01	23.39	25.13	27.63	28.39	29.01	30.63
CaO	1.98	7.25	19.02	11.80	14.85	10.67	8.29	4.81	5.09	1.41
Na ₂ O	.04	.05	.06	.03	.04	.03	.05	.05	.04	.04
K ₂ O	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
H ₂ O+	2.50	1.40	2.50	.80	1.00	4.30	1.40	3.80	5.10	5.00
TiO ₂	.07	.14	.13	.04	.05	.07	.04	.06	.05	.05
P ₂ O ₅	.02	.05	.08	.07	.09	.05	.04	.03	.03	.01
CO ₂	12.36	3.96	18.11	8.68	11.35	13.47	9.79	13.47	8.25	4.11
TOTAL	98.45	99.33	98.19	99.51	99.27	101.11	99.22	98.23	100.22	100.41
SC	8	14	14	17	19	17	14	11	12	9
V	50	56	37	22	30	59	37	21	27	66
CR	1558	1443	1275	1029	1255	1305	1805	1603	1478	2040
MN	1430	1829	3723	1473	1704	1358	1799	1846	951	606
NI	2901	1844	1078	1899	1736	2264	2303	2494	2466	2816
CU	27	38	21	20	19	25	28	28	35	29
ZN	53	89	65	36	30	42	46	56	54	80
AU	4		10		< 6	2	2	1		

Table 4. Selected analyses of talc-carbonate rocks from the North alteration zone. Samples are arranged according to increasing distance from the Ore Host Rock contact. Elements listed as oxides in wt. percent, other in ppm.

Sample #	10	9	8	7	6	5	4	3	2	1
Si	+23.9	+10.5	-1.9	+16.8	-3.4	+11.3	+21.6	-30.0	+34.7	+17.2
Al	+28.8	+16.4	+25.0	+12.5	+111.5	+118.3	+118.3	+526.0	+386.5	+78.8
Fe*	-37.0	-43.8	-22.4	-39.9	-41.4	-48.1	-53.4	-40.1	-48.4	-22.0
Mg	-16.0	-18.9	-17.2	-17.3	-28.7	-27.7	-28.7	-37.4	-34.0	-21.4
Ca	-4.9	+246.5	+241.6	+503.5	+636.6	+1017.6	+752.1	+1311.3	+411.3	+43.0
H	-20.1	-16.9	+35.5	-75.6	-29.0	-82.0	-86.2	-55.6	-76.4	-56.9
Ti	+21.2	-9.1	+21.2	-9.1	+51.5	-27.3	0.0	+184.8	+203.0	+48.5
P	-9.1	+81.8	+81.8	+172.7	+263.6	+609.1	+354.6	+545.4	+236.4	+45.4
C	+89.3	+288.2	+585.5	+392.0	+542.0	+489.7	+332.8	+827.9	+92.8	+554.2
Mn	-44.4	-16.7	+75.9	+75.9	+29.6	+71.3	+38.9	+275.0	+73.7	+38.0
Ni	+27.4	+7.8	+17.6	+7.8	+2.9	-11.8	-6.9	-47.6	-13.2	+39.2

Estimated mineral modes										
Serp	40%	35%	37%	---	30%	---	---	---	---	---
Talc	40%	40%	30%	55%	35%	43%	50%	30%	40%	35%
Carb	15%	20%	30%	40%	30%	50%	40%	60%	45%	55%
Chl	---	---	tr	1%	3%	6%	9%	7%	8%	2%
Opagues	5%	5%	3%	4%	2%	2%	1%	3%	3%	3%
Qtz	---	---	---	---	---	---	---	---	5%	5%

Table 5. Calculated percent losses and gains of various elements during talc-carbonate alteration for samples from Table 4. Calculations made assuming volume remained constant during alteration and the initial composition for all of the samples was that of sample 3, Table 3. Samples arranged according to decreasing distance from the OHR contact.

