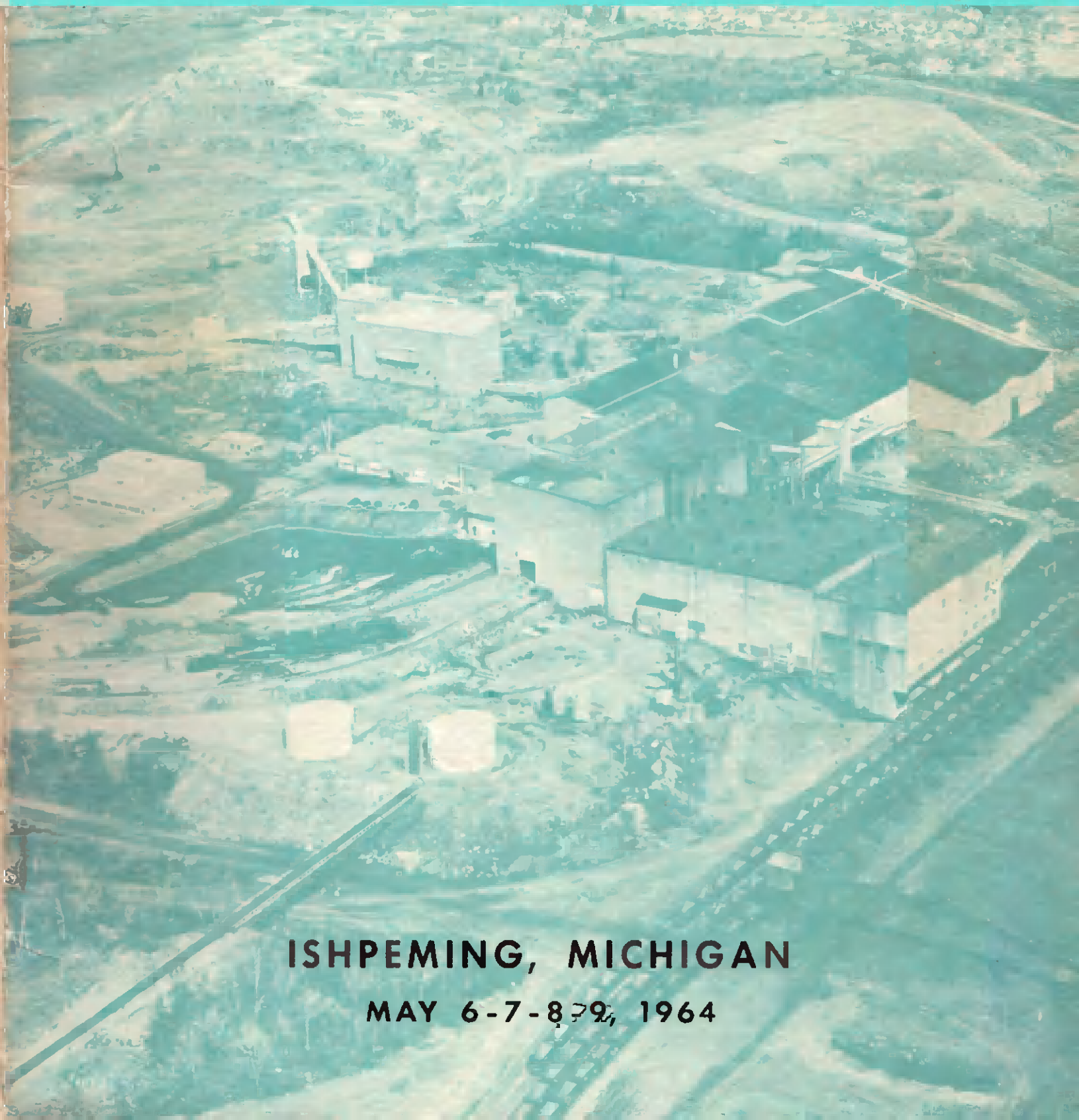


Tenth Annual Institute on Lake Superior Geology



ISHPEMING, MICHIGAN

MAY 6-7-8, 1964

TENTH ANNUAL
INSTITUTE ON LAKE SUPERIOR GEOLOGY

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PROGRAM & INDEX

Wednesday, May 6

1:00 - 2:00 PM E.S.T. REGISTRATION at the Mather Inn

2:00 PM Two concurrent field trips to the Republic and Empire Mines, respectively. (Hard hats and glasses required, Field clothes recommended. Ladies must wear slacks and low heels)

At the Republic Mine, the upper (stratigraphically) 500 feet of the Negaunee Iron formation is mined by open pit methods. This ore consists of alternating bands of quartz and coarsely crystalline specularite with minor magnetite and silicates. In this area, the lower part of the Negaunee consists of coarse iron silicates and magnetite. The Negaunee is overlain unconformably by the Goodrich quartzite which is in part rich enough to be mined also. The metamorphic grade is believed to be high, possibly above the sillimanite isograd. In the plant, this ore is crushed and ground to liberation by standard techniques and the iron is concentrated by flotation. The final cleaner float after regrinding is made after conditioning the pulp at the boiling point. The concentrate is then filtered, balled and fired in a grate-kiln. The annual capacity of this operation is 3,000,000 long tons of pellets.

At the Empire Mine, a 900 foot section in the lower part of the Negaunee Iron Formation is mined by open pit methods. The ore consists of thin, even-bedded alternating layers and mixtures of fine-grained quartz, magnetite, iron carbonate and iron silicates. The area is in the chlorite zone of metamorphism. This ore is crushed to nine inches and then the magnetic portions are reduced to about 95 % - 500 mesh in two stages of autogenous milling. The magnetite is concentrated on drums and in tank-type hydroclassifiers. The filtered concentrate is balled and then fired in a grate-kiln. The annual plant capacity is 1,200,000 long tons of pellets.

7:00 - 9:00 PM REGISTRATION at the Mather Inn.

Thursday, May 7

8:00 - 10:00 AM E.S.T. REGISTRATION at the Butler Theatre, Main St., Ishp.

8:30 - 9:00 AM BUSINESS MEETING

9:00 - 11:45 AM TECHNICAL SESSION Chairman: C.E. Dutton

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AND ADJACENT AREAS, MICHIGAN-- J. E. Case p. 1

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RAPAKIVI-TYPE GRANITES OF THE AMBERG AREA, WISCONSIN,--J.A. CAIN p.32
ARVON SLATE DEPOSITS, BARAGA COUNTY, MICHIGAN,-- Kiril Spiroff p.33

6:00 PM SOCIAL HOUR, Mather Inn

7:00 PM ANNUAL DINNER, featuring a talk on EXPLORATION--FROM ANOMALIES
TO ZANZIBAR by R.H. Pemberton, Director, Exploration Division of the
Aero Service Corporation. Mr. Pemberton will also show a new Aero
Service movie titled "PATHFINDERS".

Friday, May 8

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MICHIGAN TECH'S METHOD OF TEACHING MINERALOGY,--Kiril Spiroff p.34
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Saturday, May 9

7:30 AM - 6:00 PM MARQUETTE RANGE FIELD TRIP conducted by J. E. Gair of the U. S. Geological Survey. See the guidebook for details. Lunch will be provided en route.

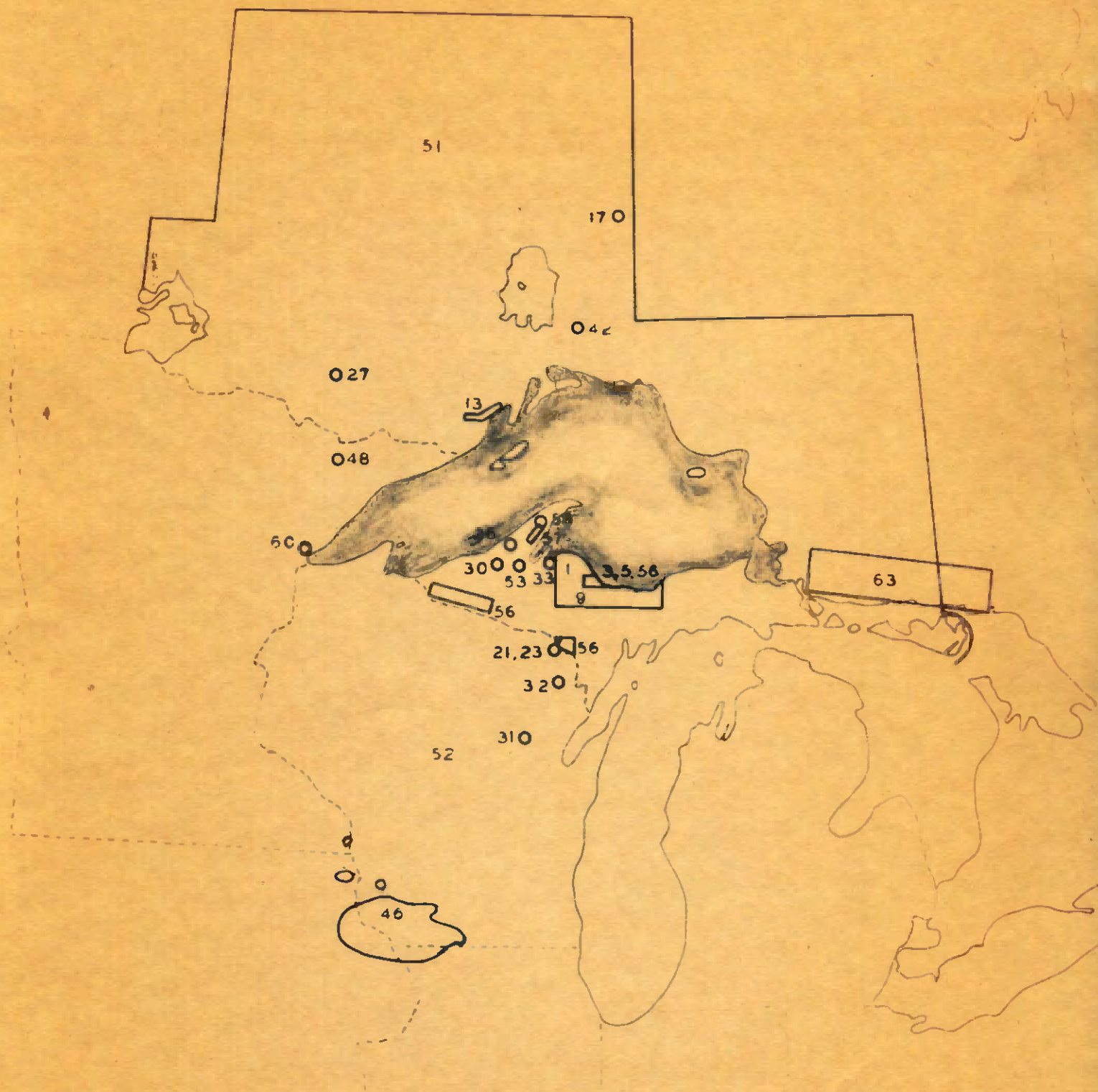
8:00 AM A second field trip to the Republic Mine.

1:15 PM A second field trip to the Empire Mine.

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consin.



PAGE NUMBER & AREA INDEX

AEROMAGNETIC SURVEY OF THE MARQUETTE IRON RANGE, REPUBLIC
TROUGH, AND ADJACENT AREAS, MICHIGAN

J. E. Case

Aeromagnetic surveys have been conducted by the U. S. Geological Survey over the Marquette iron range, Republic trough, Gwinn district, and adjacent areas on the Northern Peninsula of Michigan. The aeromagnetic surveys were flown at 500 feet above the ground along lines spaced at intervals of one-quarter mile in the western part of the area and at intervals ranging from one to three miles in the eastern part.

The resulting aeromagnetic map is characterized by six groups of anomalies or anomaly patterns. (1) In the central, western, and southwestern parts of the area, iron-formation in the Animikie Series is shown by magnetic highs ranging from 2,000 to 25,000 gammas in amplitude. The pattern of magnetic highs over iron-formation generally outlines the west-trending synclinorium along the Marquette iron range, the north-west-trending Republic trough, and the belts of Animikie rocks south and west of the Republic trough. In a few places, especially in the Ishpeming-Negaunee area, large magnetic lows are associated with Negaunee Iron-Formation, indicating that strong inverse remanent magnetization is dominant. Iron-formation in the Gwinn district does not yield recognizable aeromagnetic anomalies. (2) Serpentinized peridotite in the pre-Animikie basement northwest of Ishpeming gives rise to an aeromagnetic high of 7,000 gammas. (3) The basement of gneiss and granite is characterized by a pattern of discontinuous highs and lows of low to moderate amplitude; the anomalies are generally less than 500 gammas. (4) Intrusive greenstone in the basement gneiss is associated in some places with distinct magnetic highs of moderate amplitude, 500 gammas, or more, but in other places it is apparently only weakly magnetic. (5) Westward-trending reversely magnetized diabase dikes of Keweenawan age are shown by prominent elongate magnetic lows of moderate to high amplitude. The lows are most abundant north of the Marquette iron range in T. 48, 49, and 50 N. (6) In the eastern part of the area, between Laughing Fish Point and Grand Portal Point, where Precambrian rocks are covered by as much as 2,000 feet of lower Paleozoic sedimentary rocks, large magnetic highs and lows with relatively flat magnetic gradients predominate.

From the aeromagnetic data, vast areas can be eliminated as potential sites for prospecting for magnetic iron-formation. However, some iron deposits of commercial grade, such as those in the Gwinn district, may not be sufficiently magnetic to cause detectable aeromagnetic anomalies. Conversely, serpentinized peridotites can cause ano-

malies as large as those associated with some magnetic iron-formation. As expected, magnetic anomalies are generally of higher amplitude over magnetite-rich iron-formation than over hematite-rich iron-formation. Measurements of magnetic properties of iron-formation indicate that remanent magnetization may be of much greater importance than induced magnetization. Remanent magnetization must be evaluated if quantitative calculations based on aeromagnetic data are to be attempted.

STRUCTURES IN THE EASTERN PART OF THE MARQUETTE SYNCLINORIUM

Jacob E. Gair

The U. S. Geological Survey and the Michigan Department of Conservation began in 1957 a cooperative program of remapping the Marquette district, using new 7 1/2-minute quadrangle sheets as base maps. The district comprises 12 such quadrangles and is about 600 square miles in area. Mapping has been completed in the Marquette and Sands quadrangles at the east end of the district and is now being done in the adjoining Negaunee and Palmer quadrangles on the west. About 125 square miles has been mapped to date.

The westward-plunging Marquette synclinorium contains principally middle Precambrian metasedimentary rocks which formerly were considered Huronian, but which are now placed in the Animikie Series by the U.S. Geological Survey. The synclinorium is bordered by broad basement areas of lower Precambrian mafic metavolcanic rocks and gneiss.

The middle Precambrian (Animikie) formations in the mapped area are conformable Mesnard Quartzite, Kona Dolomite, and Weve Slate separated by an erosional unconformity from an overlying conformable sequence of Ajibik Quartzite, Siamo Slate, and Negaunee Iron-Formation.

The most comprehensive result of the mapping has been a better definition of major structures in the eastern part of the synclinorium. The major synclinal axis in the Marquette and Sands quadrangles crosses the central parts of secs. 5 and 6, T. 47 N., R. 25 W. Considering the entire synclinorium as a first-order fold, the north limb is comparatively straight and only slightly affected by second-order folds, but along the south side a series of large westward-plunging second-order folds occurs en echelon to the southwest, between the eastern end of the synclinorium and Palmer. The noses of some of these folds are sliced and offset, and some limbs are thinned or eliminated by faults trending mainly westward or southwestward. The "outlier" of middle Precambrian rocks in the Palmer area has long been attributed to downfaulting from the main part of the synclinorium along such a fault, but the structural relationship of the rocks near Palmer to the overall fold pattern of the synclinorium remained obscure. Mapping northeast and east of Palmer shows the Palmer rocks to be a downfaulted segment of a large west-plunging syncline, at least part of whose north limb was removed by the faulting. This syncline evidently is the southwesternmost in the series of second-order en echelon folds.

The eastward-plunging syncline at the easternmost end of the synclinorium is an exception to the generally westward-plunging folds and

reflects cross folding of Mesnard Quartzite and Kona Dolomite near the line between secs. 1 and 2, T. 47 N., R. 25 W.

The major westward-trending faults are located in the principal axial region of the synclinorium and along the south margin. Faults in the latter area are indicated by brecciated and silicified zones, the local absence of lowest Animikie beds, and by southward dips of higher beds toward the basement. No such direct evidence of faulting is known along the north margin where, however, rocks close to the basal Animikie contact locally display strong vertical shearing and lineation. Furthermore, top directions in steeply north-dipping basement metavolcanic rocks point north, whereas tops in the vertical or steeply south-dipping Animikie rocks point south. Deep faulting beneath the north margin is postulated to explain both this unusual "back-to-back" relationship and the shearing.

