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INSTITUTE ON LAKE SUPERIOR GEOLOGY, 3rd

May 6 - 8, 1957

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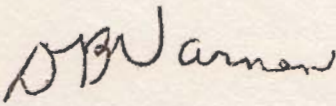
May 6, 1957

WELCOME:

It is with great pleasure that I extend to you the greetings of Michigan State University on this, the first visit of the Institute on Lake Superior Geology to our campus.

The importance of your work in helping us all to know the physical nature of our world and the discovery of the many resources that contribute so much to our daily lives is widely recognized.

We sincerely hope that your stay with us will be a stimulating and satisfying experience and that we may have the opportunity of being your host for future Institutes.


D. B. Varner
Vice President
Off-Campus Education

MICHIGAN STATE UNIVERSITY
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Institute on Lake Superior Geology

May 6 - 8, 1957

PROGRAM

May 6, 1957

Monday Morning

- 8:00 Registration - Kellogg Center Conference Desk
- 9:30 First scientific session - Kellogg Center Auditorium,
to Alan T. Broderick, Inland Steel Company, Chairman:
12:00
- 9:30 Hatten S. Yoder, Jr., Geophysical Laboratory, "Isograd problems
in metamorphosed iron-rich sediments"
- 10:30 Discussion
- 10:40 Intermission - Coffee, South end, Big Ten Room
- 11:10 James W. Villar, The Cleveland-Cliffs Iron Company, "Progress
report on a geologic investigation of the iron formation at
Humboldt, Michigan"
- 11:30 Discussion
- 11:35 Richard W. Bayley, U. S. Geological Survey, "A metamorphosed
differentiated sill in northern Michigan"
- 11:40 Discussion
- 11:45 Announcements, B. T. Sandefur, Michigan State University
- 12:00 Luncheon - Centennial Room

Monday Afternoon

- 2:00 Second scientific session - Kellogg Center Auditorium,
to Stanley A. Tyler, University of Wisconsin, Chairman:
4:30
- 2:00 Jack L. Hough, University of Illinois, "Studies of fresh-water
temperate zone lakes and their application to problems of
Huronian sedimentation"
- 2:50 Discussion
- 3:00 Intermission - Coffee, South end, Big Ten Room

PROGRAM - continued

- 3:30 Robert H. Nanz, Shell Development Company, "Philosophy and Technique for the study of sandstones"
- 3:55 Discussion
- 4:05 W. K. Hamblin, University of Michigan, "The origin of the Jacobsville formation"
- 4:25 Discussion
- 5:00 Social Hour - Transportation leaves from south entrance
- 6:30 Dinner - Centennial Room

Monday Evening

- 8:30 Tour of Abrams Aerial Survey Corporation - busses leave from main entrance of Kellogg Center

Smoker

May 7, 1957

Tuesday Morning

- 9:30 Third scientific session - Kellogg Center Auditorium,
to Burton H. Buyom, The Cleveland-Cliffs Iron Company, Chairman:
12:20
- 9:30 S. S. Goldich, University of Minnesota, " A^{40}/K^{40} dating of rocks of the Lake Superior region"
- 10:30 Discussion
- 10:40 Intermission - Coffee, South end, Big Ten Room
- 11:10 A. W. Jolliffe, Queen's University, "The uniformitarian principle and the Precambrian"
- 11:30 Discussion
- 11:35 Charles B. Sclar, Battelle Memorial Institute, "Exsolution intergrowths in titaniferous magnetite ores and their economic significance"
- 12:15 Discussion
- 12:30 Luncheon - Centennial Room

1:45 PM

PROGRAM - continued

Tuesday Afternoon

2:00 Fourth scientific session - Kellogg Center Auditorium,
to Carl E. Dutton, U. S. Geological Survey, Chairman:
4:45

2:00 A. M. Goodwin, Algoma Ore Properties, Ltd., "Stratigraphy of
the Michipicoten series: the inter-rolation of iron formation,
volcanic and sedimentary facies"

2:30 Discussion

2:35 Tsu-Ming Han, The Cleveland-Cliffs Iron Company, "Genetic
relationship between magnetite and homatite, with a special
note on martite"

3:15 [3:05] Discussion]?