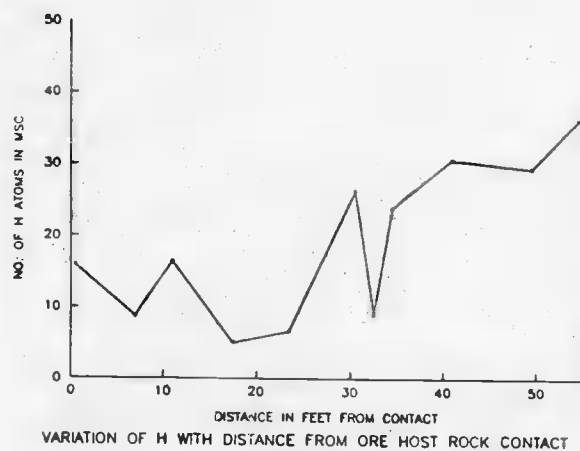
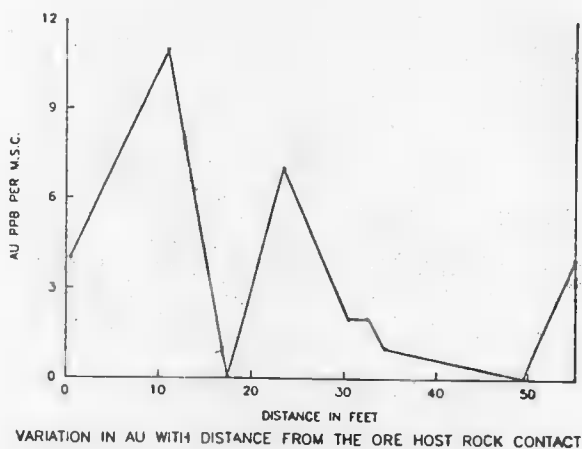
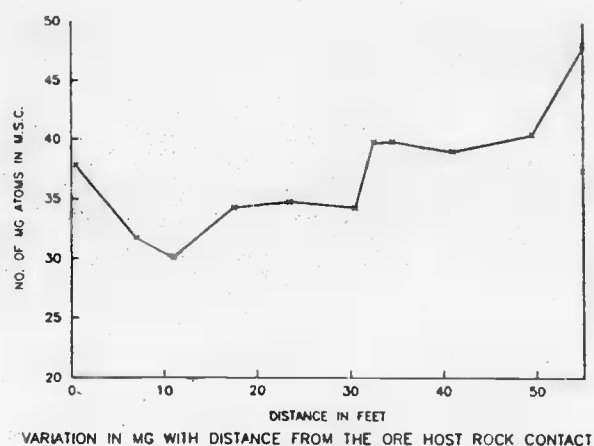
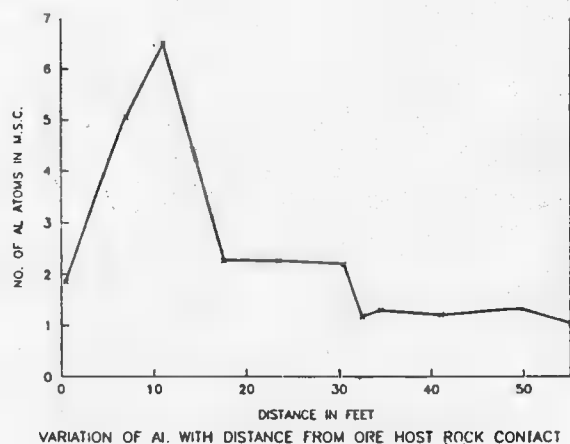
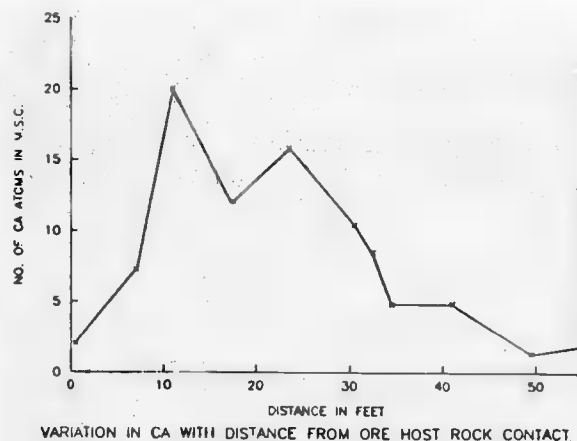
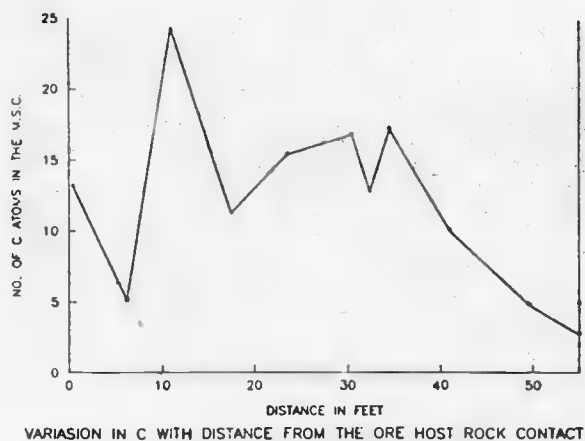


Figure 9. Plots showing changes in composition of altered serpentinites from Table 3 with distance from the ore host rock contact (left axis). Right axis represents composition of the assumed parent rock (sample 3, Table 3).

The wide distribution of talc-carbonate rock in the vicinity of the Ropes Mine required the addition of CO₂ from a very large volume of CO₂-rich fluids to the area. The presence of several generations of cross-cutting carbonate veins in the talc-carbonate rock and the nearby serpentinite suggest that this introduction of CO₂ probably occurred over a protracted period of time. The correlation between the distribution of the OHR and talc-carbonate rock suggest that the OHR may have served as a channel-way to supply CO₂-rich fluids to the serpentinite. Conversely, it may be that the disruption of the serpentinite, by the emplacement of the OHR, created the necessary permeability to facilitate the talc-carbonate alteration.