Cleavage in Animikie rocks in the eastern part of the synclinorium conforms closely to foliation and layering of probable early Precambrian age in basement rocks north and south of the synclinorium. On a regional scale the axis of the synclinorium also parallels the trend of foliation-layering in the gneiss and the greenstone. These facts suggest that the development of the synclinorium was controlled by earlier basement structures.

STRATIGRAPHY OF ANIMIKIE (FORMERLY HURONIAN) ROCKS

EAST OF TEAL LAKE, NEGAUNEE, MICHIGAN

Crawford E. Fritts

Work done in cooperation with the Geological Survey Division of the
Michigan Department of Conservation

Detailed mapping in 1963 in and near the quartzite ridges known locally as the Makwa Hills (secs. 31, 32, 33, T. 48 N., R. 26 W.) east of Teal Lake, Negaunee, Michigan, has shed new light on at least two controversial aspects of the stratigraphy of rocks of Animikie (formerly Huronian) age in the Marquette District. (1) The Mesnard Quartzite, Kona Dolomite, and Wewe Slate of early Animikie age are distinctive mappable formations that represent a valid stratigraphic sequence. They are not "...more or less lateral equivalents of a single time unit..." as suggested by Tyler and Twenhofel (1952, p. 12). Facies changes within the Kona Dolomite, however, are recognized. (2) The Ajibik Quartzite, Siamo Slate, and Negaunee Iron-Formation of middle Animikie age represent a second sequence of time-stratigraphic units separated from underlying formations by an angular unconformity, which was confirmed during the recent mapping. The unconformity, first recognized by A. E. Seaman sometime prior to August 1904 (Van Hise and others, 1905, p. 90, 91), was not recognized by Tyler and Twenhofel.

The controversy over the existence of the unconformity at the base of the Ajibik Quartzite arose mainly because Seaman's map of the Makwa Hills (Van Hise and Leith, 1911, pl. 19) shows parts of east-trending quartzites in two distinct stratigraphic positions as Ajibik. The southern unit, which is overlain conformably by the Siamo Slate, cuts across underlying formations with marked angular discordance along the southern side of the Makwa Hills, especially near the western edge of sec. 32 north of County Road 492 east of route U.S. 41. This quartzite still is recognized as Ajibik. On the other hand, the northern unit, which is exposed south of the Mesnard Quartzite in a roadcut on U.S. 41, is part of a sequence of interbedded slates and quartzites that conformably overlies the Mesnard. The conformable relationship near the roadcut was emphasized by Tyler and Twenhofel (1952, p. 24-26), but they continued to call the northern unit Ajibik. Apparently they overlooked the angular discordance displayed at the base of the typical Ajibik Quartzite in sec. 32. The quartzite exposed near U.S. 41 above the Mesnard now is recognized as the lowest of three quartzites interbedded with four slates above the Mesnard but overlain unconformably by the Ajibik. Collectively, six of the seven interbedded slates and quartzites above the Mesnard are believed to be the near-shore equivalent of the Kona Dolomite. The uppermost slate is interpreted as

Wewe (?) Slate (table 1), because there is no evidence that the uppermost slate was overlain by more rocks of Kona age before erosion in post-Wewe, pre-Ajibik time.

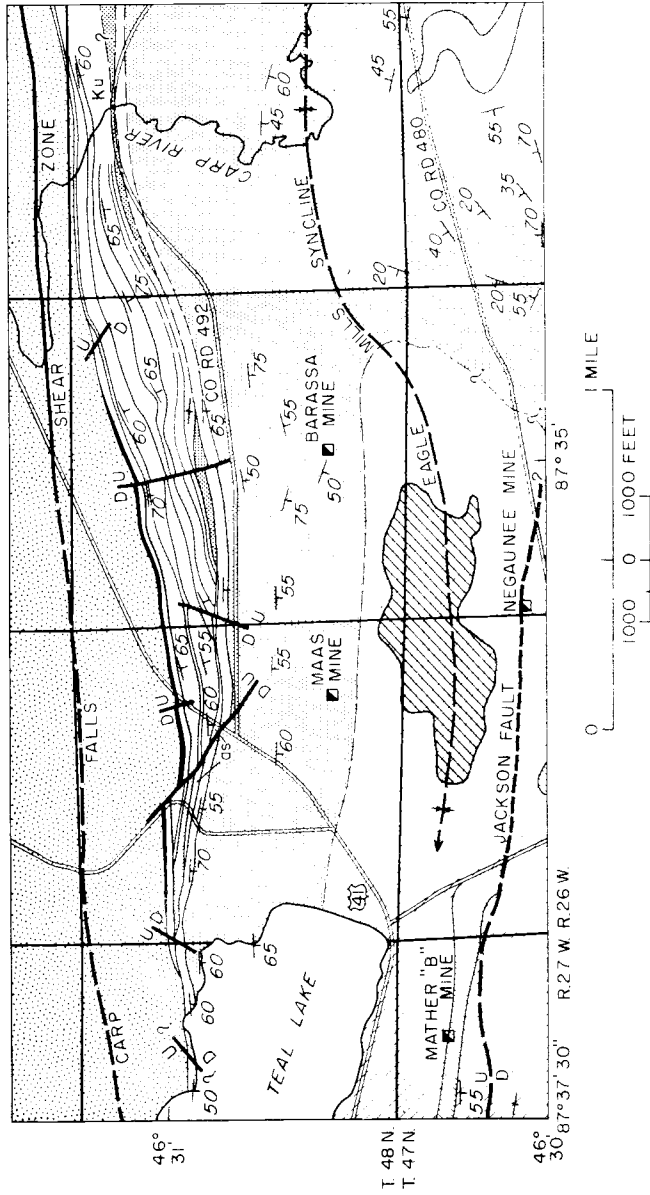
The basin in which formations of early Animikie age in the Marquette District were deposited may not have extended much farther west or northwest than the present Makwa Hills. The Mesnard Quartzite pinches out less than half a mile west of the above-mentioned roadcut. This fact, together with the westward facies change in the Kona Dolomite from largely chemical sedimentary rocks to predominantly clastic sedimentary rocks, suggests that a shoreline existed in early Animikie time near the western end of the present Makwa Hills. It is not known, however, whether this shoreline represented the edge of a major landmass or merely a local high on the basin floor in the vicinity of the Marquette District.

References cited

- Tyler, S. A., and Twenhofel, W. H., 1952, Sedimentation and stratigraphy of the Huronian of Upper Michigan: *Am. Jour. Sci.*, v. 250, no. 1 and 2, p. 1-27, 118-151.
- Van Hise, C. R., Adams, F. D., Bell, Robert, Lane, A. C., Leith, C.K., and Miller, W. G., 1905, Report of the special committee for the Lake Superior region: *Jour. Geology*, v. 13, no. 2, p. 89-104.
- Van Hise, C. R., and Leith, C. K., 1911, The geology of the Lake Superior region: *U. S. Geol. Survey Mon.* 52, 641 p.

Table 1. Stratigraphic section in and near the Makwa
Hills, Negaunee, Michigan.

Age	Formation	Stratigraphic or lithologic unit	Approximate Thickness (feet)
Middle Animikie	Negaunee Iron-Formation	Iron-formation	1500±
	Siamo Slate	Slate with subordinate quartzite	1500-1800
	Ajibik Quartzite	Quartzite (vitreous)	75-150
		Slate with minor conglomerate	0-100
UNCONFORMITY			
Early Animikie	Wewe(?) Slate	Slate	175±
	Kona Dolomite (near-shore facies)	Upper quartzite (vitreous to cherty)	50-175
		Upper slate	50-150
		Middle quartzite (vitreous to cherty)	100-200
		Middle Slate	75-300
		Lower quartzite (vitreous to cherty)	50-250
		Lower slate	0-250
	Mesnard Quartzite	Quartzite (vitreous)	0-250
		Slate and thin-bedded quartzite	0-100
		Quartz-pebble conglomerate	0-50
UNCONFORMITY			
Pre-Animikie		Metavolcanic and metasedimentary rocks, undivided	



BEDROCK GEOLOGY OF THE SOUTHWESTERN PART OF THE NEGAUNEE 7 1/2' QUADRANGLE, MICHIGAN

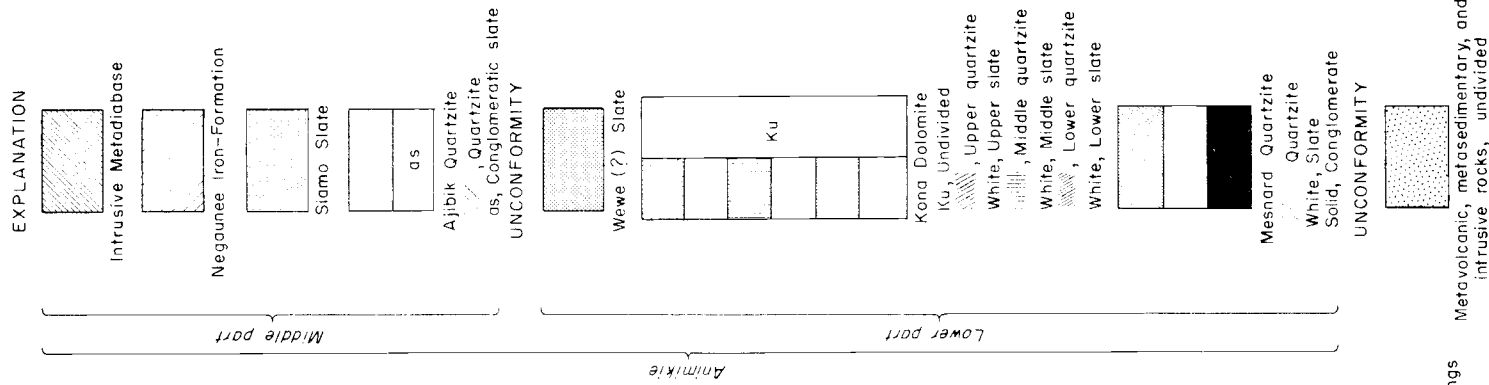
BY
C. E. FRITTS

1963

NEGAUNEE IRON-FORMATION MAPPED WITH THE AID OF SUBSURFACE DATA
OBTAINED FROM THE CLEVELAND-CLIFFS IRON COMPANY



Underground mine workings



PRECAMBRIAN

TREND SURFACE ANALYSIS OF TRACE ELEMENTS IN PEGMATITES

IN MARQUETTE COUNTY, MICHIGAN

Stephen C. Nordeng and A. K. Snelgrove

This study is a test of the application of trend surface analysis to semi-quantitative spectrographic trace element analyses made on 33 samples from pegmatites from Marquette County.

The elements used were: Pb, Zn, Cr, Li, Ga, Tl, Sr, Ba, Ti, Be, and V.

V was found to be most closely associated with Ga, Ti with Be, and Zn with Pb. Sr is most closely associated with Ba, Tl and Li with Sr, and Cr with Li.

The order of average intensity of trace elements from greatest to least is: Ti, Pb, V, Ga, Ba, Sr, Li, Cr, Be, Zn, and Tl. This ranking is similar to that of the abundance of the same elements in the lithosphere as a whole.

Trend surfaces for the sample localities were run using the lithology of the country rock of the pegmatites as a model. Numbers were assigned to Huronian, northern part of "Northern Complex", etc. A second model was based on the distance of the sample locality from the nearest Huronian contact on the assumption that this distance is related to depth beneath the surface at the time of pegmatite formation.

Comparison of the trace element trend surfaces with the two models shows that depth of emplacement may have been a major controlling factor in the amount of a given trace element present.

The greatest number of elements are present in pegmatites in the Lake Michigamme and Big Bay areas.

Used for purposes of prediction, the trend surfaces show that very large traces or greater quantities of Tl, Li, Sr, Ba, Ga, V, and Ti would have the most probability of occurring in pegmatites in the southeast part of the "Southern Complex" and in the northern part of the "Northern Complex," in the Big Bay-Huron Mountain area. Zn, Pb, and Cr should decrease to the southeast in the "Southern Complex". Zn shows increase in the direction of Presque Isle Point. Cr increases in the Lake Michigamme and Big Bay areas. Pb increases away from the Dead River Basin in the "Northern Complex" and shows a slight decrease to the south in the "Southern Complex." Ba, Sr, Li, Cr, and Be increase, and the other elements decrease, in the Republic Area.

This investigation is being extended to some 7,000 pieces of similar data available in Marquette and Baraga Counties from six other types of petrographic associations. These are described on the bases of geologic and geographic occurrence in Progress Report No. 10 of the Michigan Geological Survey: Strategic Minerals Investigations in Marquette and Baraga Counties 1943 by A. K. Snelgrove, W. A. Seaman, and V. L. Ayres, 1944.

SOME SEDIMENTARY INTERPRETATIONS OF GRANULE SIZE DISTRIBUTIONS
IN THE LAKE SUPERIOR IRON FORMATIONS

J. T. Mengel

The size distribution of the iron-rich granules in the chert matrix of the thicker bedded types of Lake Superior iron formation were studied using standard sedimentary petrographic equipment and procedures to obtain objective data for the interpretation of sedimentary conditions. Size determinations were made on 250 randomly chosen grains in each of 108 thin sections selected to illustrate the granule texture clearly, to include as wide a range of grain sizes as possible, and to give an inclusive coverage of the Lake Superior iron formations. Limited materials representing the iron formations of the Belcher Islands and the Labrador Trough were measured for comparison and found to be similar to the American material.

Granules occur in strata which exhibit graded bedding and cross bedding, and their association with chert and carbonate pebbles, fragments of algal structures, oolites and, rarely, with detrital quartz, bear out their behavior as particulate detritus during sedimentation, and permit their interpretation as a special type of sand.

The granules have a mean grain size toward the coarse end of the medium sand size range, moderately good to good sorting, a nearly symmetrical, mesokurtic, grain size distribution which is skewed toward an excess of fine material.

Plots of mean size against standard deviation indicate that the granules accumulated in a tectonically stable environment which had a low rate of deposition and in which a considerable amount of re-working took place. Oolites, associated with granules at a few horizons, have approximately the same size parameters as do the granules, but typically are slightly coarser and better sorted.

Moderately well sorted detrital quartz of fine to coarse sand size is locally present. If it is assumed that the granules and the quartz were deposited from the same current it is possible to estimate the specific gravity of the granules at the time of deposition, using the relationship:

$$\phi_A - \phi_B = 1/1.5 \quad (\log_2 \frac{D_A}{D_B})$$

where ϕ is the mean grain size in phi units, D is the density of the

mineral minus the density of water, and 1.5 is a constant for the sand size range (c.f. McIntyre, 1959, Jour. Geol., pp. 278-301.) Granule specific gravities appear to average about that of opal (i.e. about 2.0). The large grain size and low density of the granules would favor their selective transport and explain their sedimentary segregation from detrital quartz and aluminous material.

Much additional quantitative work on granule size, shape, and packing parameters is needed to give a firm basis for chemical interpretations of the origin of iron formations.

THE POSSIBLE ROLE OF LIFE IN THE FORMATION OF THE
GUNFLINT IRON FORMATION, PORT ARTHUR REGION

W. W. Moorhouse

Organic remains have been recognized for many years in the Gunflint formation in Ontario and Minnesota. Examination of several hundred thin sections from various units of the Gunflint has indicated that fossils and fossil-like structures are even more abundant than hitherto suspected, and has suggested that life may have had a profound effect on the conditions of sedimentation.

The following structures have been recognized as organic or possibly organic in nature:

1. Algal concretions, first recognized many years ago, and widely distributed in the Port Arthur area.

2. Anthraxolite, as seams and pockets, mostly associated with algal structures; carbonaceous matter in argillites, tuffs, calcareous layers, and on stylolitic surfaces; less convincing are brownish (bituminous?) stains in chert and carbonate.

3. Spherical structures, composed of carbonate, or carbonate and greenalite, some of which are 30 to 40 microns in diameter (Fig. b), others up to .2 mm. (Fig. a), in calcareous layers and in shaly greenalite beds between lenses of taconite. A few have a complicated structure (Fig. c) or unusual forms (Fig. d), and are surely organic.

4. Spherulitic structures (Fig. e), composed of chert or carbonate, found in thinly bedded chert-carbonate rocks.

5. Filaments, 20 to 30 microns wide, rarely preserved in greenalite (Fig. f) or taconites (Fig. g), may be algal filaments. Others, 1 to 3 microns thick, may represent bacterial chains or mycelia of fungi.

6. Sponge spicules have been tentatively identified from one outcrop of limestone in Port Arthur (Fig. i).

7. Spots of greenalite in chert-greenalite granules, in one specimen (Fig. k) are enclosed in carbonate showing a radiating structure (although the carbonate now extinguishes as a unit). Possibly such structures are due to organisms.