3:10 Intermission - Coffee, South end, Big Ten Room

3:40 Kiril Spiroff, Michigan College of Mining and Technology,
"Negaunee iron formation at the Blueberry Mine"

4:00 Discussion

4:05 J. Royce, Pickands Mather and Company, "The stratigraphy of
sedimentary Mesabi taconite"

4:30 Discussion

6:30 Dinner - Red Cedar Room B

May 8, 1957

Wednesday

Breakfast (State Room 7:00)
(Cafeteria 7:30)

8:00 Bus leaves main entrance for tour of Ford Plant.

COMMITTEES

Steering Committee:

B. T. Sandefur, Michigan State University, Chairman
Justin Zinn, Michigan State University, Secretary
Alan T. Broderick, Inland Steel Company
Kiril Spiroff, Michigan College of Mining and Technology
Victor Kral, Ford Motor Company
George A. Hoffmann, Jones and Laughlin Steel Corporation
Gerald J. Anderson, The Cleveland-Cliffs Iron Company
Burton H. Buyom, The Cleveland-Cliffs Iron Company
Robert C. Reed, Geological Survey Division, Michigan Department of Conservation
Harry J. Hardenberg, Geological Survey Division, Michigan Department of Conservation
William L. Daoust, Geological Survey, Division, Michigan Department of Conservation
Gerald E. Eddy, Michigan Department of Conservation
John Sanford, Wayne State University
E. N. Goddard, University of Michigan
Frederick S. Turneaure, University of Michigan
Thad Vance, Panhandle Eastern Pipeline Company (Michigan Basin Geological Society)
Claude W. Hibbard, University of Michigan (Michigan Basin Geological Society)
A. K. Snelgrove, Michigan College of Mining and Technology
G. M. Schwartz, Minnesota Geological Survey
James Trow, Michigan State University
John C. Bayless, Abrams Aerial Survey Corporation

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Gerald J. Anderson
Alan T. Broderick
George A. Hoffmann

SOCIAL COMMITTEE

B. T. Sandefur, Chairman
John C. Bayless
Burton H. Buyom
Robert C. Reed

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Mrs. B. T. Sandefur
Mrs. L. R. Champion

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Victor Kral
Harry J. Hardenberg
R. L. Bedoor (Ford Motor Company)
John Sanford

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Robert J. Rentschler

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Exploration Subsection of the Upper Peninsula Section of the American Institute of
Mining, Metallurgical, and Petroleum Engineers

Michigan Basin Geological Society
Geological Survey Division, Michigan Department of Conservation

and

Department of Geology
Continuing Education Service
Michigan State University

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A Metamorphosed Differentiated Sill
by
Richard W. Baylay
U. S. Geological Survey, Columbus, Ohio

An exceptionally thick differentiated metagabbro sill of Middle Precambrian age has been found near Mansfield Location, Iron County, Michigan. This sill, known as the West Kiernan sill, intruded the sedimentary and volcanic rocks of the Middle Precambrian Hemlock formation in late Middle Precambrian time. The sill differentiated after emplacement, was subsequently folded, and altered by low-grade regional metamorphism. Differentiation resulted from mineral fractionation and gravity sorting during crystallization. Igneous textures and structures throughout the sill indicate tectonic quiescence during the time of crystallization.

The rocks of the sill have been divided into 5 zones, each representing petrographically and chemically distinct types. These zones are, from bottom to top, ultramafic, normal metagabbroic, transitional, granophyric, and metadiabasic (chilled).

Although the mineral composition of the sill was greatly changed during regional metamorphism, its chemical make up chiefly reflects variations imposed during differentiation.

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A^{40}/K^{40} DATING OF ROCKS OF THE LAKE SUPERIOR REGION

S. S. Goldich, A.O. Nier, and H. Baadsgaard
University of Minnesota, Minneapolis, Minnesota

A large number of rock samples from Minnesota and adjacent areas have been dated by A^{40}/K^{40} determinations on mica. The Northern Light gneiss, Minnesota-Ontario boundary area, is dated at 2.7 billion years. A number of samples between the Vermilion iron district and NW Angle, Minnesota are 2.5-2.7 b y. Gabbro (Duluth gabbro complex) intruding the Biwabik formation near Babbitt is 1.1 b y, and a similar age was obtained for diabase from the Beaver Bay complex.