Evidence for Shearing in the Deer Lake Peridotite

If the Deer Lake Peridotite is an alpine-type, tectonically intruded mass, there should be evidence for considerable deformation within and around the body. This is reviewed in the paragraphs that follow.

The Deer Lake Peridotite has undergone considerable shearing in the vicinity of the ore host rock and probably elsewhere. The clearest evidence is exposed along the shore of Deer Lake where the surface trend of the OHR intercepts the outcropping serpentinites. Along the ORH trend, in a zone some 200 feet wide, the serpentinites exposed are Type B, locally with a strong foliation. As noted earlier, such recrystallized serpentinite textures can be correlated with shearing (Wicks and Whittaker, 1977). At Deer Lake the Type B serpentinite has been dolomitized, altering the color from medium green to a yellowish white. Such dolomitization also suggests that the zone had enhanced permeability. The serpentinite outcrops to the north and south of the shear zone are predominantly Type A serpentinite, with abundant, closely spaced fractures, as well as a number of picrolite and cross fiber serpentine veins, now partially replaced by carbonate. These features also suggest deformation for the production of the openings (Jahns, 1967).

To the immediate south of the shear zone, outcrops show elongate pods, resembling pillows, of relatively unveined Type A serpentinite, ranging in size from several inches near the shear zone contact, to several feet further away from the contact. The pattern is formed by prominent, anastomosing, 2 to 5 cm wide ribbons of closely spaced sets of 1 to 2 mm, subparallel veins of cross-fiber serpentine outlining the pods. Morgan and DeCristoforo (1980) note a resemblance in shape between these structures and lava pillows and suggest that they may be evidence for an extrusive origin for the Deer Lake Peridotite. However, they differ from pillows in their lack of asymmetrical top indicators: rounded tops and cusped bases. By contrast, the authors have noted similarities between these structures and shear polyhedra described by Jahns (1967) in alpine type ultramafics in Vermont (Figure 10). Jahns describes shear polyhedra as pillow-like masses of less broken or sheared serpentinite in a matrix of highly sheared serpentinite. Shear polyhedra form along the margins of intensely sheared serpentinite and progressively increase in size away from the shear zone (Jahns, 1967). However, the shear polyhedra described by Jahns do not contain the cross fiber serpentine veins that are prominent at Deer Lake.

Evidence for shearing in the talc-carbonate zones surrounding the OHR, from underground openings and drill cores, include: 1) local development of contorted foliations in intensely altered talc-carbonate zones along with obliteration of relict serpentinite features; 2) intense boudinaging of chlorite schist layers, thought to represent mafic dikes, in the talc-carbonate zone; 3) abundance of fracture filling carbonate in both the talc-carbonate zones and the serpentinites; and 4) boudinaging of quartz veins.