8. A variety of larger, more complicated structures (Fig. j) possibly organic.

Having regard for the great age (possibly 2000 m.y.) and complicated replacement history of these rocks, the number of delicate structures preserved is surprising. It is tempting to assign a much more important role to the activity of organisms than has been the case hitherto. The following functions may have been performed by the life of the Animikie:

1. As urged by some authorities for over forty years, organisms may have been one of the most important agents of deposition of iron (iron bacteria, fungi, algae), of carbonate (algae and other primitive plants), and of silica.

2. Organic growth and decay controlled the pH and Eh of the waters in which deposition of iron, silica, and carbonate took place. Thus, at the same time, in adjacent environments, oxides, carbonates, silicates, and sulphides of iron were deposited, due to a variety of local environments, modulated by the proliferation or decay of organisms.

3. Algal filaments and sea-weeds on the sea floor acted as binders for the accumulating silicate, oxide, and carbonate granules. They stabilized these fragments in drifts or windrows, producing the characteristic wavy bedding of taconites.

4. Abundant growth of phytoplankton in sheltered bays may have produced stagnant areas where the thinly and evenly bedded chert-carbonate sections accumulated. The waxing and waning of these planktonic swamps with the seasons would conveniently explain the alternation of chert and carbonate layers.

5. The growth of algal reefs may have brought added complication to local environments, by introducing barriers, and forming isolated lagoons.

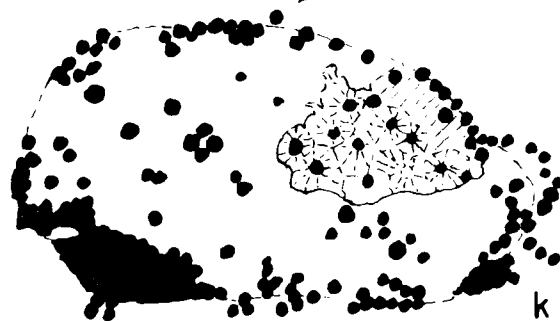
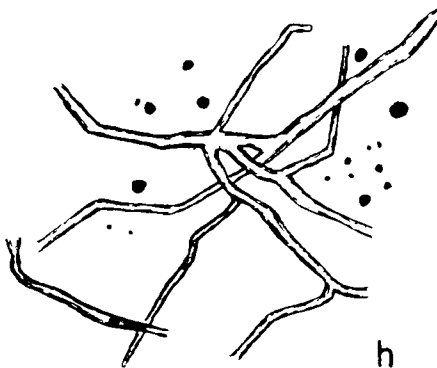
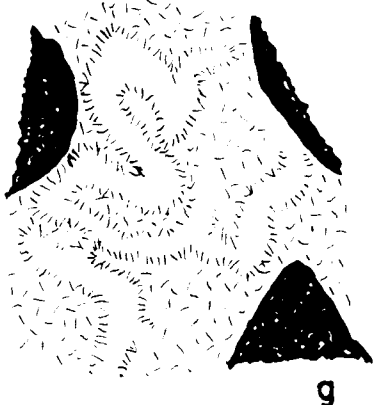
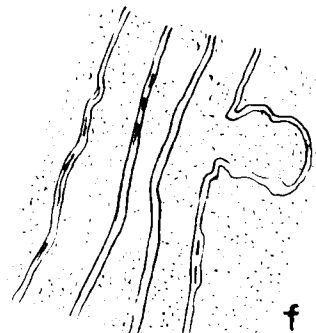
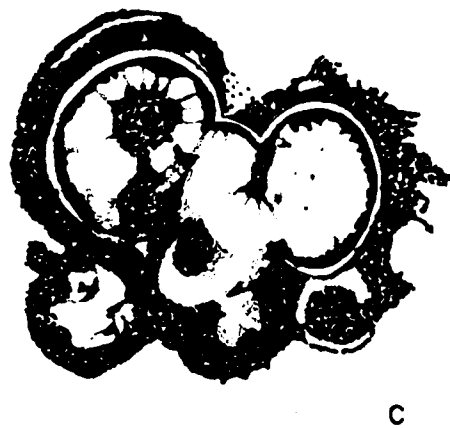
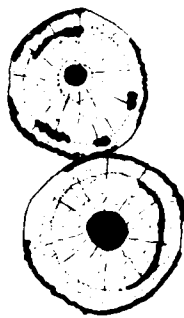
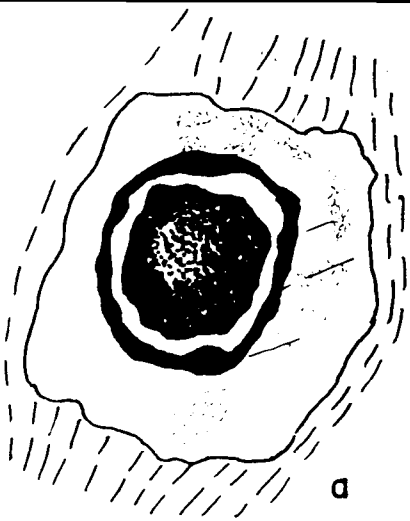
In conclusion, there are indications here of a population explosion of primitive plants, in particular those capable of precipitating iron. This may have been an important if not major factor in making the Proterozoic the most prolific period of sedimentary iron ore deposition.

Illustration:

Organic or pseudo-organic structures from the Gunflint iron formation. The horizontal bar beneath each sketch represents 0.1 mm.

a) Spherical structure (carbonate) enclosed in greenalite.

- b) Spherical structure (carbonate), imbedded in chert, in a carbonate layer.
- c) Complex "colony" of spherical structures.
- d) Spore-like structure, same thin-section as c.
- e) Spherulitic structure in chert, brecciated chert-carbonate rock.
- f) Filaments (with reproductive cyst?), in greenalite.
- g) Twisted filaments, outlined by greenalite, in chert; dark areas are parts of greenalite granules; from taconite.
- h) Filaments in algal chert; black spots are hematite dust.
- i) Suspected sponge spicules, from limestone.
- j) Spherical structure (organic?) of carbonate and greenalite(black).
- k) Chert-greenalite granule, containing circular spots of greenalite; some of the greenalite enclosed in carbonate showing radiating structure.



STRUCTURAL GEOLOGY OF THE SKIBI LAKE IRON PROPERTY

NORTHWESTERN ONTARIO

Paul A. Lindberg

The Skibi Lake iron property, owned by Anaconda Iron Ore (Ontario) Ltd., is located in northwestern Ontario about 70 miles north of the town of Geraldton. Bands of Archean iron formation and schist outcrop intermittently along an eastwest strike length of over 20 miles and probably represent an eastward extension of the St. Joseph Lake iron formations. These metasediments have been isoclinally folded and metamorphosed, faulted and secondarily folded, and intruded by granitic rocks, commonly pegmatite. According to Kindle (1931, Part IV, Vol. XL, Ann. Report on Ontario Dept. of Mines) they are included in the Marshall Lake series of Couthiching (?) age. Potassium-argon age dating by Goldich et al (1961, Bull. 41, Minnesota Geol. Survey) revealed ages of 2.60 b.y. for the quartz biotite schist and 2.54 b.y. for the intruding pegmatite. The bulk of the tectonic deformation of this area was completed following the widespread granitic intrusions of the Algoman orogeny. Late Precambrian diabase dikes cut the region causing local disruptions.

The iron formations are magnetite and quartz-rich horizons and are in general of two related types. The most important is composed of banded magnetite and quartz with small amounts of amphibole and biotite, and commonly has a grade of 25-30% iron. The other type consists of cyclic layers of magnetite, schist and often quartz and ranges in grade from 10-30% iron. Garnet and mafic minerals are often concentrated at the interfaces between schist and iron formation. Any chert which may have been present initially is now completely recrystallized to quartz. The enclosing schist is composed of quartz, feldspars and biotite with lesser amounts of garnet and muscovite. Pre-pegmatite amphibolite dikes are sometimes encountered, and later intrusions were comprised of pegmatite, granite and granodiorite.

The older horizon of iron formation was followed by $\pm$ 2000 feet of barren sediments before another horizon of iron was deposited under similar geologic conditions to the first. This latter formation is dominantly composed of a basal iron-bearing band and an upper higher grade band, separated by a layer of schist. The upper band varies from 10 to perhaps 80 feet in thickness across the district and constitutes the economically important strata from which the ore zones were later formed. Further deposition of barren sediments was followed by layers of volcanic rocks which now lie to the north.

Large scale tectonic folding resulted from steady compression directed from the north and south. With very little apparent faulting a huge isoclinal fold developed much like the folds formed when a rug is pushed together. The present orientation of the axial planes of these folds is vertical at the west end of the district with a steady flattening towards the east where north dips as low as 20° are observed. At this point the apex of the isoclinal fold appears to have over-reached its crustal support and a large fault block dropped several thousand feet forming the present Two Mile ore zone. Widespread faulting of the district was followed by pegmatitic intrusions along zones of weakness.

The economically potential ore zones are the result of thickening of higher grade iron bands by isoclinal folding. The Briarcliffe ore zone is a tight Z-type fold where the limb of the regional isoclinal fold is in turn "isoclinally drag-folded" to yield widths of up to 500 feet of 25-30% iron. The Two Mile ore zone represents the fold nose of the regional isoclinal anticline.

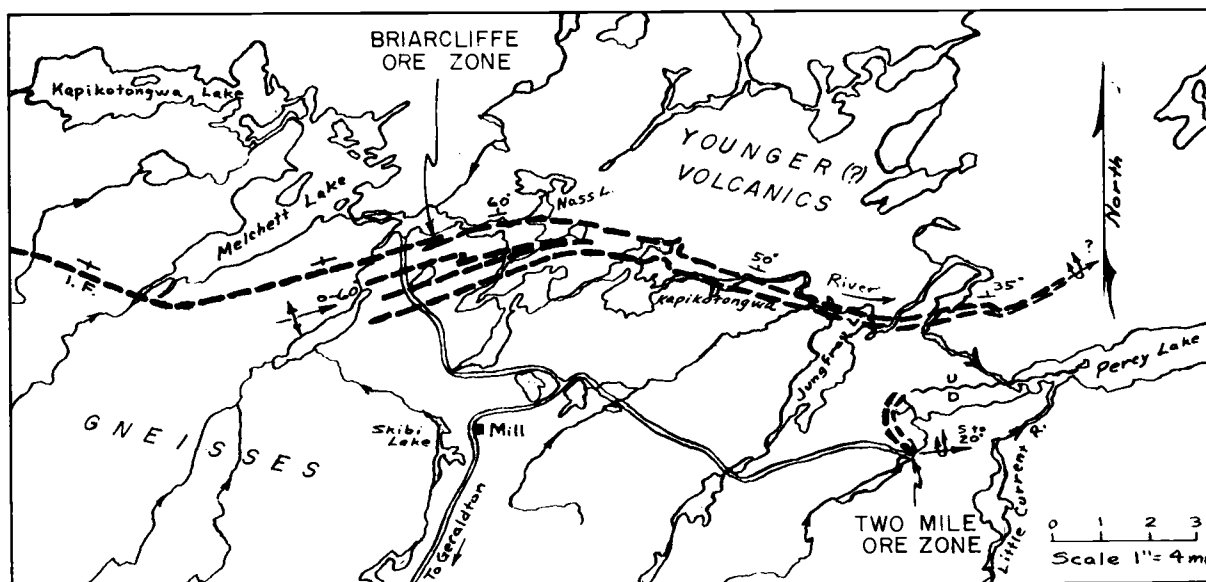


FIG. 1 SKETCH MAP OF SKIBI LAKE IRON PROPERTY SHOWING MAJOR STRUCTURAL ELEMENTS. TWO HORIZONS OF IRON FORMATION AND ENCLOSING SCHIST APPEAR TO BE ISOCLINALLY FOLDED ACROSS THE PROPERTY. ORE ZONES ARE THE RESULT OF FOLDING OF GOOD GRADE NARROW IRON FORMATION BANDS TO MANY TIMES THEIR ORIGINAL THICKNESSES. BRIARCLIFFE IS ON THE NORTH LIMB AND TWO MILE APPEARS TO BE THE DOWN-FAULTED ANTICLINAL NOSE.

FIG. 2 (RIGHT) MAP SHOWING DETAIL OF EAST END OF BRIARCLIFFE ORE ZONE. THE UNFOLDED IRON BAND AT (A) IS GREATLY INCREASED BY FOLDING IN THE ISOCLINAL "ANTICLINORIUM" AT (B). NOTE THE OBSERVED HABIT OF THE PEGMATITE DIKES AND SILLS TO WRAP AROUND FOLD NOSES.

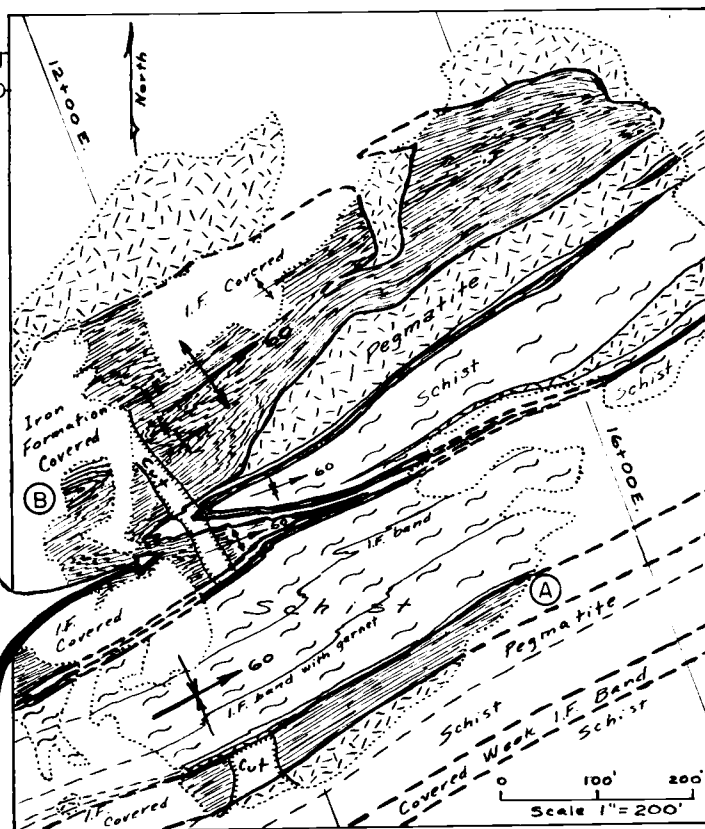


FIG. 3 (LEFT) SKETCH FROM PHOTOGRAPH SHOWING NATURE OF ISOCLINALLY FOLDED IRON FORMATION AS SHOWN IN FIGURE 2. VIEW IS LOOKING TO THE NORTHEAST IN THE DIRECTION OF THE FOLD PLUNGES.

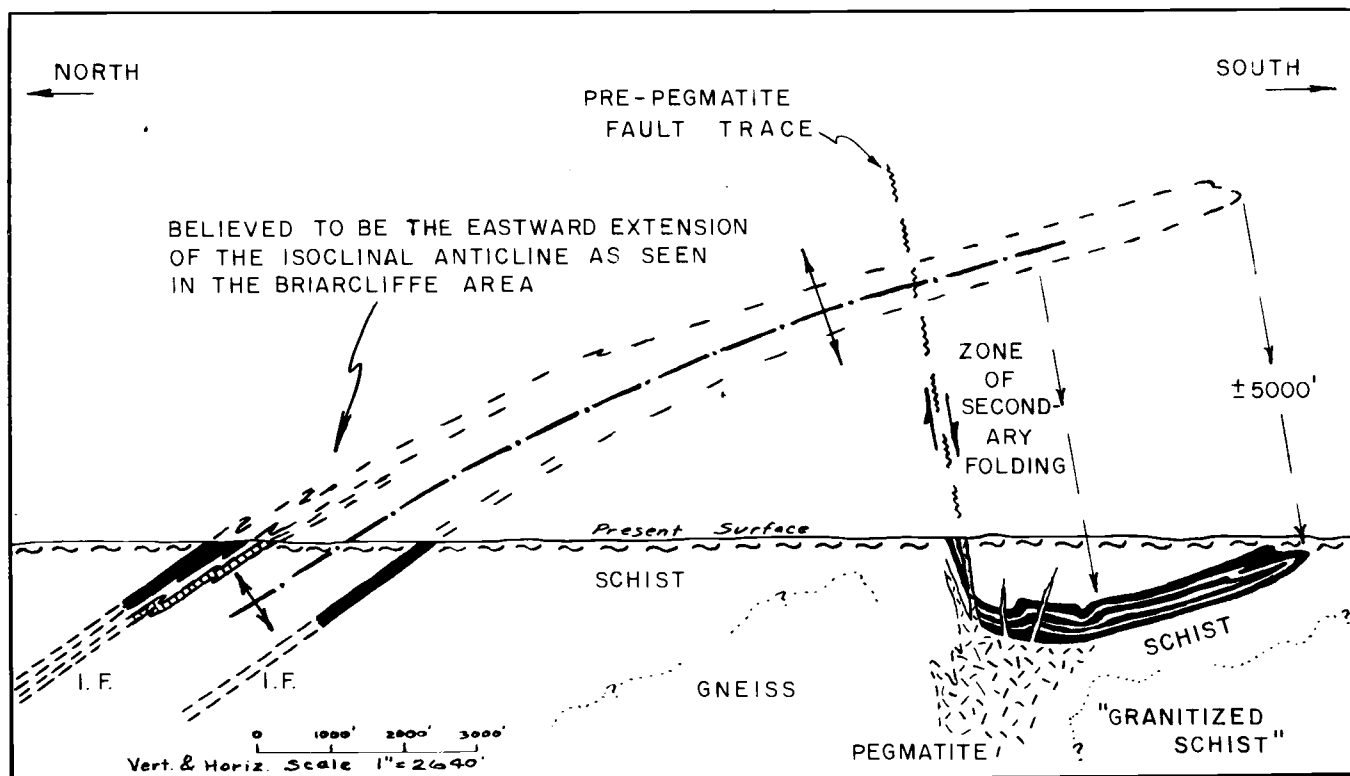


FIG. 4 VIEW LOOKING EAST SHOWING PROBABLE DEVELOPMENT OF THE TWO MILE ORE ZONE AS THE DOWN-FAULTED ANTICLINALLY FOLDED IRON FORMATION FOLD NOSE. THE FAULT TRACE IS INTRUDED BY PEGMATITE DIKES PARALLEL TO DRAGGED SELVAGES OF IRON FORMATION. NOTE THE TWO AGES OF FOLDING: (1) ISOCLINAL FOLDING TRACEABLE FOR SCORES OF MILES WITH A PERSISTENT EASTERLY PLUNGE, (2) SECONDARY FOLDING OF LOCAL IMPORTANCE WHICH EXHIBITS OPEN FOLDS, WARPS AND CONTORTED BEDS. PEGMATITE INTRUSION FOLLOWED THE LATTER.