In the Minnesota Valley, granite and granite gneiss, formerly correlated on petrographic criteria, are of very different ages, ranging from 2.6 b y for the Morton gneiss in the southeast part of the Valley to 1.71 b y for Bellingham granite near the South Dakota boundary line.

In east-central Minnesota the Thomson formation was involved in an orogeny accompanied by granitization and granite intrusion dated at about 1.7 b y. The iron formation of the Cuyuna district and iron formation in northern Wisconsin and in Michigan were involved in this period of folding. Many of the granitic intrusions in central Minnesota formerly classified either as Algoman (pre-Animikie) or as Killarney (late Keweenawan) are neither; they are properly assigned to the late Huronian-early Keweenawan orogeny (1.7 $\pm$ b y).

Development of the A^{40}/K^{40} dating technique within recent years through the combined efforts of a number of laboratories in this country and in Canada has made this method a valuable geologic tool. Both in cost and in time required the A^{40}/K^{40} method has advantages over the Pb/U methods, but the greatest advantage lies in the widespread occurrence of potassium-bearing minerals. Refinements in instrumentation make the method applicable to very young rocks, so that the time scale from oldest Precambrian to late Tertiary is now within range.

The technique involves the quantitative determination of K^{40} and its decay product A^{40} . The radioactive decay of K^{40} is a dual one yielding Ca^{40} and A^{40} . Uncertainty in the branching ratio (relative amounts of the two decay products) has been largely resolved, and a good correlation has been established between A^{40}/K^{40} and Pb/U dates over a wide range of geologic time. Studies also have been made of the relative retentivity of argon by different minerals. The micas apparently are the best retainers; K-feldspars are variable, and work at Minnesota suggests that there may be some relationship between the time rate of loss of argon from feldspar and the geologic occurrence.

Continuation of S. S. Goldich, A. O. Nier, and H. Baadsgaard

Not only can the time of formation of potassium-bearing minerals in igneous rocks or of potassium-bearing volcanic glass be determined, but also the time of metamorphism, of folding, and of diagenesis. Glauconite, authigenic adularia, and sericite or illite are potential minerals for dating purposes. It should be emphasized that careful geologic interpretation is needed, and that only the close cooperation of geologists, physicists, and chemists will bring to realization the full potential of radioactive dating.

The A^{40}/K^{40} project for dating the rocks of the Lake Superior region is supported by a grant from the National Science Foundation with additional support from the Graduate School of the University of Minnesota and from the Minnesota Geological Survey. The cooperation of a number of geologists in the Lake Superior region has contributed materially to the project.

Volcanics are closely associated with iron formation. There is one principal horizon of sedimentary rocks termed the Dore in Minnesota. Thicker and coarser facies occur to the west and thinner and finer grained facies to the east. Iron formation occurs in stratigraphic proximity to sediments. Iron formation is completely enclosed in sediments in the western portion of the area and in volcanics in the eastern portion. The gradation from sedimentary to volcanic environments is reflected in contrasting facies in the iron formation. The facies are described and genetic aspects discussed.

Diagrams and slides

1. Structure of Michigan area - showing distribution of iron formation, large sediments and volcanics.
2. Longitudinal stratigraphic section illustrating relative position of sedimentary and volcanic facies.
3. About 6 colored slides showing rock types of the area.

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STRATIGRAPHIC RELATIONS IN THE MICHIPICOTEN SERIES

by

A. M. Goodwin
Algoma Ore Properties, Limited
Jamestown, Ontario

The Michipicoten series consists of a volcanic sequence containing conformable horizons of sediments and iron formation. Volcanics are mainly intermediate to basic in composition; however, horizons of acid volcanics are closely associated with iron formation. There is one principal horizon of sedimentary rocks termed the Dore; in general, thicker and coarser facies occur to the west and thinner and finer grained facies to the east. Iron formation occurs in stratigraphic proximity to sediments. Iron formation is completely enclosed in sediments in the western portion of the area and in volcanics in the eastern portion. The gradation from sedimentary to volcanic environments is reflected in contrasting facies in the iron formation. The facies are described and genetic aspects discussed.