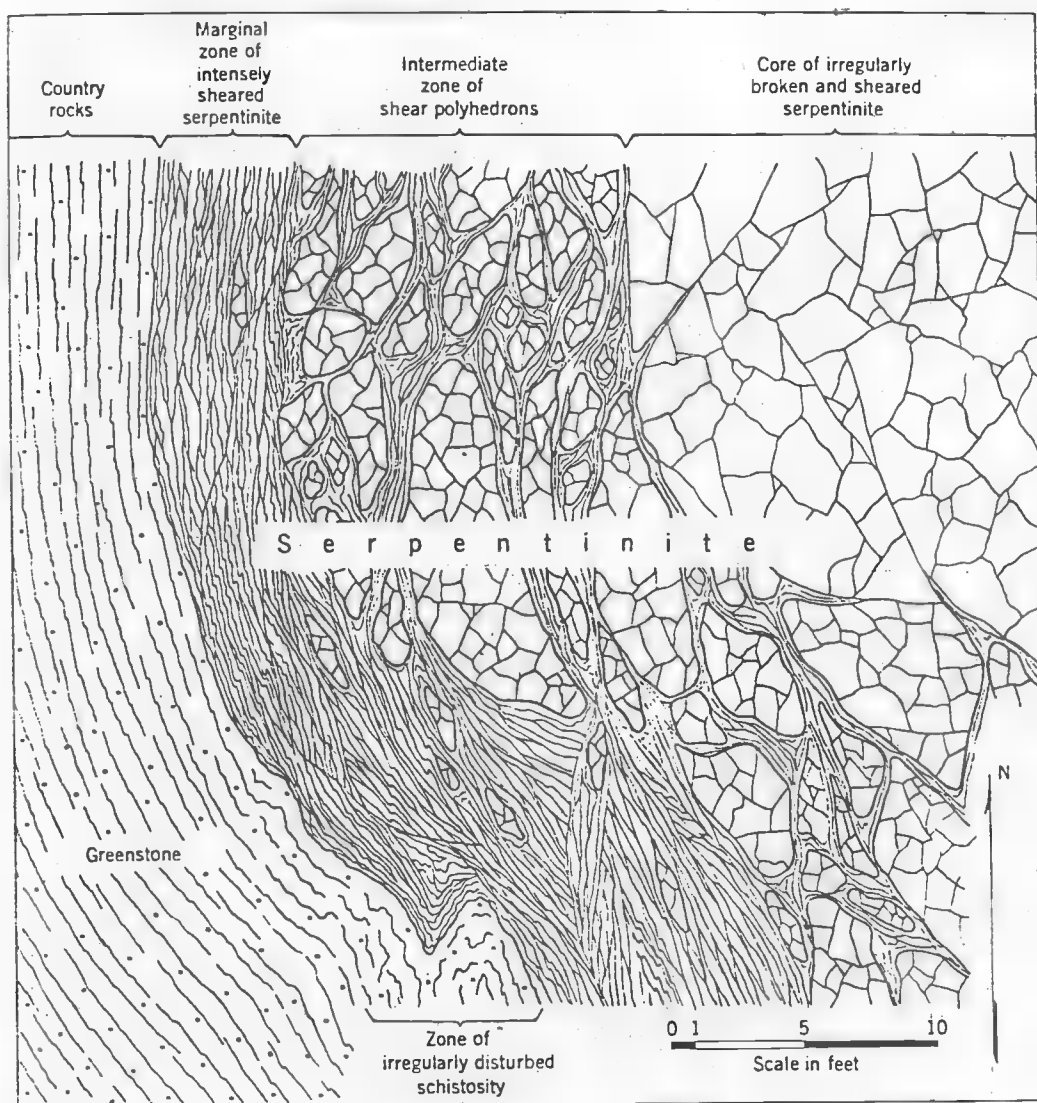


Figure 10. Idealized diagram showing shear zones around a serpentinite body, Roxbury Dist., Vermont (Jahns, 1967).

There is much evidence for deformation within the Deer Lake Peridotite, as one would expect for an alpine-type intrusion. Similarly, there is an apparent lack of contact metamorphic effects by the Deer Lake Peridotite on the ore host rock and the Kitchi Schist as one would expect from an intruded hot body. Finally, the OHR in the Deer Lake Peridotite shows a close analogy to the septum of country rock in the alpine-type ultramafic body in Ludlow Township, Vermont (Gregg, 1975). Thus, for these reasons the writers favor the alpine-type peridotite model.

Conclusions

1. The ore host rock at the Ropes Gold Mine probably consists primarily of intermediate to felsic volcanic rock.
2. The available information suggests that the Deer Lake Peridotite, surrounding the ore host rock, was originally a harzburgite-lherzolite pluton, and that it was probably tectonically emplaced into the Kitchi Schists as a solid.
3. The juxtaposition of the Deer Lake Peridotite and the ore host rock is at least in part the result of tectonism. This tectonism may or may not have occurred concurrently with the tectonic emplacement of the Deer Lake Peridotite.
4. The substantial talc-carbonate alteration of serpentinite and portions of the OHR required the introduction of large quantities of CO_2 into these rocks.
5. The extent of talc-carbonate alteration is, in part, controlled by the distribution of the OHR.
6. The gold content of the serpentinites of the Deer Lake Peridotite (1-4 ppb) is not higher than typical crustal material.
7. The existing evidence points to there being little or no loss of gold from serpentinites during talc-carbonate alteration.
8. Two types of gold mineralization are found in the Ropes ore body: a higher grade vein mineralization and a lower grade disseminated mineralization.
9. There are several possible modes of origin for the gold mineralization:
 - A) 1. The disseminated gold ore may represent an early syngenetic deposition, associated with the formation of the OHR, prior to its emplacement within the Deer Lake Peridotite.
 2. The high-grade vein ore may represent a remobilized facies, derived from the early disseminated ore, and deposited in sites that were structurally prepared during emplacement of the OHR.
 - B) 1. The high-grade vein-type ore may be epigenetic, with mineralizing fluids introduced into the OHR from an outside source, and the gold deposited in structures formed during emplacement of the OHR into the Deer Lake Peridotite.
 2. The disseminated ore represents a halo around the high grade veins introduced from the same outside source.

- C) The disseminated and vein-type ores were formed independently of each other.
- D) Gold was transported as a carbonyl or carbonate complex in a CO_2 -rich fluid from some outside source, and introduced into the OHR. Subsequent carbonate-forming reactions in the ultramafic rock surrounding the OHR caused the deposition of gold in structures formed in the OHR during its emplacement into the peridotite.