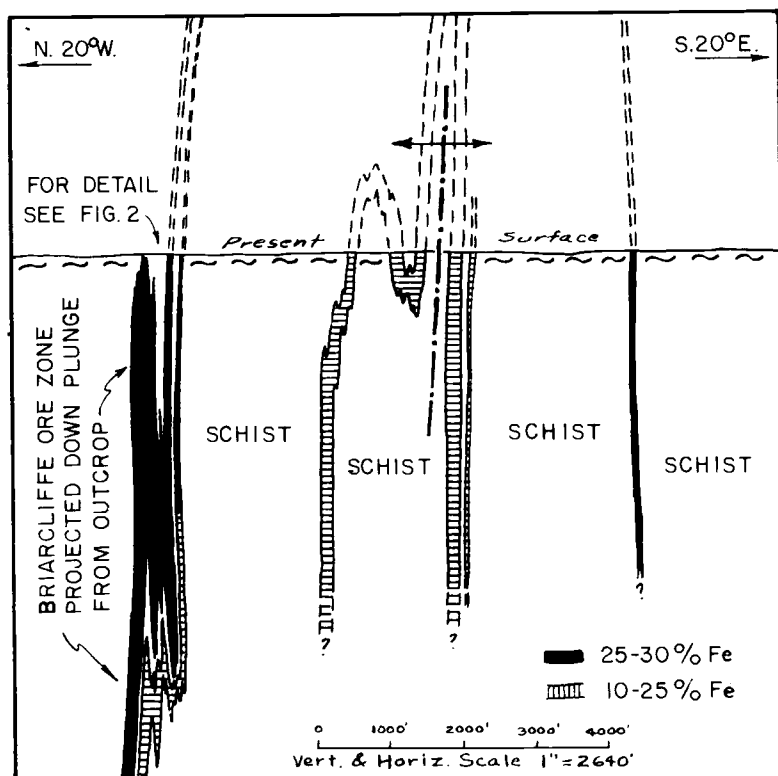


FIG. 5 DIAGRAMATIC CROSS SECTION OF THE BRIARCLIFFE AREA SHOWING INFERRED AXIS OF MAJOR ISOCLINAL FOLD. TWO HORIZONS OF IRON FORMATION APPEAR TO BE PRESENT. THE OLDER IS LOWER IN GRADE, BUT GEOLOGICALLY SIMILAR TO THE YOUNGER, AND IS SEPARATED FROM IT STRATIGRAPHICALLY BY LESS THAN 2000'. NOTE THE UNFOLDED SOUTHERLY LIMBS IN BOTH FIGURES AND THE ISOCLINALLY "OVERFOLDED" NORTHERN ELEMENTS WHICH ARE OF ECONOMIC IMPORTANCE.

GEOLOGY OF THE FLORENCE AREA, WISCONSIN-MICHIGAN

Carl E. Dutton

The Florence area, in Wisconsin and Michigan, is the middle third of the Menominee iron-bearing district, which trends northwestward for approximately 50 miles. The geology is especially significant because this middle area contains the distinctive stratigraphic and structural features that characterize each terminal part, and reveals the relationships of these features. Investigation of the Florence area was a cooperative project by the Wisconsin Geological and Natural History Survey; the Geological Survey Division, Michigan Department of Conservation; and the U. S. Geological Survey.

Metasedimentary and metavolcanic rocks of middle Precambrian age are at the bedrock surface in most of the Florence area, but metavolcanic rocks of early Precambrian age intruded by mafic and felsic masses of middle Precambrian age underlie the southern one-fourth. Pleistocene deposits are widespread, so outcrops are generally small and scattered.

Lower Precambrian rocks in the area constitute the Quinnesec Formation, which is mainly metabasalt and much less abundant felsic metavolcanic rock. The metabasalt is locally ellipsoidal.

Middle Precambrian rocks in the Florence area are, from oldest to youngest, Michigamme Slate, Badwater Greenstone, Dunn Creek Slate, Riverton Iron-Formation, and undifferentiated post-Riverton strata. Except for two discontinuities of the Riverton, conformable relations are generally prevalent. The Michigamme Slate is predominantly argillite and slate; associated rocks are conglomeratic quartzite that is locally well crossbedded, quartz graywacke, amphibolite, and schist. The Badwater Greenstone is almost exclusively metabasalt, in which the orientation of ellipsoids and the trend of thin layers of magnetitic grunerite schist locally provide important structural data. The Dunn Creek Slate is mainly sericitic slate and quartz graywacke, but the upper part is graphitic slate with a local very distinctive breccia. The Riverton Iron-Formation consists of ferruginous layers--hematite-limonite, or siderite, or grunerite-magnetite-alternating with equally abundant meta-chert layers. The post-Riverton strata are mainly slate and graywacke.

Metagabbro and metadiabase of late middle Precambrian age are exposed mainly within elongate areas parallel to foliation in the Quinnesec Formation or to the bedding of metasedimentary rocks in the Badwater Greenstone, but contacts are not exposed. The Quinnesec is locally

cut by granite dikes and pegmatites, which are probably offshoots from a granite pluton in the southwestern part of the area. Similar granite in the nearby Aurora-Niagara area is probably late middle Precambrian in age.

The Florence area is divided into four blocks by faults of northwesterly trend whose southwest sides are relatively upthrown. The northernmost block is principally a northwestward-plunging major syncline containing the sequence from Michigamme Slate to post-Riverton strata, but most of the southwest limb is missing because of faulting and erosion. The synclinal structure, with widely diverging limbs, extends northwestward into and characterizes the geology of southern Iron County, Michigan; only Badwater Greenstone and Michigamme Slate continue southeastward along the syncline to its termination at a short distance within southern Dickinson County, Michigan. The adjacent block on the southwest is mainly a vertical to steeply southward-dipping homocline of Michigamme Slate, but the west end is modified by southeastward-plunging folds of the Michigamme to post-Riverton sequence. This block is not known to continue northwestward beyond the Florence area; eastward to the end of the district it continues as a homocline of Michigamme and pre-Michigamme formations of middle Precambrian age. The next block is apparently also a homocline of Michigamme Slate with vertical to steep southerly inclination and top to the south; this block, like the one previously mentioned, extends eastward only and also contains pre-Michigamme strata. The southernmost block is underlain by the Quinnesec Formation of early Precambrian age, and the top is northward; this block extends eastward and in part probably northwestward.

Metamorphism of the Precambrian rocks in the Florence area is mainly at chlorite grade along the central part of the plunging major syncline, and rises to garnet grade to north and south. Continuity of isograds appears to have been affected by faulting.

GEOLOGY OF THE PINE RIVER (BREAKWATER) QUARTZITE

CONGLOMERATE AND THE KEYES LAKE QUARTZITE,

FLORENCE COUNTY, WISCONSIN

T. H. Nilsen

Setting:

The Pine River (formerly Breakwater) and Keyes Lake units are informally designated members of the Michigamme Slate in the Baraga Group of the Animikie Series of the Middle Precambrian. They crop out in separate fault blocks as resistant northwest-southeast-trending ridges in northeastern Florence County, Wisconsin. Because they occur as steeply dipping homoclines, it is impossible to judge their original extent; also the lateral boundaries are generally vague due to lack of outcrop. They appear to be anomalous local lenticular quartz-rich bodies within the more typical dark Michigamme slates, graywackes and basic volcanics.

Pine River:

The Pine River quartzite conglomerate crops out near the Pine River Reservoir five miles south of Florence and consists of a lower conglomerate, middle cross-stratified quartzite and pebbly quartzite, and an upper conglomerate, each of which thins to the northwest from a maximum total thickness of 600 feet to 150 feet in a distance of three miles. The underlying stratigraphic sequence indicates an upward gradational change from a reducing to an oxidizing depositional environment, i.e. from amphibolite and graphitic-pyritic slate to gruneritic quartz wacke to specularite-rich conglomerate. The strike of the homocline is northwest-southeast with a dip of about 70° to the southwest; the top of the unit everywhere faces southwest.

The conglomerates consist of elongate pebbles of white and blue-gray recrystallized chert, interstratified chert and specularite, mosaic quartzite, and rounded strained vitreous quartz (probably vein quartz) in a fine granular quartzitic matrix that contains variable amounts of specularite, magnetite or martite, sericite and muscovite, biotite, chlorite, garnet, and locally grunerite and chloritoid. The middle unit is more quartzose and has small-scale inclined and festoon cross-strata that increase in abundance to the east. To the extreme northwest this

unit is present in minor amounts as thin lenses of parallel-stratified quartzite within the conglomerate.

Structural deformation along pairs of symmetrical shear planes produced elongation of pebbles parallel to the intersection of the shear planes, or the direction of tectonic elongation. Brief petrofabric study of orientation of quartz c-axes within pebbles suggests a deformation-produced fabric that has been considerably modified. Translation gliding within the quartz grains is suggested as the mechanism of elongation, with associated small faults, quartz-filled tension fractures, foliation and lineation on the foliation also explained by the shear planes. Metamorphism is at garnet grade, and it is suggested that it followed deformation, although a few strained and rolled garnets indicate some post-metamorphic deformation as well. Kyanite was found in one thin section, as well as coarse blades in quartz veins associated with coarsely crystalline specularite.

Eighty percent of the 97 paleocurrent measurements indicate currents flowing toward the southeast quadrant. The postulated depositional environment was a shallow marine basin close to a local tectonically active source area that contributed coarse debris in two pulses, with transgression and regression of the sea possible contributing factors in the distribution of the sediment. Outcrops of apparently laterally equivalent chert breccias with magnetite and gruneritic iron formation to the southeast indicate a less energetic and possibly deeper water environment.

Keyes Lake:

The Keyes Lake quartzite crops out as a vertically-dipping, northwest-southeast striking homocline about two miles southwest of Florence. It is bounded on the north by a major fault and grades laterally into iron-rich rocks of the Little Commonwealth area to the southeast. The unit consists of horizontally-stratified quartzites, profusely cross-stratified quartzites and finer quartzose phyllites that can be traced for variable distances parallel to the strike. Thin persistent conglomeratic zones containing pebbles of rounded red and white vitreous vein quartz, fine quartzite and/or chert, and rare interstratified chert and specularite found in the northwest become finer, thinner, and apparently discontinuous to the southeast. The quartzite consists of rounded vitreous quartz clasts suspended in a finer, granular quartz-sericite matrix with scattered zircons and magnetite-martite.

Rare outcrops of units below this quartzite consist of hematitic quartzose phyllite and sericitic quartzose phyllite that grade upward into the quartzite. A variety of probably conformable rocks overlie it, such as chloritic-graphitic slate, chloritic slate with chert lenses or pebbles, and graywacke.

Outcrop width narrows from 3000 feet to 250 feet in the southeast, and the abundant cross-stratification has inclinations up to 65°. The

cross-strata are of the inclined and festoon varieties with 89 percent of 144 paleocurrent measurements indicating current directions toward the southeast quadrant. Rare ripple markings confirm this pattern. The quartzite is extensively sheared, but the prominent foliation has a constant orientation regardless of the strike of the bedding.

The unit has been subjected to chlorite grade metamorphism, but due to its composition the quartzite is not a good indicator of grade. The presence of chloritic, magnetitic, stilpnomelane-bearing rocks in one area overlying the quartzite that also contain grunerite and garnet suggests a local higher grade.

This unit is postulated to have been deposited in a shallow marine basin that became somewhat shallower to the southeast before grading into deeper water deposits of the Little Commonwealth area, which contains a sedimentary breccia interpreted by Johnson (1958) to represent slumping along a surface of steep initial dip. Possibly the breccia is a result of intraformational "rip-up" in the postulated area of shallower water.

Synthesis:

The two quartzitic members were probably never coextensive, but may represent deposition in different areas along the same Precambrian coast line, or possibly under basically similar conditions at different times. Brief investigation of other quartzites in the Michigamme Slate indicates dissimilarity in composition, texture and stratigraphic features from the Keyes Lake and Pine River members.

ANCIENT STREAM CHANNELS AND THEIR EFFECT ON MINE PLANNING AND GRADE

CONTROL AT THE WHITE PINE MINE, MICHIGAN

John W. Trammell and Chester O. Ensign, Jr.

The "Upper Sandstone" is an arkosic, fluvial sandstone body that occurs in the basal ten to twenty feet of the Nonesuch formation, within the ore zone mined by White Pine Copper Company. For parts of this room-and-pillar mine, the "Upper Sandstone" forms the mine roof; in other parts, it is extracted as part of the ore, along with cupriferous shales and siltstones. Since the sandstone is nearly barren of copper mineralization, and its physical characteristics are quite variable, detailed knowledge of changes in thickness and lithology is important in deciding which of the two mining methods will be used in any given area of the mine. The 1000-foot spacing of the property's diamond drill holes, while adequate for most purposes, is not always sufficient to reveal variations in the "Upper Sandstone" in the detail needed for mine planning.

A study of the abundant current markings at the base of the "Upper Sandstone" exposed in mined-out areas has been a valuable aid in modifying the data obtained from the diamond drilling. These features, as well as cross-bedding and facies changes, indicate that the source area for the "Upper Sandstone" was southwest of the mine, and that transport of sediments was to the northeast. Moreover, it is apparent that, while the strata that comprise the "Upper Sandstone" are ubiquitous throughout the mine area, massive sandstone beds at the base of the unit were increasingly concentrated in highly linear channels as distance from the source of the sediments increased. Thus, when "Upper Sandstone" channels are projected beyond the limits of the mine openings, thickness and lithology of the sandstone can be predicted with greater accuracy than is possible when only conventional thickness contouring based entirely on drill hole data is used.

THE UNIQUE OCCURRENCE OF HEMATITE AT CANADIAN

CHARLESON LTD., ATIKOKAN, ONTARIO

M. W. Bartley

Erosion has produced several concentrations of minerals as superficial deposits throughout the world. Most of the alluvial occurrences of iron-bearing material are fine-grained sands containing varying amounts of magnetite or titaniferous magnetite. The source rocks which gave rise to the concentrations are usually intrusive bodies containing less than ten percent iron in the form of oxides.