Diagrams and slides

1. Structure of Michipicoten area - showing distribution of iron formation, Dore sediments and volcanics.
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THE ORIGIN OF THE JACOBVILLE FORMATION
by
William Kenneth Hamblin
University of Michigan, Ann Arbor, Michigan

The Jacobsville formation was deposited upon a highly irregular surface cut into Precambrian rocks which range in age from Laurentian to middle Keweenaw. Sorting, composition, variations in thickness and sedimentary structures indicate that it is a terrestrial deposit which accumulated in an intermountain basin. Cross-bedding dip directions indicate that the source area was an elongated highland extending in an east-west direction through the Upper Peninsula of Michigan. The upper contact suggests peneplanation prior to or during the advancement of the Paleozoic seas into the Michigan Basin.

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GENETIC RELATIONSHIP BETWEEN MAGNETITE AND HEMATITE
WITH A SPECIAL NOTE ON MARTITE

Tsu-Ming Han

The Cleveland-Cliffs Iron Company
Ishpeming, Michigan

For the last four years, the author has microscopically examined more than a thousand iron ore specimens and samples from various parts of the American Continent. Based on these results, the writer draws a general conclusion on the genetic relationship between magnetite and hematite occurring in various types of iron deposits in the American Continent. He also concluded that the so-called martite actually is a hematite aggregate confined within a crystal form of magnetite or perhaps pyrite.

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STUDIES OF FRESH-WATER, TEMPERATE-ZONE LAKES,
AND THEIR APPLICATION TO PRE-CAMBRIAN CHEMICAL SEDIMENTATION
by

Jack L. Hough
University of Illinois

Bottom core samples from deep water in the Great Lakes contain rhythmically-banded sediments which indicate a cyclic deposition of iron. This has led the speaker to consider the possibility that Pre-Cambrian banded silica-iron formations were deposited in fresh water lakes in a temperate climatic zone. In order to investigate this possibility, a review of the physical and chemical properties of such lakes is presented, with emphasis on the regular annual variations which give rhythmic deposition of iron and which may also give rhythmic deposition of silica, alternating with the times of iron deposition.

It is suggested that the typical sequence of quartzite-slate-banded silica and iron formation was deposited during a period when the land was brought to a progressively lower level by erosion and when chemical weathering first removed the more soluble oxides, then delivered only the more stable oxides of silica and iron to the basin of deposition. The basin of deposition was sinking downward slowly. During deposition of the quartzite the basin floor was continually built up, and water depths remained shallow; during deposition of the slate materials sedimentation did not keep pace with downsinking of the basin. By the time of deposition of the banded iron formations the delivery of clastic sediments from the watershed was negligible, and the basin waters were deep. Because the basin was not connected with the sea, and because the waters flowing into the basin contained little Calcium, Sodium, Magnesium, Potassium, and Phosphorous, the organic productivity of the basin waters was low and strongly reducing conditions did not develop. Silica and iron were relatively abundant, and these were precipitated under conditions similar to those existing in some of the large fresh-water lakes of the present time. The annual alternation of chemical conditions in these lakes is adequate to account for the rhythmically-banded iron and silica formations, in the absence of clastic sedimentation, if an adequate amount of iron and silica were available.

Where the sediments overlying the banded silica and iron formations are limestones or highly pyritic black shales, it may be presumed that sea-water flooded into the basin of deposition, to provide the calcium, magnesium, and sulfur necessary for the formation of these rocks.

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THE UNIFORMITARIAN PRINCIPLE AND THE PRECAMBRIAN

by

A. W. Jolliffe

Queen's University, Kingston, Ontario, Canada

Anomalous features of Precambrian rocks include: undue abundance of granites, anorthosites, and Keewatin-type flows; abnormal thicknesses of undifferentiated clastic sediments such as graywacke--argillite and conglomerate; widespread iron formations. Structures that are more common (or more easily recognized) in Precambrian terranes include steeply-plunging folds and strike-slip faults. A dearth of nappe structures, low-angle overthrusts, biogenic deposits, and evaporates likewise seems to be characteristic.

Presumably, most of these departures from the normal are a reflection of the deeper cross-sections of orogenic belts that are exposed in Shield areas; some may represent actual violations of strict uniformitarianism in early geologic history.