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FIELD TRIP LOG

ROPES GOLD MINE AND THE MICHIGAN GOLD MINE

Dean Rossell and J. Kalliokoski

Road Log, Ropes Gold Mine and the Michigan Gold Mine.

Dean Rossell and J. Kalliokoski

This field trip is designed as a one-day excursion to examine the geological setting of the Ropes and Michigan gold mines. The trip involves five stops (Fig. 1), most on private property. Please use discretion in gaining access.¹

Proceed east from Houghton to the junction with County Road 573 (traffic light, Ishpeming). Turn left and continue around Deer Lake for 3.6 miles (0.7 miles past the Carp Lake intersection) to a gravel side road on the left. Turn left, continue 650 feet. Proceed on foot 100 feet north of road to a pit at base of the hill.

Stop 1 - Discovery Pit (Fig. 1b)

At this pit Julius Ropes made the initial discovery of the Ropes Gold Mine. Analyses of three samples between the pit and the peridotite contact, uphill from the pit suggest the ore host rock to be an intermediate volcanic (Fig. 2). The contact with the strongly carbonatized Deer Lake Peridotite (DPL) is exposed along the north edge of the outcrop. This locality marks the known eastern extent of the ore host rock septum, the host to gold mineralization.

In thin section the OHR in the pit is a quartz-chlorite-sericite schist with abundant 0.1 to 0.3 mm grains of quartz. To the north, six feet south of the contact with the talc-carbonate-altered peridotite, the rock displays in thin section a micro-breccia texture consisting of sharply angular fragments of darker quartz-sericite matrix. There are also a few 1 mm quartz grains. At the talc-carbonate contact the quartz-sericite schist is highly fractured, and sporadically replaced by coarser grained sericite and by younger veinlets of chlorite and carbonate.

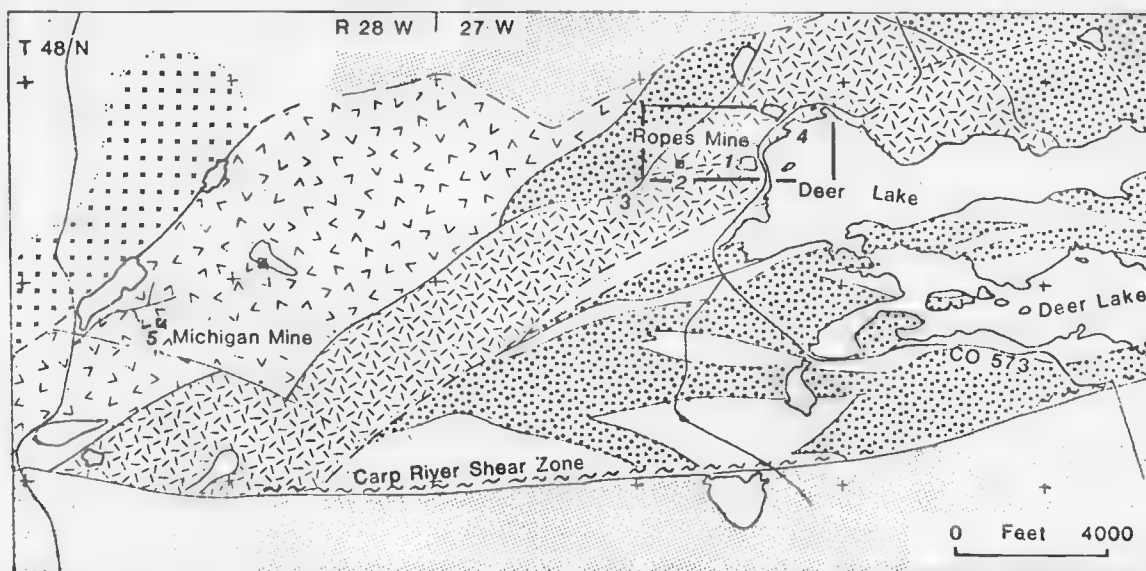
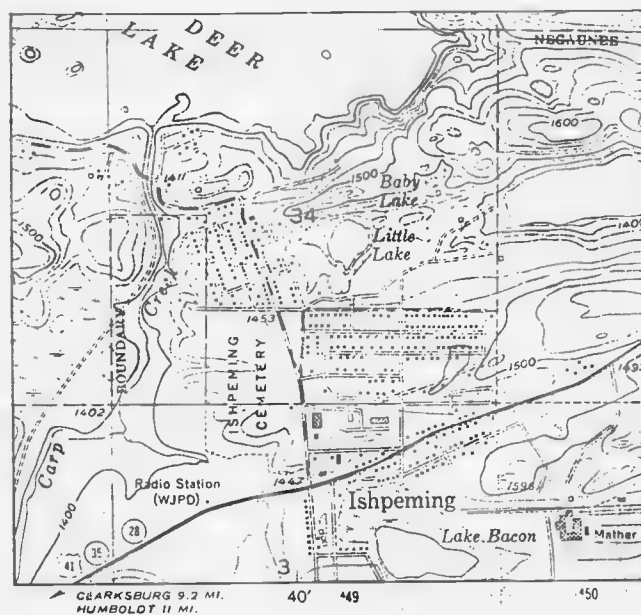
Return to the gravel road and proceed 450 feet west to the fork in the road. Outcrops to the south are relatively uncarbonatized serpentinite. This is also the approximate projection of the east end of the 15th level. Continue 1200 feet along the left fork to the shaft house. Reddish weathered outcrops along the road are strongly carbonatized DLP from the southern altered zone.