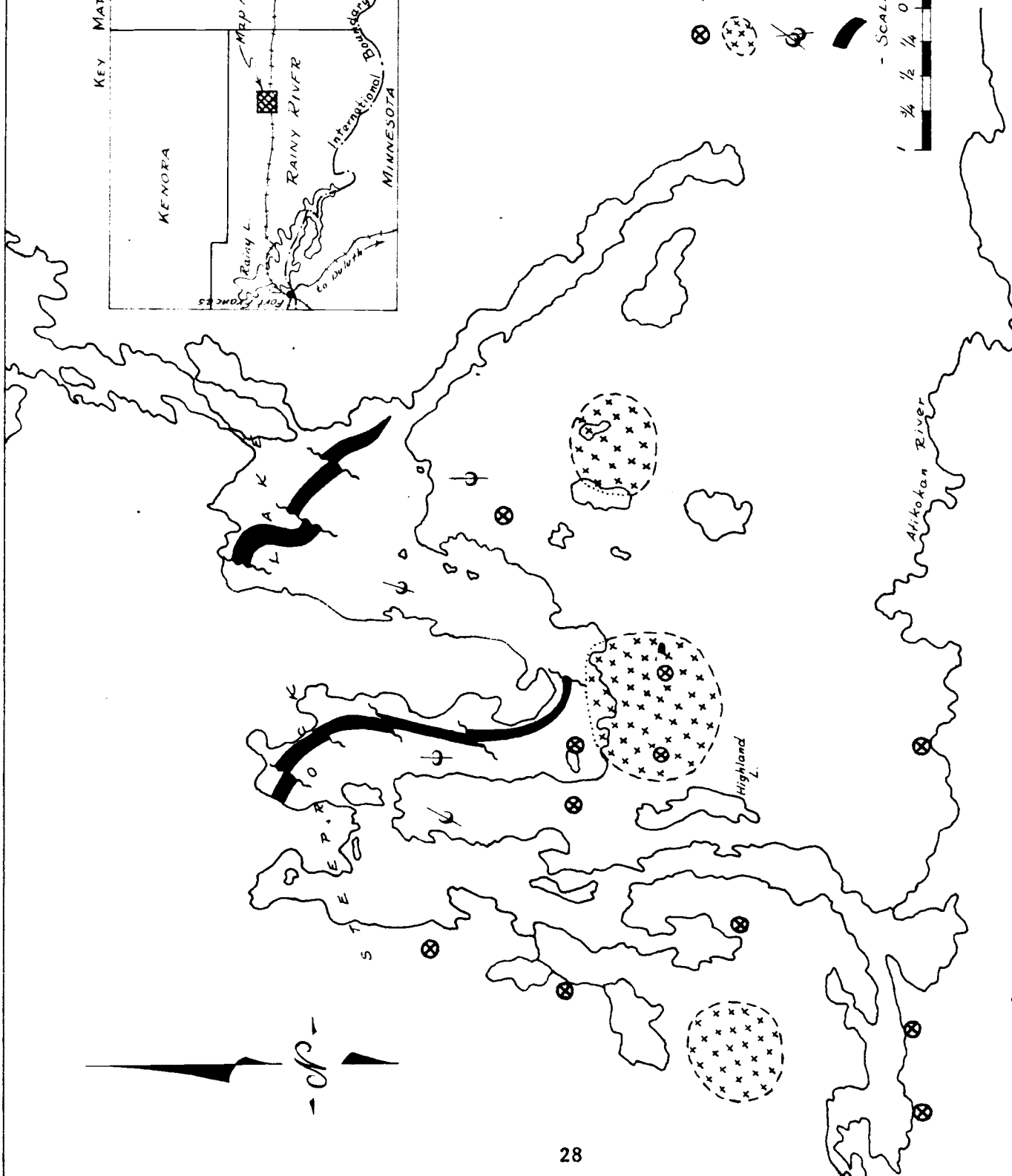
The deposit presently being exploited by Canadian Charleson Ltd. is a concentration of hematite eroded by glacial scouring from the high grade hematite orebodies located in the bed of Steeprock Lake and emplaced as sand and gravel beds within a glacial outwash during Pleistocene time.

Hematite-rich gravels cover an area of approximately 300 acres and in places extend to depths of 250 feet although the minable average is much less. The iron content of the glacial debris varies directly as the size consist of the material: silt up to 6% iron, fine sand up to 10% iron, coarse sand up to 15% iron and gravel up to 30% iron. The average iron content of the recoverable "ore" is approximately 10%. It is estimated that there are 25,000,000 long tons of sand and gravel from which 3,500,000 long tons of "natural pellets" in the form of sand and gravel grains averaging 55.25% iron and 5.75% silica can be recovered by simple gravity separation.

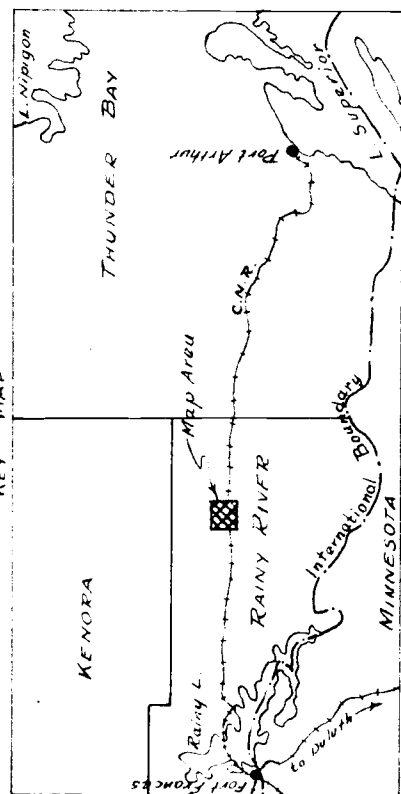
"Mining" is done by means of large scrapers which dig and haul the crude to a treatment plant. The material is sized by screening, the plus one inch oversize going directly to a reject pile and the minus one inch undersize utilized as plant feed. The separation of the hematite from the dross is accomplished principally by jigs aided by spirals. The concentrate is split into two sizes, coarse and fine, and stockpiled for shipment. The non-ferrous "waste" is screened and stockpiled to be sold as concrete aggregate, railroad ballast, asphalt aggregate or common fill.

The operation is as unique as the occurrence since all products derived from the crude have value and combined represent an economic operation.

STEELROCK LAKE AREA RAINY RIVER DIST., ONTARIO.



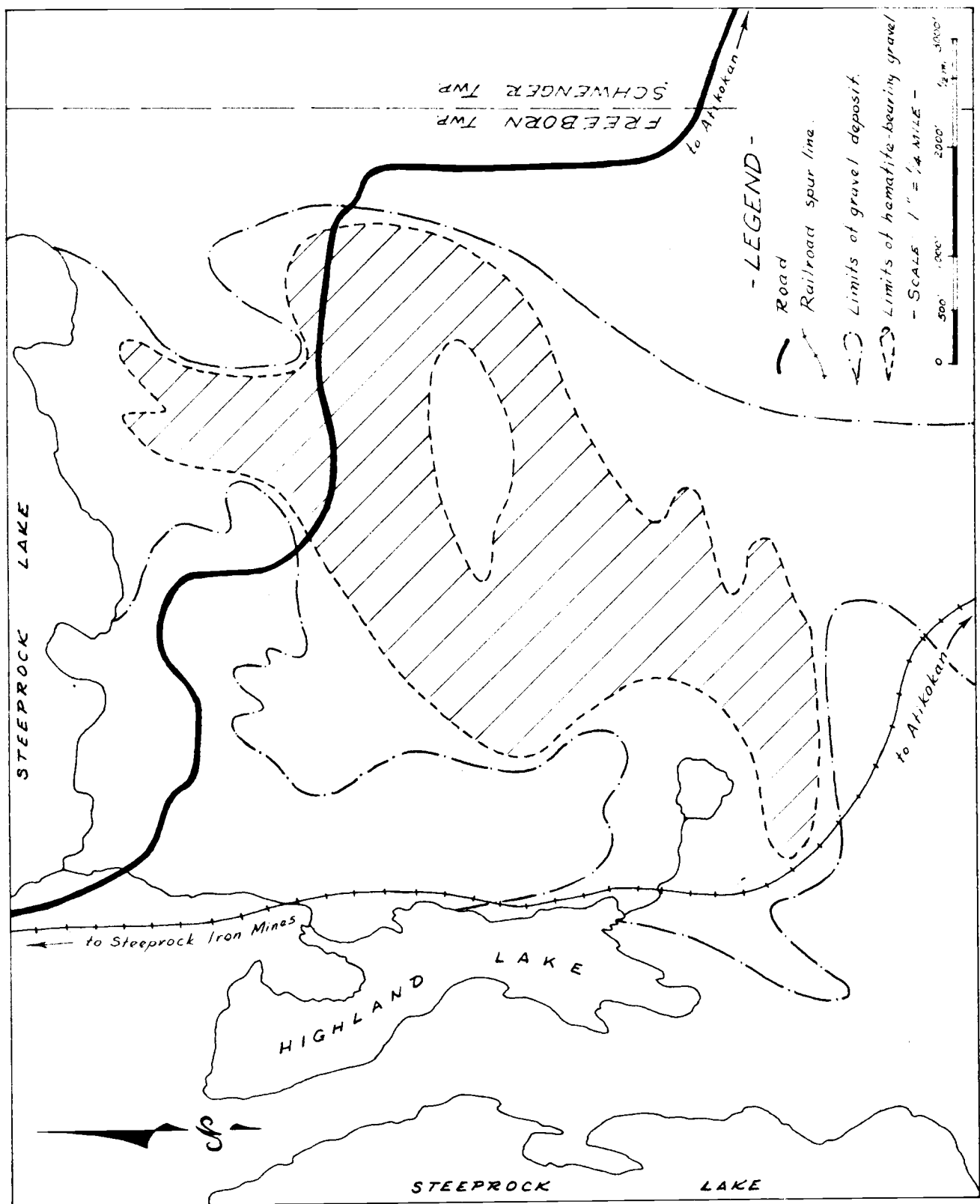
KEY MAP



- LEGEND -

- Location of hematite boulders
- Areas of concentration of hematite pebbles
- Direction of principal glacial striae.
- Hematite ore bodies.





HEMATITE - BEARING GRAVEL AREA

LANDSLIDING AND RIVER EROSION AT VICTORIA GENERATING STATION,

ONTONAGON COUNTY, MICHIGAN

J. M. Neilson

River bank erosion and massive slides of Ontonagon clay long have plagued the Upper Peninsula Power Company at its Victoria Generating Station on the West Branch of the Ontonagon River in Ontonagon County, Michigan.

Water ponded by the Victoria Dam is conducted to the generating station turbines through a 6000-foot wood stave pipeline approximately ten feet in diameter. Normally the entire flow of the river passes through the pipeline but during spring run-off, the excess flow (estimated at 10,000 c.f.s.) is diverted through the river channel. Over a period of nearly 35 years, the run-off water has eroded the boulder, sand, and clay banks to a point where the power substation is threatened. Various river-training schemes and revettment systems are under study in an effort to check further erosion.

Landsliding is a problem of more immediate concern. A particularly damaging slide occurred shortly after commencement of the river erosion study. The slide involved a mass of clay 250 feet wide and 1000 feet long. It effectually dammed the tailrace and this naturally resulted in reduction of the effective head and a major and costly curtailment in power output. Several remedial measures were considered. One solution was to restore the tailrace section by digging through the toe of the slide; another was to excavate a new section around the toe through a wooded area. Study of air photos and examination of the site revealed that the power station had been built on an abandoned meander. It was decided to construct a new tailrace in the bed of the old meander channel with a drag-line and dozer and this proved to be a simple and practical remedy. Although future slides may be expected in the area, it is unlikely that any further damage will be caused to the installation.

ORIGIN OF THE TIGERTON ANORTHOSITE

Leonard W. Weis

The Tigerton anorthosite occupies about 200 square miles in western Shawano County, Wisconsin. It is a hornblende anorthosite of igneous origin. The plagioclase is generally high andesine or low labradorite, with occasional grains low andesine or high labradorite. Accessory minerals include hornblende, magnetite, ilmenite, sphene, chlorite, biotite, pyroxene, epidote. In places the rock is crushed, in places it shows a non-diagnostic foliation. It is surrounded and cut by the Bowler granite which is considered an independent unit. Structurally, the anorthosite occurs as at least two roof pendants in the granite. The country rock invaded by the anorthosite was probably a series of metasediments, but the evidence is scanty.

Igneous origin for the anorthosite is stated, *inter alia*, because of the optical character of the plagioclase, the characteristics of the ore minerals, the textural relations, and several minor features. Post-formational metamorphism certainly occurred, explaining at least in part the crushing and foliation. The possibility of the formation of an independent anorthosite magma has been demonstrated by Yoder & Tilley (1962) and the Tigerton anorthosite is an example of the emplacement of such a magma.

RAPAKIVI-TYPE GRANITES OF THE AMBERG AREA, WISCONSIN

J. Allan Cain

The Precambrian granite of the Amberg area, Marinette County, Wisconsin, is mainly a pink type, locally showing rapakivi texture, with a peripheral gray gneissic variety forming the northern margin with the older metavolcanic Quinnesec Formation. Pink rapakivi-type granite crops out for at least 20 miles to the southwest of Amberg. Within the rapakivi granite, foliation, xenoliths, and pegmatites are rare, contacts are sharp and discordant, and chilled margins are not well displayed. Chemically, rapakivi granite is enriched in K and F, as well as Ba, Hf, Pb, Rb, Ta, and Zr.

Petrographically, the rapakivi granite is typified by ovoid phenocrysts of potash feldspar mantled by oligoclase, together with unmantled feldspar phenocrysts. Quartz and orthoclase occur in two generations and have crystallized before biotite and hornblende. Locally, fluorite is an important accessory.

Presumably the rapakivi texture results from the early crystallization of quartz and orthoclase which thus enriches the residual magma in plagioclase and mafic minerals. It should be noted, however, that much pink granite in this area does not show rapakivi texture (or the unusual crystallization sequence).

THE ARVON SLATE DEPOSITS, BARAGA COUNTY, MICHIGAN

Kiril Spiroff

In the Arvon slate quarry area, the stratigraphic succession is as follows: a pure, massive, vitreous quartzite, probably Ajibik, which is the oldest rock exposed; a thin quartz conglomerate; a reddish to black quartzite; a thin cherty carbonate member; gray to variegated slate; black satiny slate, and, lastly, pyritic black slate.

Three small pits in the black satiny slate were worked from 1872 to 1890, during which time 50,000 squares of roofing slate worth 188,000 were produced. These deposits are probably not of commercial value today.

MICHIGAN TECH'S METHOD OF TEACHING MINERALOGY

Kiril Spiroff

The technique of megascopic mineral identification which is taught at Michigan Tech differs from that of most schools in that it puts greater stress on the use of cleavage and/or crystal form whenever these features are present in the unknown mineral.

Michigan Tech's system starts with the placing of the unknown mineral into one of three classes as shown in Plate 1. This shows that the specimen can be:

1. A cleavage fragment, or
2. A crystal, or
3. Massive, that is, fine-grained so that neither crystals nor cleavages can be observed.

1. Cleavage Fragments

Cleavage is a property a mineral possesses due to its atomic arrangement and is recognized by the greater amount of light which is reflected per unit area from cleavage planes. Cleavage may be considered from three aspects: number, perfection, and angular relations (Plate 2). In number there can be one, two, three, four or six separate cleavages. In perfection we recognize seven types, from perfect to distinct. In angular relations we deal with and measure only 60° , 75° and 90° angles.

The student starts with large simple fragments and works toward smaller, less perfect fragments.

The specimen is held in the right hand and turned until a light flash from a mineral cleavage plane is observed. Then the specimen is rotated to the next flash by using the wrist, not the fingers. The amount of rotation is noted as well as the cleavage perfection. If this is done objectively, the eyes will observe the patterns produced by the number of cleavages and their angular relations. After practice, the angles 60° , 75° , and 90° can be easily distinguished.

At this point, the identity of many minerals will have been established. For example, a mineral showing four perfect cleavages and having a vitreous luster is Fluorite.

2. Crystals

If the specimen shows crystal faces, it is pigeon-holed into the proper crystal system by the study of the geometry of those faces.

The unknown crystal is first studied with the unaided eye or with the hand lens. The planes of the observed crystal faces, if they are incomplete, are extended mentally until they intersect so that the com-

plete crystal form is visualized.

The crystal is held vertically and rotated around an imaginary axis and the angles of repetition are observed. If the faces are repeated every 90° or four times during one revolution, the crystal possesses a four-fold symmetry. If the crystal face repeats itself every 60° , or six times during a complete revolution, it has a six-fold symmetry. If the crystal face repeats itself every 120° , or three times during a complete revolution, it has a three-fold symmetry. Using these symmetries, minerals can be classified into the various systems shown in Plate 3.

This takes care of one-half of the systems, but all crystals do not possess a four, three or six-fold symmetry. In crystals which lack these symmetries, a prism is sought. A prism consists of two or more planes which, if extended, will intersect and have the same angular relationship to some other plane. The prism is held vertically, and by using the principles shown in Plate 4, it can be classified into the proper system.

If the complete crystal form cannot be visualized and classified in this way, the next step is to construct an accurate picture of a perfect crystal of the unknown mineral by working from theoretical axes and Miller indices. Orthographic and Clinographic projections are used. The unknown crystal is sketched as architects sketch a building: by drawing a plan and front view. A side view is also helpful. After the proper system has been determined and an accurate sketch has been drawn, the forms characteristic of the system can be studied.

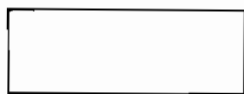
At a more advanced stage in the course, atomic arrangement is discussed and the use of X rays is explained.

3. Massive Specimens.

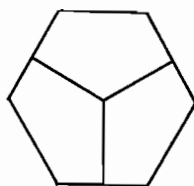
If the unknown mineral is megascopically massive, the usual methods of identification are used as outlined in Plate 5.