Geochemical considerations suggest that both atmosphere and hydrosphere have evolved throughout geologic time, and that, in consequence, earliest Precambrian conditions of weathering, erosion, and sedimentation may have been markedly different from those of the present.

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PHILOSOPHY AND TECHNIQUE FOR THE STUDY OF SANDSTONES

R. H. Nanz

Shell Development Company, Houston 25, Texas

Knowledge of the origin, distribution and diagenesis of various sediment types is of value in the exploration for and the production of petroleum in two ways - as an aid (1) in determining optimum prospecting belts from the standpoint of reservoir beds and oil source, and (2) in determining the location of traps formed by combinations of stratigraphic and structural elements.

Sedimentologic research should provide (1) criteria for making an evaluation or diagnosis of what stratigraphic condition exists at a certain locale, and (2) models from which extrapolations or predications can be made. Such criteria and models are derived from studies of Recent sediments and from well-documented subsurface studies.

For sandstones, it is important to understand the significance of texture (microscopic scale), composition, sedimentary structures, depositional current indicators, external form, position in depositional sequence, and location relative to basin framework.

A study of an Oligocene alluvial sand in the Seeligson field of South Texas illustrates for one sediment type, the application of the various techniques. The results of such a study are useful in determining the probable distribution of sands of alluvial origin in regions where geologic control is limited.

When related to tectonic framework and depositional cycle, one sees that the number of sedimentologic "models" needed is not infinite. In addition, there is reason to expect similarities between the Precambrian and later clastic strata, including the Recent.

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EXSOLUTION INTERGROWTHS IN TITANIFEROUS MAGNETITE
ORES AND THEIR ECONOMIC SIGNIFICANCE

by
Charles B. Sclar
Battelle Memorial Institute
Columbus, Ohio

The titaniferous magnetite ores occur as irregular segregations with gradational contacts, lenticular bodies with relatively small gradational border zones, and sharp-walled tabular masses enclosed in anorthosite, gabbro, and norite. They are characteristically massive granular aggregates of ilmenite, "magnetite", and the essential silicates of the associated igneous rocks in highly variable proportions; in a few deposits apatite is a major constituent. Vanadium appears to be an index element of these ores much as chromium and nickel are index elements of peridotite.

Although the ilmenite grains in titaniferous magnetite ores are typically homogeneous, the "magnetite" grains are almost invariably intimate microintergrowths of magnetite with one or more of the following minerals: (1) ilmenite, (2) ulvöspinel (magnetic Fe_2TiO_4 or $2\text{FeO} \cdot \text{TiO}_2$), (3) nonopaque pleonaste spinel $[\text{Ca} \cdot (\text{Mg}, \text{Fe}^{2+}) (\text{Al}, \text{Fe}^{3+})_2 \text{O}_4]$. Magnetite may constitute as little as 50 per cent by volume of some of the "magnetite" grains. The ilmenite has the form of lamellae, rods, or granules oriented parallel to the octahedral planes of the magnetite host. A fine and a coarse set of ilmenite lamellae or rods may occur in a single magnetite grain, and, rarely, the finer of the two sets of ilmenite inclusions forms a subgraphic intergrowth with the magnetite. Spinel occurs as (1) lamellae oriented parallel to the cubic planes of the magnetite host, (2) discrete grains and dendritic or skeletal forms disseminated nonuniformly through the magnetite, although if aggregated they show some tendency toward orientation parallel to the cubic planes of the magnetite host, (3) minute grains disseminated through or concentrated at the borders of the ilmenite lamellae enclosed in the magnetite, and (4) myrmekitic intergrowths with magnetite at magnetite-ilmenite grain boundaries. Ulvöspinel occurs as (1) exceedingly fine lamellae oriented parallel to the cubic planes of the magnetite host, (2) coarser lamellae which are associated with, parallel to, but separated from the spinel lamellae which are oriented parallel to the cubic planes of the magnetite host, (3) relatively coarse box-like forms which surround but are not in contact with the spinel lamellae which parallel the cubic planes of the magnetite host, (4) square or rectangular forms which are oriented parallel to the cubic planes of the magnetite host and which form a "checkerboard" or "parquet" pattern with the magnetite. Not enough data are available to make any generalizations regarding the content of titania in solid solution in the magnetite host of the intergrowths. Buddington et. al. (1955) designated ilmenite-magnetite intergrowths as "ilmenomagnetite", and ulvöspinel-magnetite intergrowths as "mogensenite". Additional terms for the magnetite-spinel intergrowth and multiple intergrowths of magnetite, ilmenite, ulvöspinel, and spinel would be superfluous.