Stop 2 - Shaft House (Fig. 1b)

The buildings have been constructed since 1979 as part of the Callahan Mining Corp. on-going exploration at the Ropes Mine. The head frame is over the Curry shaft, the principal production shaft from the late 1800's. This stop provides an opportunity to examine drill core, hand samples, and mine plans and cross sections.

Proceed on foot about 1200 feet west past the shaft house. The gravel road follows the contact of the ore host rock and the southern alteration zone of the Deer Lake Peridotite out to the contact with the Kitchi Schist. The road then turns south and follows the contact of the Kitchi Schist (north) and the DLP (south).

¹The Organizing Committee for this 1983 Field Trip is appreciative of the permission given by Dr. Bruce A. Bouley, Chief Geologist, Callahan Mining Corporation to visit



(Cannon and Klasner, 1975; Clark and others, 1975)

Proterozoic

Marquette Range Supergroup

Archean

Granite

Deer Lake Peridotite

Age relations uncertain

Kitchi Schist

Agglomerate

Inters. to fels. volcs.

Amphibolite

5 Field trip stops

**GEOLOGY OF THE AREA AROUND
THE ROPES AND MICHIGAN GOLD MINES**

Figure 1a, Access to Deer Lake; 1b, geology between Deer Lake and the Michigan Mine

	5	6	7
SiO ₂	48.39	50.05	49.57
Al ₂ O ₃	15.07	15.68	17.85
Fe ₂ O ₃	10.28	8.27	7.67
FeO	.00	.00	.00
MgO	16.57	14.33	11.67
CaO	.60	1.23	.35
Na ₂ O	.18	.19	.20
K ₂ O	3.01	3.55	4.54
TiO ₂	1.01	.98	.77
P ₂ O ₅	.08	.07	.17
MnO	.05	.05	.03
CO ₂	.00	.00	.00
TOTAL	95.24	94.40	92.82
SC	19	20	13
V	131	124	94
CR	171	175	48
NI	255	191	178
CU	10	10	10
ZN	119	95	138
RB	68	79	114
SR	19	26	20
Y	16	18	18
ZR	96	101	129
NB	17	17	21
LA	15	12	12
CE	56	53	42

Figure 2. Chemical analyses of the ore host rock (by Bornhorst and Rose, 1983). Analyses in wt. percent. No. 5, contact with talc-carbonate rock; b), 6 feet south of contact; 7, discovery pit.

Stop 3 - Verde Antique Quarry (Fig. 1b)

The Deer Lake Peridotite is altered extensively to carbonate and talc along the Kitchi Schist contact. In the quarry the serpentinite was mined around the turn of the century for dimension stone ("verde antique" or "serpentine marble"). The contact runs slightly north of the road. Thus, the front part of the pit (now largely removed) was primarily talc-carbonate rock, but some remains on the west side of the pit. This rock grades into moderately carbonatized serpentinite, now exposed along the south and east sides of the quarry. Carbonate veins are abundant in the serpentinite, with as many as four generations seen in some blocks. Early veins are typically carbonate replacing cross-fiber serpentine and picrolite. Younger veinlets are generally coarse grained carbonate with no pseudomorphic textures.

Proceed back to the shaft house, and back to intersection with CO 573. Turn left and proceed 1000 feet to where the road crosses an arm of Deer Lake. Be careful; the road is narrow and traffic can be heavy.

Stop 4 - Serpentinite along Deer Lake (Fig. 3)

Outcrops along the shore of Deer Lake show the two main serpentine textural types described in the text. Samples from Outcrop A (Fig. 3) show well-developed 1-5 mm serpentine pseudomorphs after olivine and a probable cumulate texture. The serpentinite is designated as "Type A" in the text, and is the most common variety on outcrops of DLP.