The basic objective of Michigan Tech's Mineralogical System is to train the student to observe the physical properties of minerals in a systematic way, particularly their cleavages and crystal forms, and to put what has been seen on paper in a neat and orderly fashion. When this has been done, the identification of the mineral is usually a simple matter of correlating his findings with any standard mineralogy text or mineral table.

1
CLEAVAGE
FRAGMENT



2
CRYSTAL



3
NEITHER
MASSIVE



PLATE 1

CLEAVAGE

1, NUMBER

1, 2, 3, 4, 6.

2, PERFECTION

PERF ++

MUSCOVITE GRAPHITE

PERF +

CALCITE GALENA

PERF

ORTHOCLASE "C" ENARGITE

PERF -

ORTHOCLASE "B" COBALTITE

DIST +

WERNERITE PYRITE

DIST

APATITE ARSENOPYRITE

DIST -

CASSITERITE TANTALITE

3, ANGULAR RELATIONS 60°, 75°, 90°

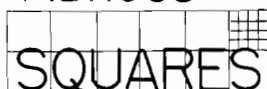
PATTERNS PRODUCED

1 PLATY

2 FIBROUS



3



SQUARES

BRICKS



RHOMBS

4



6



PLATE 2

CRYSTALLOGRAPHY

1
PLANES
HAND LENSE

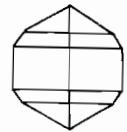
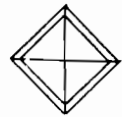
2
AXIS
DRAWING

3
ATOMS
X-RAY EQUIPMENT

MUST SKETCH CRYSTAL

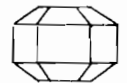
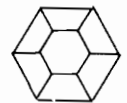
TETRAGONAL

ONE ONLY FOUR-FOLD $\square$ SYMMETRY



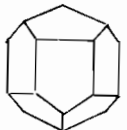
HEXAGONAL

ONE ONLY SIX-FOLD $\hexagon$ SYMMETRY



TRIGONAL

ONE ONLY THREE-FOLD $\triangle$ SYMMETRY

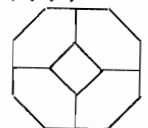
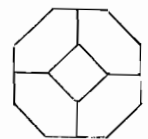


ISOMETRIC

MORE THAN ONE FOUR-FOLD SYMMETRY

MORE THAN ONE THREE-FOLD SYMMETRY

COMBINATION OF FOUR AND THREE FOLD SYMMETRY



IN CRYSTALS WHICH LACK □ △ ◇ SYMMETRY

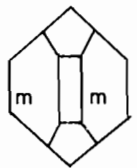
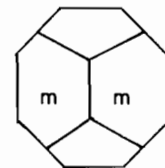
LOOK FOR A PRISM

A PRISM IS TWO OR MORE PLANES IF EXTENDED
WILL INTERSECT AND HAVE THE SAME ANGULAR
RELATIONSHIP TO SOME OTHER PLANE.

HOLD PRISM VERTICAL

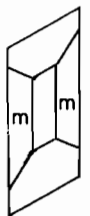
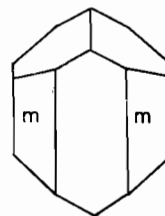
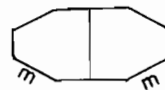
ORTHORHOMBIC

TOP IS STRAIGHT ACROSS



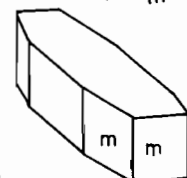
MONOCLINIC

TOP SLANTS



TRICLINIC

TOP IS CROOKED



MASSIVE

LACKS CLEAVAGE OR ITS TOO FINE TO SEE CRYSTAL-LINE HABIT

LUSTER = APPEARANCE OF MINERAL SURFACE IN REFLECTED LIGHT CAUSED BY ABSORPTION AND REFRACTION

MINERAL	N	TYPE
WATER	1.33	VITREOUS
CORUNDUM	1.77	RESINOUS
SPHALERITE	2.5	ADAMANTINE
COPPER	--	METALLIC

HARDNESS = MINERALS ABILITY TO ABRAID OR SCRATCH SOME OTHER SUBSTANCE
STUDENT EROSION --- KNIFE --- FEEL --- SOUND---

SPECIFIC GRAVITY = MINERALS WEIGHT IN AIR COMPAIRED TO THE WEIGHT OF AN EQUAL VOLUME OF WATER. USUALLY ASSOCIATE GRAVITY WITH THE LUSTER OF THE MINERALS.

COLOR IF IT HAS A DEFINITE **STREAK** FINE POWDER.

TASTE OF SOLUBLE MINERALS. **ODOR** WHEN SCRATCHED

FRACTURE AND **TENACITY** CONCHOIDAL. SECTILE. ELASTIC.

MAGNETISM MAGNETITE PYRRHOTITE. **CHEMICALS** HCL

ASSOCIATION "KIN FOLKS" PRESSURE TEMPERATURE TIME

PETROGRAPHIC ANALYSIS OF MESABI NONMAGNETIC TACONITE

USING THE POINT COUNTER

R. E. Lubker

The objective of this study was the application of the point-counting method to samples of West Mesabi nonmagnetic taconites for quantitative mineral analysis. Samples used were a screen fraction of each of 159 composites, which were taken in a sampling area extending for 50 miles along the range. Samples were split in a microsplitter, briquetted with a cold-setting plastic, polished on a leather lap with chromium oxide, and counted with an electronic point counter.

Weight-percent of each mineral was calculated from the modal analysis by using a standardized density value, and the iron-bearing minerals were multiplied by their respective iron factors. For each sample, these calculated iron values were added to give total count Fe. The count analysis was compared with the chemical Fe analysis and an arbitrary limit of $2\frac{1}{2}$ percent difference of count Fe from chemical Fe was established. Ninety-one percent of the samples fell within this limit; the failure of those which did not, after several recounts, can be attributed to adverse physical characteristics and mineral association.

PREPARATION OF MINERAL SPECIMENS

FOR ELECTRON MICROSCOPY

Virginia L. Doane

In the preparation of specimen mounts for examination by electron microscopy, two limitations are imposed, due to the fact that the mass of the electron is so small that its movement can be impeded by infinitesimal amounts of matter. These limitations are (1) the specimen must be ultra thin and (2) the examination must be conducted in an ultra high vacuum.

With these limitations in mind, four classes of specimen mounts can be examined: (1) suspensions of microscopic and submicroscopic solids, (2) ultra thin sections, (3) surface films and deposits and (4) replicas which reproduce the surface structure.

This paper describes the preparation of these four types of specimen mounts and is illustrated by the electron microscopic study of nuclei formed by the direct reduction of hematite.

ALTERED SPODUMENE OF THE LITHIUM PEGMATITE DEPOSITS

OF THE GEORGIA LAKE AREA, ONTARIO

E. G. Pye and V. G. Milne

Because of alteration, some of the spodumene in certain lithium pegmatite bodies of Archean age in the Georgia Lake area has low lithia and high iron contents and is not marketable. In several cases it detracts appreciably from the values of the deposits containing it and is of considerable economic significance. There are two types of altered spodumene. In one, the spodumene has been altered to a granular-textured aggregate of muscovite, in the other, it has been sericitized and rendered dark green to black.

Muscovitized spodumene is associated with cogenetic aplite and muscovite-quartz veins and replacement units of saccaroidal albite or of muscovite-albite intergrowths. Sericitized spodumene is post-pegmatite in age and is believed to be related in space and time to Proterozoic diabase intrusives.

Chemical Analyses of Spodumene Crystals

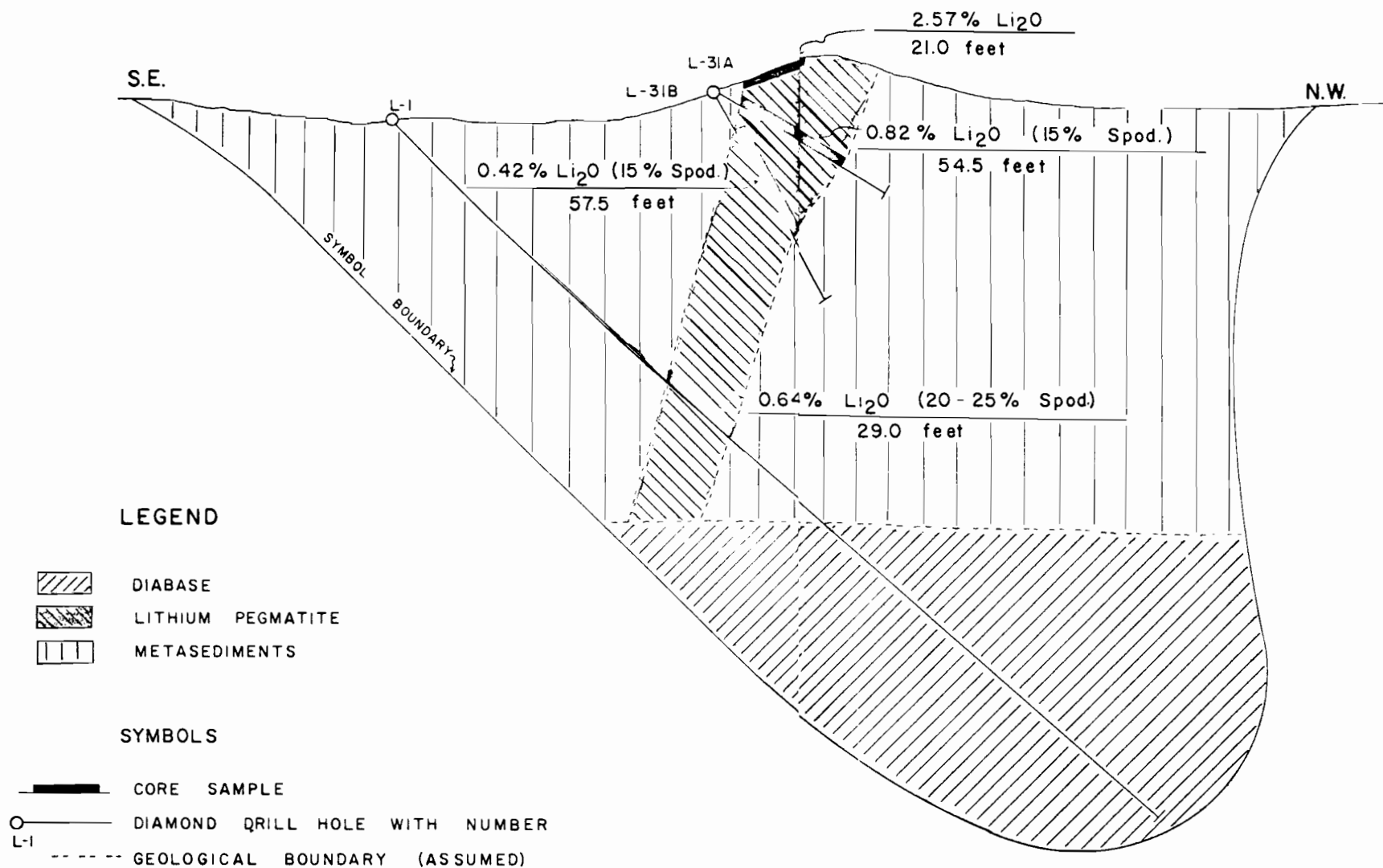
Georgia Lake Area

(Analyses Nos. 1-5 by the Laboratories Branch, Ontario
Department of Mines)

	Unaltered Spodumenes			Altered Spodumenes		Muscovites	
	No.1	No.2	No.3	No.4	No.5	No.6	No.7
SiO ₂	60.85	62.70	61.44	48.84	49.57	45.21	48.76
Al ₂ O ₃	27.60	27.27	29.06	29.78	28.23	33.40	29.91
Fe ₂ O ₃	0.29	1.53	1.22	1.50	4.59	2.78	4.24
FeO	0.44	0.31	0.33	2.19	1.56	2.00	0.41
CaO	-	0.34	0.28	-	0.40	-	0.33
MgO	0.32	0.22	0.16	.00	2.73	1.58	2.63
Li ₂ O ₃	6.62	5.33	5.63	0.43	0.15	-	-
K ₂ O	0.23	0.16	0.33	8.99	6.50	10.71	6.83
Na ₂ O	0.24	0.17	0.12	0.20	0.16	0.42	2.31
H ₂ O	-	-	-	-	-	3.95	4.60
F	-	-	-	-	-	0.94	-
L.O.I.	1.20	0.65	0.70	5.73	5.26	-	-
Totals	97.79	98.68	99.27	100.66	98.95	100.99	100.02

- No. 1. - No. 1 deposit, Jean Lake Lithium Mines Ltd.
 No. 2. - North zone, Nama Creek Mines Ltd.
 No. 3. - North zone, Nama Creek Mines Ltd.
 No. 4. - No. 1 deposit, Jean Lake Lithium Mines Ltd.
 No. 5. - North zone, Nama Creek Mines Ltd.
 No. 6. - Muscovite No. 11 (Dana, 1909).
 No. 7. - Muscovite No. 16 (Dana, 1909).

VERTICAL SECTION 4900N
NO. 1 DYKE
LUN ECHO GOLD MINES LIMITED



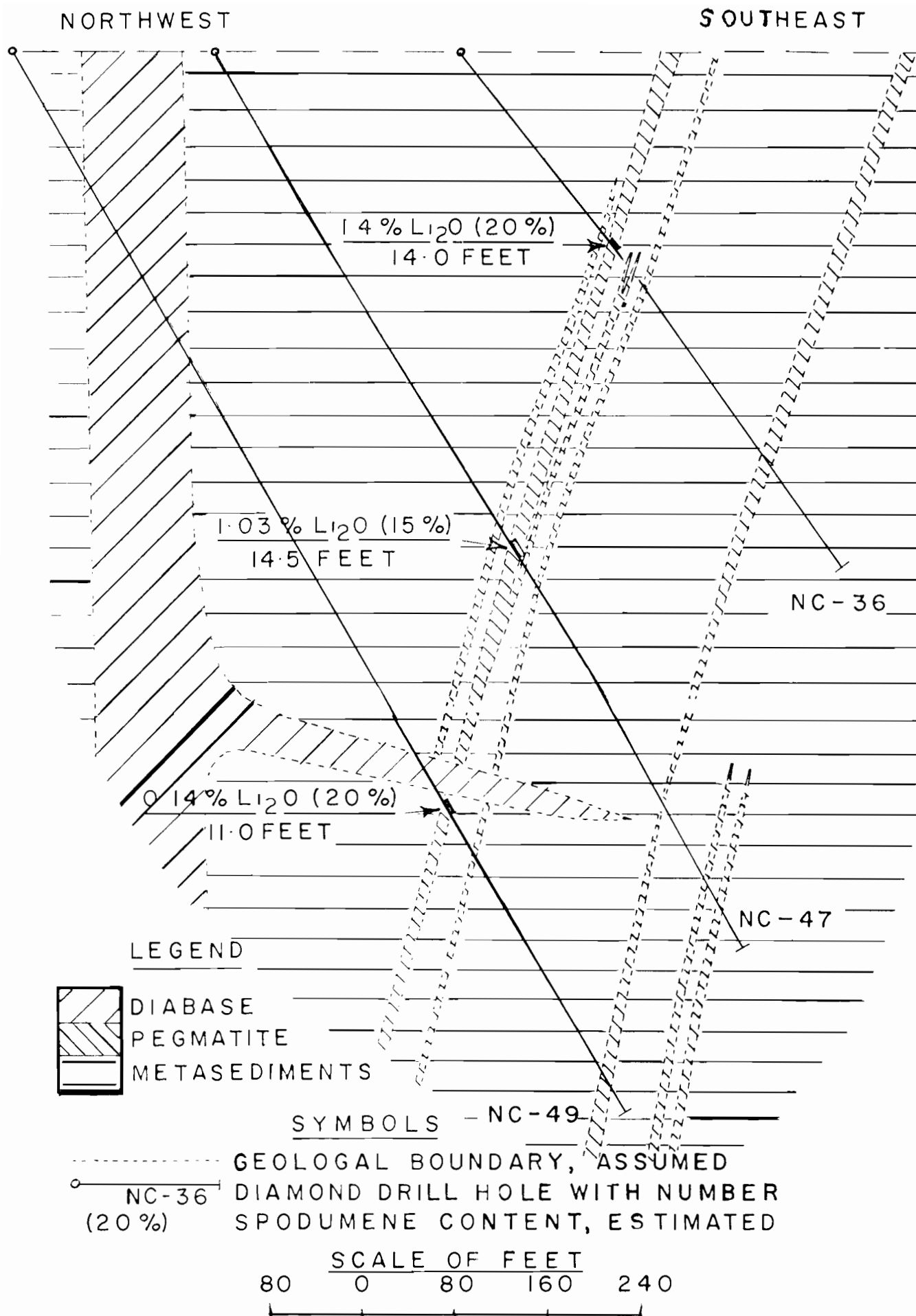


Fig. 9.