Continuation of Charles B. Sclar

In most of the titaniferous magnetite ores examined by the writer, the magnetite is not uniform from grain to grain; that is, in any particular ore some of the grains of magnetite may appear to be optically homogeneous and free from optically resolvable intergrowths, whereas adjoining grains may show incipient to highly developed intergrowths with one or more of the constituents which have been described. In addition, the intergrowth structure may not be uniformly distributed within individual magnetite grains. The particle size and habit (lamellar, granular, etc.) of the mineral which is intergrown with the magnetite may also vary from grain to grain and from place to place within a single grain. These observations parallel those of Schwartz (in Grout, 1949-1950) on the titaniferous magnetite ores of the Duluth gabbro.

The intergrowths of magnetite with ilmenite, ulvöspinel and spinel are interpreted as exsolution phenomena. Microtextural evidence from many ores suggests the tentative conclusion that these minerals exsolve from magnetite with decreasing temperature in the following sequence: (1) ulvöspinel, (2) ilmenite, and (3) spinel (both the lamellae in magnetite and the minute grains associated with ilmenite exsolution lamellae). The relationship of these intergrowths to the origin of the titaniferous magnetite ores is discussed in the light of the following current hypotheses: (1) late magmatic residual liquid as summarized by Bateman (1951), (2) immiscible liquid segregation as suggested by Buddington et. al. (1955), (3) metamorphic differentiation as proposed by Ramberg (1948) and DeVore (1953, 1955). Buddington et. al. (1955) concluded that in the $\text{Fe}_3\text{O}_4\text{-FeO}\cdot\text{TiO}_2$ system, where ilmenite is present in excess as independent grains, the per cent of TiO_2 in magnetite is largely a function of temperature. The limiting factors which underlie this conclusion are discussed.

The microintergrowths of magnetite, ilmenite, ulvöspinel, and spinel adversely affect the amenability of the titaniferous magnetite ores to magnetic concentration if the objective is to produce separate iron and titanium concentrates. Magnetite concentrates obtained from titaniferous magnetite ores are typically contaminated with titania. They are either rejected as uneconomic with respect to the prevailing market or are blended with nontitaniferous ores to meet current specifications for an acceptable blast furnace feed. Ilmenite concentrates of an acceptable grade may be obtained from some titaniferous magnetite ores by such physical-concentration methods as tabling, magnetic separation, and electrostatic separation. However, the concentrates typically contain only on the order of two-fifths to three-fifths of the total titania in the ore, inasmuch as the ilmenite and/or the ulvöspinel which is intergrown with the magnetite and some of the unliberated discrete ilmenite grains report in the magnetite-rich product. Further, most of the titaniferous magnetite ores have too low a content of titania to be processed solely for ilmenite on an economic basis at present.

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THE NEGAUNEE IRON FORMATION AT THE BLUEBERRY MINE

by

Kiril Spiroff

Michigan College of Mining and Technology, Houghton, Michigan

Slides and polished specimens of the Negaunee iron formation
at the Blueberry Mine, Ishpeming.

The structural pattern consists of a north-south trending branching
aligning northeast and turning sharply to the east at both the northern and
southern extremities of the pit limits. Numerous orientations have been
superimposed on the major structure. Field mapping indicates a predominantly
divergent pattern for linear and planar elements inherent to the minor
structures.

Typical $\alpha\alpha$ and $\alpha\beta$ tension fractures dominate the joint system. The
spoke tectonics of conjugate sets reveals very little diastrophic consistency.
Numerous gauge zones have been mapped but fault planes are, for the most part,
assumed in order to resolve lithologic discontinuities. There are indications
that the complex structural pattern can not be regarded lightly in deter-
mining the primary factors for iron oxide localization.