At Outcrop B the serpentinite is "Type-B", finer-grained and lighter in color than "Type-A", shows no relict igneous textures, and is commonly strongly foliated. In the mine there is evidence of shearing along the contacts between the ore host rock and the talc-carbonate zones. Further, the ore host rock appears to pinch out west of CO 573. Thus, this zone of non-pseudomorphic serpentinite ("Type-B") may represent the extension of the shear zone beyond the ore host rock, east into the Deer Lake Peridotite. These outcrops also display veinlets of picrolite and cross-fiber asbestos, carbonate-replaced serpentine veinlets, and strongly jointed peridotite.

At Outcrop C, "Type-B" serpentinite occurs near the waterline, in sharp contact with another variety that consists of shear polyhedra. These polyhedra are formed by a series of anastomosing sets of subparallel cross-fiber serpentine veins, surrounding elongate blocks that are much less well veined. The polyhedra are smaller toward the shear zone, and have been proposed as pillows by Morgan and DeCristoforo (1981). These features are discussed in greater detail in the text. Chemical analyses of HR 197 and HR 232 are listed as Nos. 4 and 10 in Table 3 in the text.

Proceed east along CO 573 to Cooper Lake Road, and to U.S. 41. Turn right on U.S. 41 and drive about 3.2 miles to junction of CO 478 (party store on left). Turn right and continue 0.1 miles to junction with Diorite Road (CO 496). Turn left and proceed 1.0 miles to fork. Take right fork and drive 1.6 miles to Gold Mine Lake Road (CO CU) marked by a Gold Mine Lake Realty sign. Turn right and continue 0.4 miles to dirt road on the right, closed by a gate. Proceed on foot along dirt road for 1300 feet to old mine workings. Use extreme caution around fenced areas that mark open shafts and stopes.

Stop 5 - The Michigan Mine

The Michigan Mine operated from 1890 to 1898 and became the second largest gold producer in the Michigan gold belt -- 64 kg. gold. The mine was reopened in 1934, a mill was constructed, and several hundred tons of ore was processed. The min-

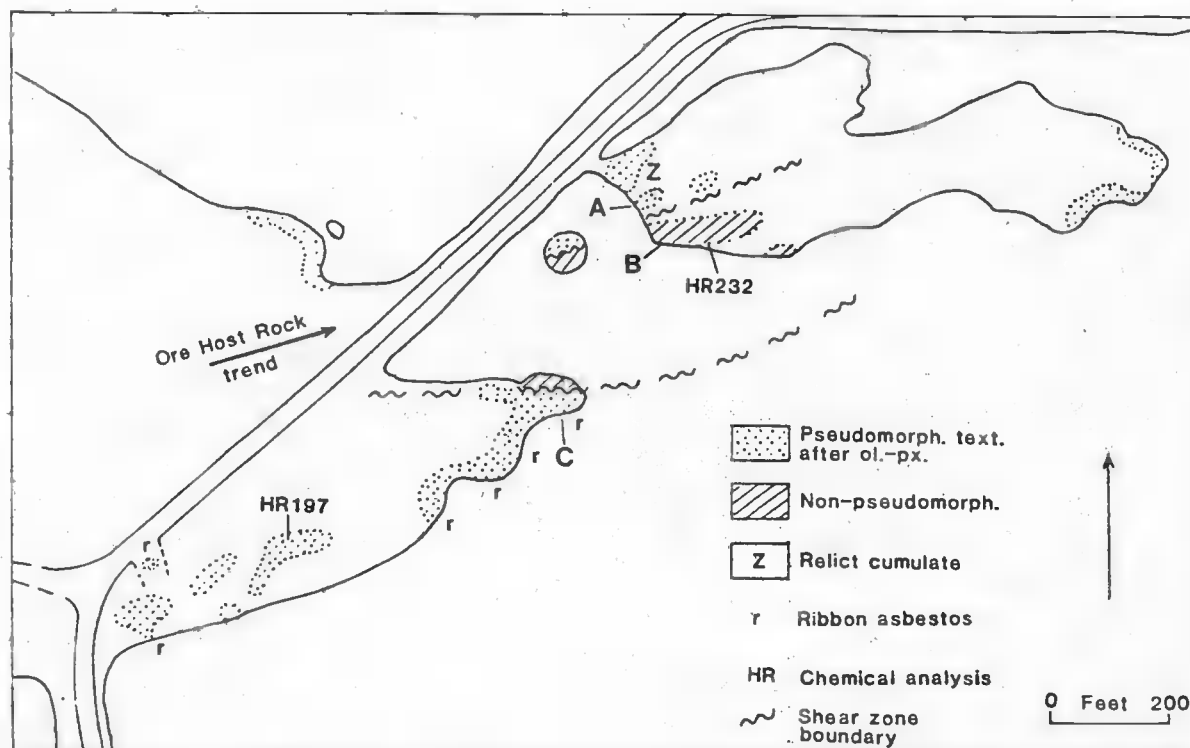


Figure 3. Serpentinite outcrops, shore of Deer Lake..

eralogical zone was exposed about 600 feet on strike. Six shafts have been sunk and workings extend to a depth of 250 feet with levels at 60, 150, and 250 feet (Bodwell, 1972; Morgan and DeCristoforo, 1981).