CLAY-MINERAL ALTERATIONS AND OTHER COORDINATED GEOCHEMICAL STUDIES IN
THE UPPER MISSISSIPPI VALLEY ZINC-LEAD DISTRICT, A PROGRESS REPORT*

A. V. Heyl, J. W. Hosterman, W. E. Hall, and M. R. Brock

The U. S. Geological Survey is investigating topical aspects of the geology and geochemistry of the lead, zinc, barite, and copper deposits of the Upper Mississippi Valley mining district as part of a larger study of deposits elsewhere in the Mississippi Valley. Emphasis has been on wall-rock alteration and on the ore-forming fluids as represented by liquid inclusions in ore and gangue minerals. Studies in the Thompson-Temperly mine near New Diggings, Wis., have been particularly instructive because of the unusually complete exposures through two ore bodies and extensive areas between and around them.

X-ray diffraction of a series of samples from a thin carbonaceous basal shale bed of the Quimbys Mill Member of the Platteville Formation shows well-defined alteration aureoles around the ore bodies. Clay minerals change progressively from the Md polymorph of illite in the unaltered rock to 1M and 2M illite in the aureoles, and the 2M polymorph increases markedly within the ore deposits themselves. In the same samples, calcite decreases, and dolomite and microcline increase toward the ore zone.

Stable isotope studies show little fractionation of O^{18}/O^{16} and C^{13}/C^{12} of coexisting limestone and dolomite samples from the same mine and nearby mines as compared to that from barren outcrops. However, the calcite in ore bodies contains markedly lower O^{18}/O^{16} ratios than that in the barren limestone wall rocks of the Quimbys Mill Member beyond the alteration aureoles. The calcite and dolomite of the altered wall rock of the ore body and alteration aureole contain slightly lower O^{18}/O^{16} ratios than the barren limestone of the Quimbys Mill Member. Further studies are in progress to study possible fractionation of the oxygen isotopes between carbonates and silica.

Qualitative X-ray fluorescence analyses of the samples show slight decreases in potassium, aluminum, magnesium, silica, titanium, iron, and manganese in the outer part of the alteration aureoles and marked increases in the ore zone. For example, aluminum shows a marked decrease at the outer edge of the altered zone from the amount in the unaltered wall rock. At the inner edge it increases slightly, and in the ore zone, markedly. In contrast, calcium increases slightly in the altered zone and decreases markedly in the ore zone. These facts indicate leaching

* Published by permission of the Director, U. S. Geological Survey.

in the outer fringe of the aureole and migration of the elements toward the ore zone. However, the proportionate volumes and contents of the leached zone as compared with those of the inner alteration aureole and ore zone suggest that much of the aluminum, iron, silica, titanium, and manganese were added by the ore-bearing solutions from sources other than the narrow leached outer part.

Other studies in progress of samples from the Thompson-Temperly mine include:

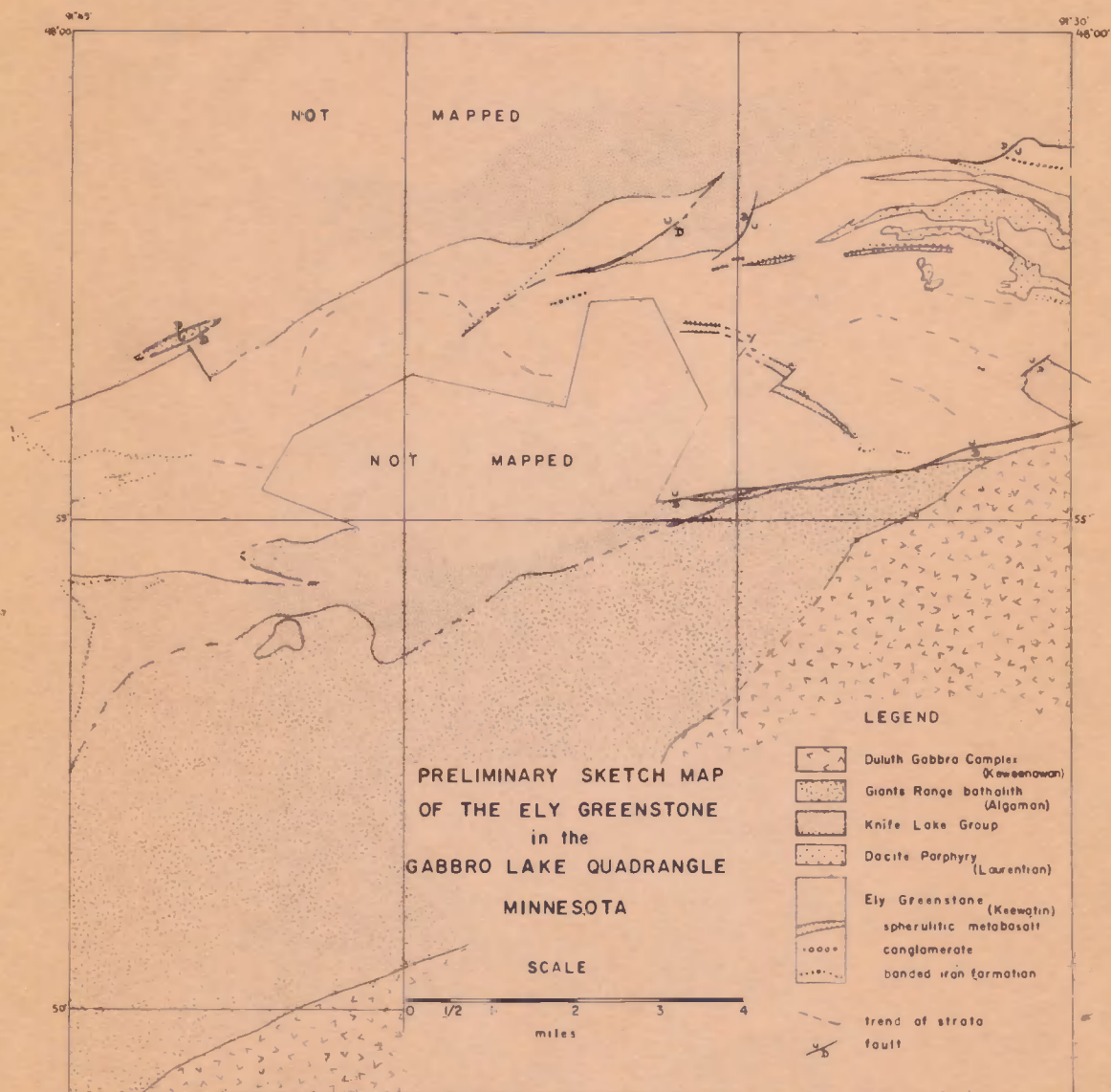
- (1) X-ray diffraction analyses which indicate that an abundant gray cobaltian iron sulfide from the mine is pyrite with micro-intergrowths of probable cobaltite.
- (2) Calcite grew in four successive crystal habits; scalenohedral forms predominate in earlier stages, rhombohedral forms in later stages. These habits can be easily traced, in the same depositional order, not only in the Thompson-Temperly mine where they are well developed, but throughout the 3,000 square miles of the district. By contrast, preliminary studies by Philip Bethke and Paul Barton on thin compositional layering in sphalerite have shown that although this layering can be correlated with confidence throughout the Thompson ore body, attempts to trace it even to nearby mines are, as yet, inconclusive.
- (3) Preliminary measurements of thermoluminescence suggest a distinct variation between the reaction of barren and altered rock to heating.
- (4) Semiquantitative spectrographic analyses of compositional variations in minerals of the altered zone, and quantitative determinations of the amounts of calcite and dolomite by a combination of X-ray diffraction and other geochemical tests.
- (5) W. E. Hall and Irving Friedman's work on fluid inclusions from ore minerals in the district shows that the mineralizing solutions were highly concentrated sodium-calcium chloride brines similar to connate waters found today in deep wells in the Illinois basin. Temperature studies by Darrell Pinckney in the inclusions from the Thompson-Temperly mine are in progress. Eugene Roseboom is studying the copper mineralogy. H. T. Shacklette has made a district-wide geobotanical study of minor-element variations in the vegetation.

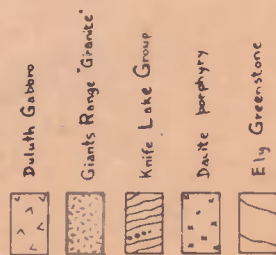
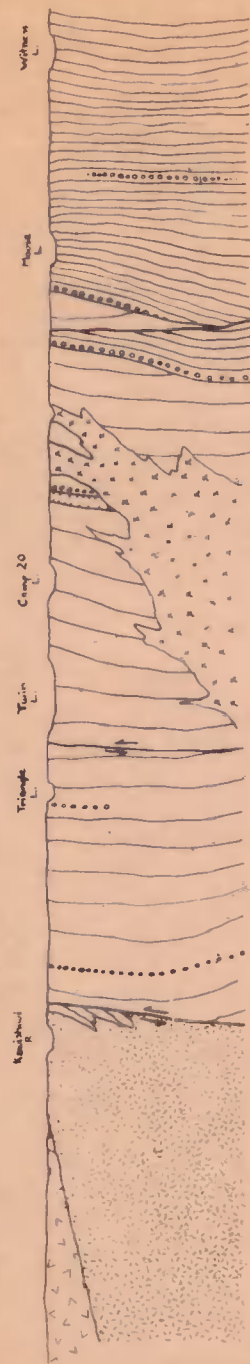
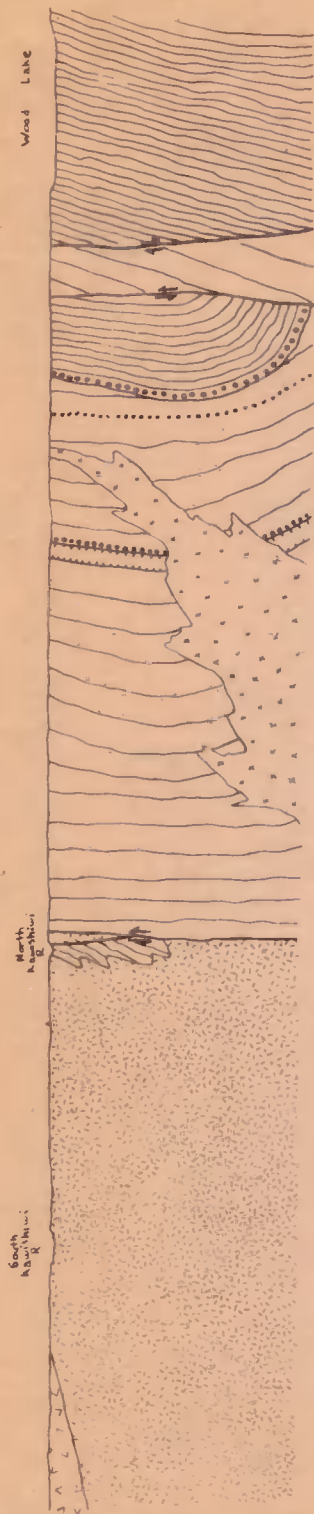
CURRENT INVESTIGATIONS OF THE PRECAMBRIAN ELY GREENSTONE
IN NORTHERN MINNESOTA

John C. Green

Mapping and study, now in progress, of pre-Keweenawan rocks in the 15-minute Gabbro Lake quadrangle just east of Ely, Minnesota has shown that the Ely Greenstone, the oldest formation in the area, consists predominantly of pillowed metabasalt, intruded by abundant diabasic sills. The formation is estimated to be at least 10,000 feet thick; the base is not exposed. Thin stringers of banded chert-hematite-magnetite iron formation occur at several horizons within the formation, and possible algal structures were found in one exposure. Conglomerates and some graywacke occur sporadically in the greenstone; those high in the section contain pebbles of the Laurentian dacite porphyry that elsewhere in the area intrudes the formation. Mappable stratigraphic units are rare, but a dacite flow or tuff, stringers of iron formation, and a spherulitic pillowed metabasalt can each be traced for a few miles.

Deformation occurred mostly during the Algoman orogeny, and probably took place at shallow depths; the rocks have deformed mainly by local shearing and some brecciation, and the metamorphic grade is mostly low. The strata are roughly vertical throughout the area. Some major faulting followed intrusion of the Giants Range batholith. Between shear zones, minor structures are well preserved in much of the rock. The Ely Greenstone is overlain, perhaps entirely by fault contact, by the slightly younger but pre-Algoman Knife Lake Group.





Scale



GEOLOGIC AEROMAGNETIC INTERPRETATION OF PART OF ONTARIO LYING

NORTH OF LAKE SUPERIOR

A.S. MacLaren and S. Duffell

Since 1959 the Federal Government of Canada and the Province of Ontario have cooperated in a systematic aeromagnetic survey of the Precambrian Shield in that province. To date 421 1-mile maps covering an area of 165,000 square miles have been published. In conjunction with these surveys a large scale mapping program covering 50,000 square miles was carried out in 1960 and 1961. This survey included bedrock and pleistocene geology, geochemistry and geophysics.

This paper compares geological data with aeromagnetic data covering an area of 150,000 square miles north of Lake Superior. It contrasts magnetic data in the Superior and Grenville provinces.

Typical circular to ovoid anomalies are described and their origin discussed. The use of airborne magnetic data and reconnaissance gravity surveys are described as a means of prospecting for alkaline-ultramafic plugs containing magnetite, apatite and columbite. The magnetic expression of iron formation is discussed and evaluated.

This type of broad aeromagnetic survey has, in the past, been an incentive for private companies to carry out selective electromagnetic surveys to track down sulphide mineralization,

As a direct result of these surveys there is an increased realization by both the geologist and geophysicist that the best geological maps are made when geological and geophysical data are used to supplement one another.

PRESENTATION OF A REGIONAL AEROMAGNETIC MAP
OF WISCONSIN

Robert Patenaude

The aeromagnetic map of Wisconsin is most distinctive in the northwest quadrant of the state by virtue of a strongly developed northeast-southwest lineation in the contours. The positive magnetic zones appear to coincide in location with the mid-continent gravity high and with Huronian iron formation and its metamorphosed equivalent. The Gogebic iron range in particular is marked by a strong positive magnetic anomaly.

In the north central part of the state a zone of positive anomalies extends to the east and northeast from the vicinity of Wausau. Another group of positive magnetic anomalies occurs in the vicinity of Eau Claire.

A relatively undisturbed magnetic pattern extends from east central Wisconsin to the southwest portion of the state. In the southeast part of Wisconsin the magnetic pattern again becomes stronger and more irregular.

A METHOD FOR COMPUTING THE MAGNETIZATION OF DIKES WITH EXAMPLES
OF ITS APPLICATION TO DIKES NORTH OF COVINGTON

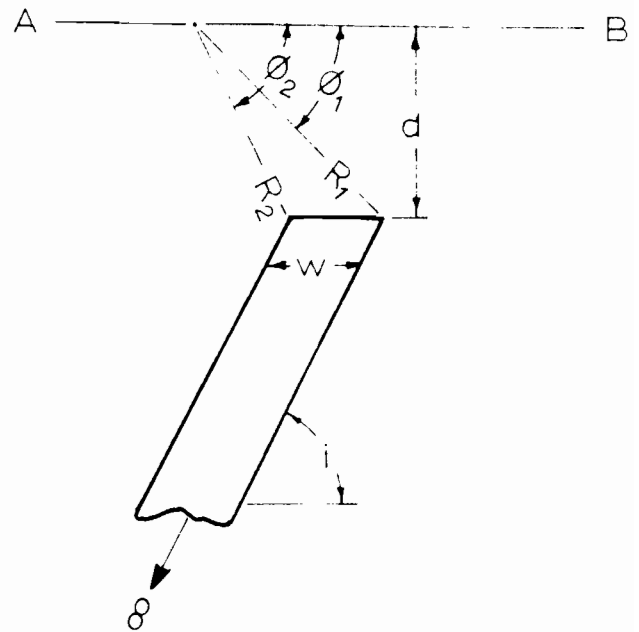
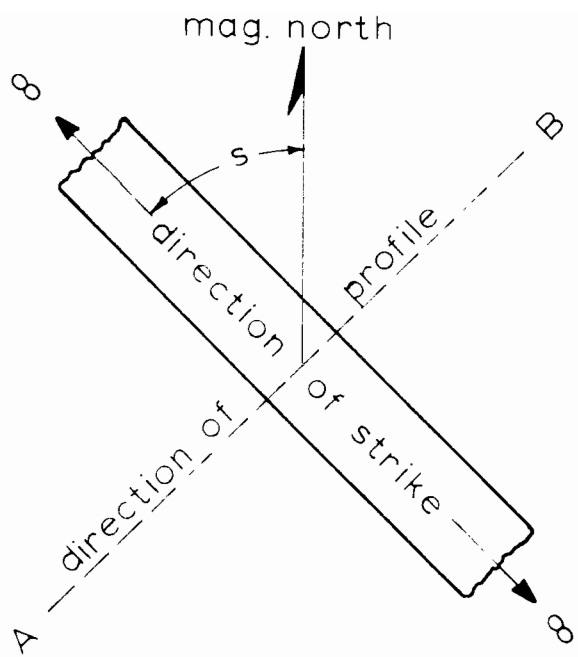
Gerald Van Voorhis and Lloyal Bacon

When interpreting the data from a magnetic survey, it is often helpful to be able to compute the magnetic anomaly for various geologic structures. Because of the difficulty in computing the magnetic effect of three-dimensional bodies, most computations are limited to the two-dimensional case. One of the most frequently encountered two-dimensional structures is the dike. Since the depth extent of a dike is not usually known, and the magnetic effect of the bottom surface is small if the depth is large, it is often assumed in making calculations that the dike extends to infinity.