A few of the specific topics which are presently being pursued in an
attempt to resolve the sequence and evolution of the metamorphic complex are:

- (1) Delineating zones of varying degrees of secondary oxidation by
classifying the localities of magnetization.
- (2) Determining the relative ages of the local intrusive-like masses
cutting the iron-formation. In conjunction with this, a study of
the time sequence of the various types, as well as their possible
control on the localization of treatable iron-formation, is of
particular interest.
- (3) A petrologic analysis of quartz in various habitats to supplement
detailed field mapping and possibly provide data relative to the
nature of the deformational forces.

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PROGRESS REPORT ON A GEOLOGIC INVESTIGATION
OF THE IRON FORMATION AT HUMBOLDT, MICHIGAN

James W. Villar

Cleveland-Cliffs Iron Company, Ishpeming, Michigan

This paper merely outlines a few of the geologic observations and phases of study presently being pursued in conjunction with an initial investigation of the low-grade iron deposit occurring near Humboldt, Michigan. As a result of open-pit mining operations, numerous exposures of this Precambrian complex are being made available for detailed examination.

The treatable iron-formation is one of several known low-grade deposits found in the upper part of the Negaunee Iron-Formation. A tentative framework is proposed for subdividing the iron-formation into generalized units possessing distinctive mineral assemblages, spacial relationships and textures. Those recognized to date are : (1) Cherty Specularite or Micaceous Hematite; (2) Cherty Magnetite; (3) Cherty Grunerite and (4) Sericitic Schists. All of these rock types have been subjected to intense metamorphism and deformation.

The structural pattern consists of a north-south trending monocline dipping westward and turning sharply to the east at both the northern and southern extremities of the pit limits. Numerous crenulations have been superimposed on the major structure. Field mapping indicates a predominately divergent pattern for linear and planar elements inherent to the minor structures.

Typical ac and ab tension fractures dominate the joint systems. The acute bisectrix of conjugate sets reveals very little directional consistency. Numerous gouge zones have been mapped but fault planes are, for the most part, assumed in order to resolve lithologic discordancies. There are indications that the complex structural pattern must not be regarded lightly in determining the primary factors for iron oxide localization.

A few of the specific topics which are presently being pursued in an attempt to resolve the parentage and evolution of the metamorphic complex are:

- (1) Delineating zones of varying degrees of secondary oxidation by classifying the completeness of martitization.
- (2) Determining the relative ages of the basic intrusive-like masses cutting the iron-formation. In conjunction with this, a study of the true ancestry of the various types, as well as their possible control on the localization of treatable iron-formation, is of particular interest.
- (3) A petrofabric analysis of quartz in various habitats to supplement detailed field mapping and possibly provide data relative to the nature of the deformational forces.

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ISOGRAD PROBLEMS IN METAMORPHOSED IRON-RICH SEDIMENTS

by

Hatten S. Yoder, Jr.

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The probable phase assemblages in the progressive metamorphism of sediments in which greenalite is a principal phase may be related to the $\text{FeO-Fe}_3\text{O}_4\text{-SiO}_2\text{-H}_2\text{O}$ system. With increasing temperature the following phases become stable in the presence of water and magnetite: greenalite, minnesotaite, and grunerite. The serpentinization of iron-rich olivines in the presence of magnetite requires either the addition of silica or the loss of iron, as well as the addition of water. The restrictions free oxygen places on possible phase assemblages are described for the low partial pressures of oxygen believed to exist during metamorphism.

The probable phase assemblages in the progressive metamorphism of sediments in which chamosite is a principal phase may be related to the $\text{FeO-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$ system. The minerals in addition to chamosite in a sediment required to yield on metamorphism a quartz + magnetite + 14A chlorite + 2M muscovite + stilpnomelane or chloritoid schist are deduced. With continued rise in temperature the reactions most likely to produce biotite, almandite, staurolite, kyanite, sillimanite, and orthoclase, the index minerals of the isograds, are described and the difficulties in establishing the reacting minerals are outlined. The necessity of specifying the reaction for each isograd and the fact that an isograd represents a range of pressure and temperature for a fixed bulk composition are emphasized.

Unpublished experimental data on the stability of chloritoid, stilpnomelane, almandite, iron-cordierite, staurolite, and annite are presented and applied to the isograd problems.