The deposit is situated in the lower amphibolite member of the Kitchi Schist that is intruded by relatively fresh appearing quartz-feldspar porphyry dikes. Quartz veins, erratic in strike, dip and width generally are found along the contact between these two rock types.

Pyrite-gold mineralization occurs along the margin of quartz veins, and the property has yielded some spectacular high-grade specimens, the largest weighing over 15 oz., but in general the values were sporadic. Pyrite is the principal sulfide, with minor chalcopyrite, galena, sphalerite, and molybdenite (Bodwell, 1972).

CONSTITUTION OF INSTITUTE ON LAKE SUPERIOR GEOLOGY

Article I Name

The name of the organization shall be the "Institute on Lake Superior Geology."

Article II Objectives

The objectives of this organization are:

- A. To provide a means whereby geologists in the Great Lakes region may exchange ideas and scientific data.
- B. To promote better understanding of the geology of the Lake Superior region.
- C. To plan and conduct geological field trips.

Article III Status

No part of the income of the organization shall inure to the benefit of any member or individual. In the event of dissolution the assets of the organization shall be distributed to _____ (some tax free organization).

[To avoid Federal and State income taxes, the organization should be not only "scientific" or "educational" but also "non-profit."]

Minn. Stat. Anno. 290.01, subd. 4

" " " 290.05(9)

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

Article IV Membership

The membership of the organization shall consist of the board of directors. Any geologist interested shall be permitted to attend and participate in and vote at the annual meetings.

Article V Meetings

The organization shall meet once a year, preferably during the month of April. The place and exact date of each meeting will be designated by the board of directors.

Article VI Directors

The board of directors shall consist of the Chairman, Secretary-Treasurer and the last three past Chairmen; but if the board should at any time consist of less than five persons, by reason of unwillingness or inability of any of the above persons to serve as directors, the vacancies on the board may be filled by the annual meeting so as to bring the membership of the board up to five members.

Article VII Officers

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

- A. The Chairman shall be elected each year by the board of directors, who shall give due consideration to the wishes of any group that may be promoting the next annual meeting. His term of office as Chairman will terminate at the close of the annual meeting over which he presides or when his successor shall have been appointed. He will then serve for a period of three years as a member of the board of directors.
- B. The Secretary-Treasurer shall be elected at the annual meeting. His term of office shall be two years or until his successor shall have been appointed.

Article VIII Amendments

This constitution may be amended by a majority vote of those persons who are personally present at, participating in, and voting at any annual meeting of the organization.

BY-LAWS

I. Duties of the Officers and Directors

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

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

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

1. Keep accurate attendance records of all annual meetings.
2. Keep accurate records of all meetings of, and correspondence between, the board of directors.
3. Hold all funds that may accrue as profits from annual meetings or field trips and to make these funds available for the organization and operation of future meetings as required.

C. It shall be the duty of the board of directors to plan locations of annual meetings and to advise on the organization and financing of all meetings.

II. Dues and Expenses

1. There shall be no regular membership dues.
2. Registration fees for the annual meetings shall be determined by the Chairman in consultation with the board of directors. It is strongly recommended that these be kept at a minimum to encourage attendance of graduate students.

III. Rules or Order

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

IV. Amendments

These by-laws may be amended by a majority vote of those persons who are personally present at, participating in, and voting at any annual meeting of the organization; provided that such modifications shall not conflict with the constitution as presently adopted or subsequently amended.

INSTITUTES ON LAKE SUPERIOR GEOLOGY

<u>INSTITUTE NUMBER</u>	<u>DATE</u>	<u>PLACE</u>
1	1955	Minneapolis, MN
2	1956	Houghton, MI
3	1957	East Lansing, MI
4	1958	Duluth, MN
5	1959	Minneapolis, MN
6	1960	Madison, WI
7	1961	Port Arthur, Ont. (Thunder Bay)
8	1962	Houghton, MI
9	1963	Duluth, MN
10	1964	Ishpeming, MI
11	1965	St. Paul, MN
12	1966	Sault Ste. Marie, MI
13	1967	East Lansing, MI
14	1968	Superior, WI
15	1969	Oshkosh, WI
16	1970	Thunder Bay, Ont.
17	1971	Duluth, MN
18	1972	Houghton, MI
19	1973	Madison, WI
20	1974	Sault Ste. Marie, MI
21	1975	Marquette, MI
22	1976	St. Paul, MN
23	1977	Thunder Bay, Ont.
24	1978	Milwaukee, WI
25	1979	Duluth, MN
26	1980	Eau Claire, WI
27	1981	East Lansing, MI
28	1982	International Falls, MN
29	1983	Houghton, MI
30	1984	Wausau, WI