A formula for computing the magnetic anomaly of a dike of infinite depth extent is given in Figure 1. From Figure 1 it is seen that the effects of the dike's dip and magnetization are contained in the constants C_1 and C_2 . Generally these factors will be unknown. On the otherhand, the variables L and Φ depend only on the depth of burial and width of the dike and are usually known. If the magnetic anomaly of the dike has been measured, C_1 and C_2 can be determined by least squares. If the dip of the dike is known, the magnetization in the plane normal to its strike can then be computed.

Frequently, the depth of burial of the dike is known, but its width is not known from available geologic information. The width can be determined from the measured magnetic anomaly. Figure 2 is a plot of the anomaly and the corresponding L and Φ terms for a specific dike. The L term has odd and the Φ term has even symmetry about the center of the dike. If the dike anomaly is folded about the center as shown on Figure 3 and the sum and difference of the resulting curves plotted, the sum curve will equal $2C_2\Phi$ and the difference curve will equal $2C_1L$. The maxima and minima of the L term and the points of maximum slope of the Φ term fall at the same distance, r , from the center of the dike. If a semicircle of radius r is drawn as shown on Figure 3, the intersection of the semicircle with the depth of burial plane will define the edges of the dike.

The above techniques have been applied to the analysis of the measured anomalies of known dikes. In one case, oriented samples of the dike had been studied previously and provided a check on the least square calculation. In that case the computed results checked with the measured values to within the error of measurement.



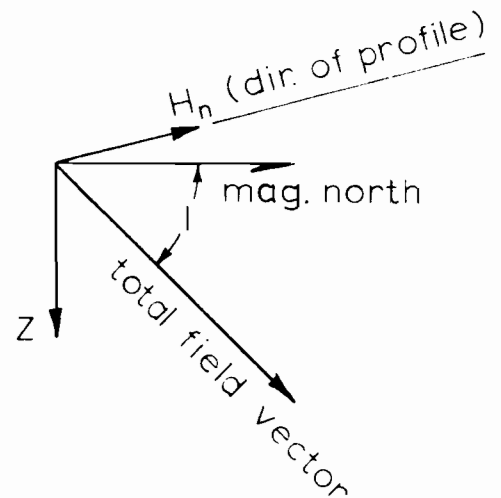
$$\text{anomaly} = C_1 L + C_2 \Phi$$

$$L = 2 \log (R_1 / R_2)$$

$$\Phi = 2(\phi_1 - \phi_2)$$

$$A = H_n \sin^2 i + Z \sin i \cos i$$

$$B = Z \sin i - H_n \sin i \cos i$$



component	C_1	C_2
vertical	A	- B
horizontal	B	A
total field	$A \sin i + B \cos i \sin s$	$A \cos i \sin s - B \sin i$

Figure 1. Geometry, notation, and formula for infinite dike.

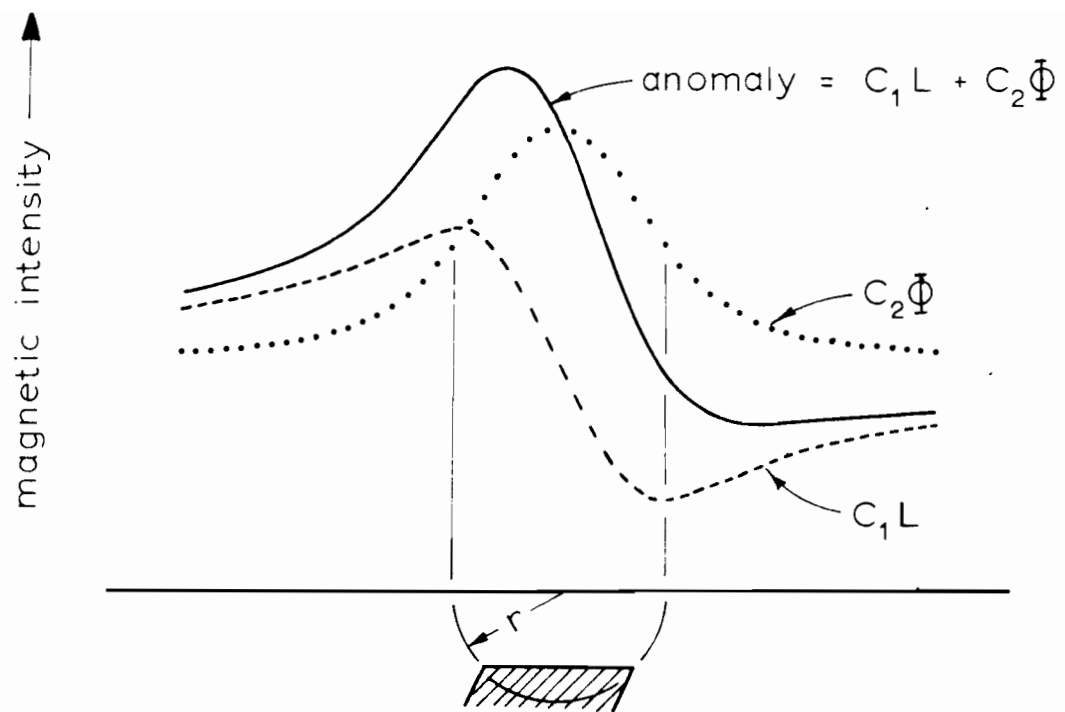


Figure 2. Illustration of symmetry used for dike width determination.

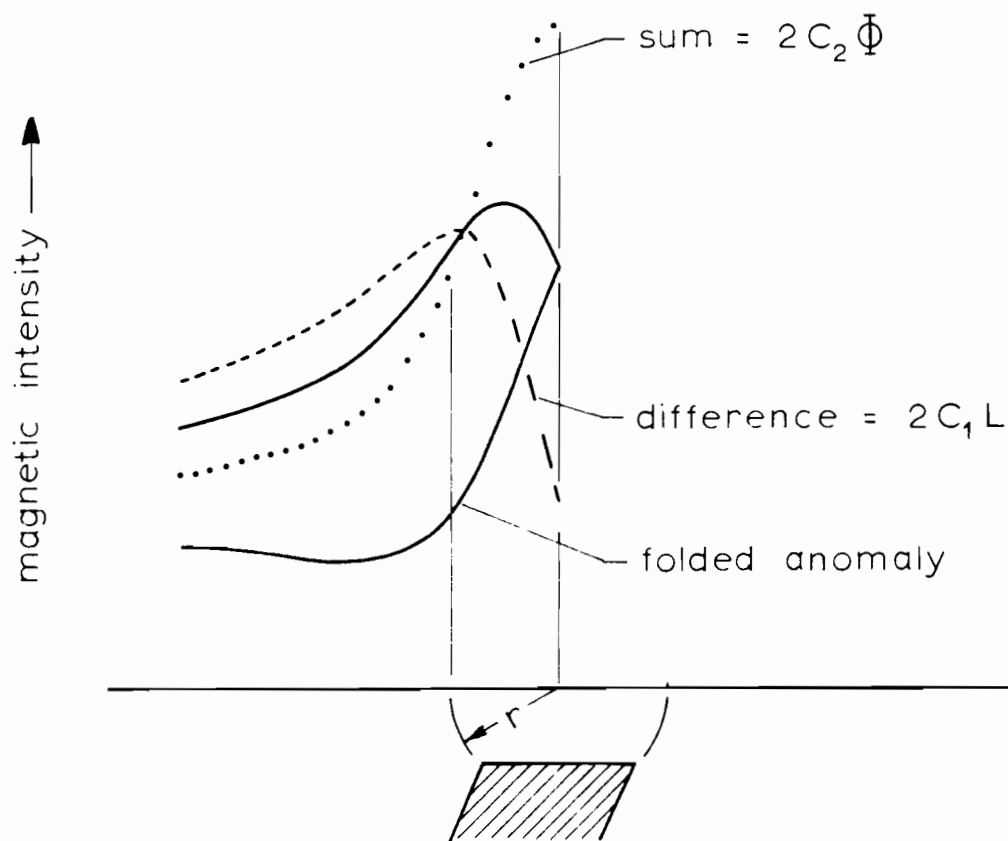


Figure 3. Anomaly folding to obtain sum and difference terms.

THE APPLICATION OF RADIO FIELD INTENSITY MEASUREMENTS TO

MAPPING PRECAMBRIAN GEOLOGICAL FEATURES

Charles E. Kerman and William J. Hinze

The intensity of radio waves received from A.M. broadcasting stations is a function of many factors including the electrical and magnetic properties of the underlying earth formations. In areas where the effects of the earth formations are great enough to override the other factors or the other factors can be eliminated, the radio field intensity method can be utilized for detecting changes in these physical properties. These physical properties may be related to specific geological formations and structures, therefore this method is potentially applicable to geological mapping.

A radio field intensity survey was conducted in the Marquette, Iron Mountain, Ironwood, and Keweenaw areas of the Northern Peninsula of Michigan to determine the applicability of this method to mapping Precambrian geological features in the Lake Superior region. Measurements were made from a vehicle utilizing continuous recording techniques. Correlation of radio field intensity variations with known geology indicates that this method offers promise as an economical and rapid method of geological mapping particularly for tracing and extending known faults, contacts, and formations where cultural and topographical effects are not severe and the glacial drift is thin.

INVESTIGATION OF THE THICKNESS OF THE JACOBSTOWN SANDSTONE

BY SEISMIC REFLECTION METHODS -- A PROGRESS REPORT

Lloyal O. Bacon

The area just east and south of the Keweenaw fault has a very thick section of Jacobstown sandstone of Cambrian (Ozarkian?) age. Previous gravity work by the author indicated a throw of the Keweenaw fault of the order of 10,000 feet, with an indication that a parallel fault existed to the east and the possibility of at least one major nearly normal to the strike of the Keweenaw fault. A seismic reflection program was instituted to check the gravity interpretation.

Seismic reflections can be obtained from within or at the base of the sedimentary section if appropriate care is used in shot location and with the use of multiple geophones and signal mixing.

The seismic evidence substantiates previous estimates of about 10,000 feet throw for the Keweenaw fault; however, the limited data obtained does not substantiate the presence of a cross fault near Limestone Mountain as interpreted from gravity data.

THE APPLICATION OF INDUCED POLARIZATION PROBING TECHNIQUES UNDERGROUND;

MICHIGAN NATIVE COPPER DISTRICT

A. W. Schillinger

Exploration drilling with a success factor (discovery ratio) of only 34% did not initially prove entirely satisfactory in the search for native copper mineralization in the footwall of the Osceola Amygdaloid workings. Mining experience proved the oreshoots to be more continuous than drilling results indicated, but additional fill-in drilling was impractical. An auxiliary exploration tool was needed. At the request of Calumet & Hecla, Inc., the Geophysics Department of Michigan Technology University evaluated the measurable electrical properties of native copper mineralization and recommended that their efforts be directed to developing an induced polarization method adaptable to drill hole probing techniques.

As developed by the University, the apparatus consists of a semi-rigid coiled probe and a power supply/instrument case easily transported and operated by one man. A standard AM (3 electrode) logging configuration is used with a spacing of 2' - 4" - 0.5' resulting in a sampling radius of 5'±. Readings are generally taken at two-foot intervals in the hole. The three probe electrodes are sponge-covered, non-polarizing lead/lead oxide types and the remote current electrode is wire gauze. A constant current of 5, 10, or 20 ma. of alternately reversed polarity is pulsed at 3.5 sec. intervals. Potential readings are taken during the "on" cycle for resistivity determinations. During the "off" cycle, after a 10 ms. delay, the I.P. potential is sampled for a 10 ms. interval and recorded. Field data is computed in the office and both resistivity values (ohm-feet) and "S" values (mv/v) are plotted together on semi-log paper.

The interpretation of the probe results consists of

- (1) plotting a lithologic log based on the calculated resistivity, and
- (2) delimiting, on a semi-quantitative basis, anomalous zones based on inspection of the "S" values and their corresponding resistivity values. The Osceola Amygdaloid, averaging 30 feet in true thickness, consists of hanging-wall, intermediate, and footwall amygdaloidal zones of low resistivity separated by one or more "bars" or sills of high resistivity footwall-type basaltic trap. Comparing a large number of lithologic resistivity logs with the corresponding core logs showed that remarkably good correlation was obtainable and amygdaloid-trap contacts could frequently be picked to ±.5' from resistivity logs alone. Based on resistivity data, it was now possible to make up geologic logs of long steel holes to augment or even replace the time-consuming, only partially satisfactory sludge logging procedures. Based on laboratory data and empirical observations in mining areas, a threshold "S" value

of 30 mv/v was established as the lower limit of diagnostic induced polarization effects in mineralized anygdaloidal vein. Above 30 mv/v anomalous zones were designated "slight" (30 - 50 mv/v); "fair" (50 - 100 mv/v); "good" (100 - 200 mv/v) and "very good" (plus 200 mv/v). No attempt has been made to assign absolute grade values to corresponding "S" values, although two points "fair" or better are considered ore from a development standpoint.

Since 1956, 876 diamond drill and long steel holes aggregating 47,000 feet have been drilled in the Osceola mine workings. Of the 914 footwall zones penetrated, 316 have been probed with the I.P. equipment yielding 203 "fair" or better anomalies. The success factor (discovery ratio) has increased from 34% for drilling only to 72% for drilling and probing combined. Forty-six probe results were checked by subsequent drifting or crosscutting and the interpretations were found to be correct 78% of the time. Incorrect results consisted of the probe not detecting copper mineralization at all or of the interpreter underestimating the significance of an anomaly. However, in no case was a false anomaly found.

The use of the I.P. probe has increased the discovery ratio two-fold by greatly increasing the sampling radius of exploration holes and has proven a greater continuity of footwall ore than drill results alone indicate. In addition, long steel drilling can now be employed with more confidence inasmuch as contacts can be plotted more accurately and ore zones delineated without the necessity of saving sludge samples. However, in the search for ore and favorable structures, maximum results from the use of the probe can only be realized if geological reasoning is applied in the interpretation of the data and its subsequent use on geologic plans and sections.

THE AGE OF THE DULUTH GABBRO AND THE ENDION SILL

BY THE WHOLE-ROCK Rb-Sr METHOD

G. Faure and P.M. Hurley

Isotopic compositions of strontium and concentrations of rubidium and strontium have been determined for suites of rock specimens of the Duluth Gabbro and the Endion Sill. The samples of the Duluth Gabbro were collected largely in the Enger Tower area of Duluth and along Skyline Drive. The Endion sill was sampled along the shore of Lake Superior at Duluth.

The analytical data for the two intrusives are summarized in Tables 1 and 2 and are plotted in Figures 1 and 2. On a plot of $\text{Sr}^{87}/\text{Sr}^{86}$ versus $\text{Rb}^{87}/\text{Sr}^{86}$, rocks having a common age and common initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio will lie on a straight line, called the isochron. The goodness of fit of the data on a straight line provides a check on the above assumptions.

The age of the two intrusives was determined from the slopes of the isochrons which were fitted to the points by the method of least squares and included both regression's of y on x and x on y. In doing so, the assumption is implied that deviations of the points from the isochron are due only to random errors and not to differences in age or initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios of the rocks.

Using a value of $\lambda = 1.39 \times 10^{-11} \text{ yrs}^{-1}$ for the decay constant of Rb^{87} , the following ages were calculated. The errors are standard deviations calculated from the least squares regressions and represent 95% confidence limits.

Duluth Gabbro		Endion Sill	
Age in B.Y.		Age in B.Y.	
Y on X	0.97 ± 0.07		1.08 ± 0.02
X on Y	1.02 ± 0.07		1.08 ± 0.05
Mean	1.00 ± 0.07		1.08 ± 0.05

The initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios for the Duluth Gabbro and the Endion Sill are 0.7052 ± 0.0009 and 0.7050 ± 0.0009 , respectively. These values are typical of primary strontium of basaltic or gabbroic rocks which originate from the upper mantle.

The ages and initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios of the Duluth Gabbro and the Endion Sill are indistinguishable from each other at the 95% confidence limit.

Table 1
Analytical Data for Duluth Gabbro

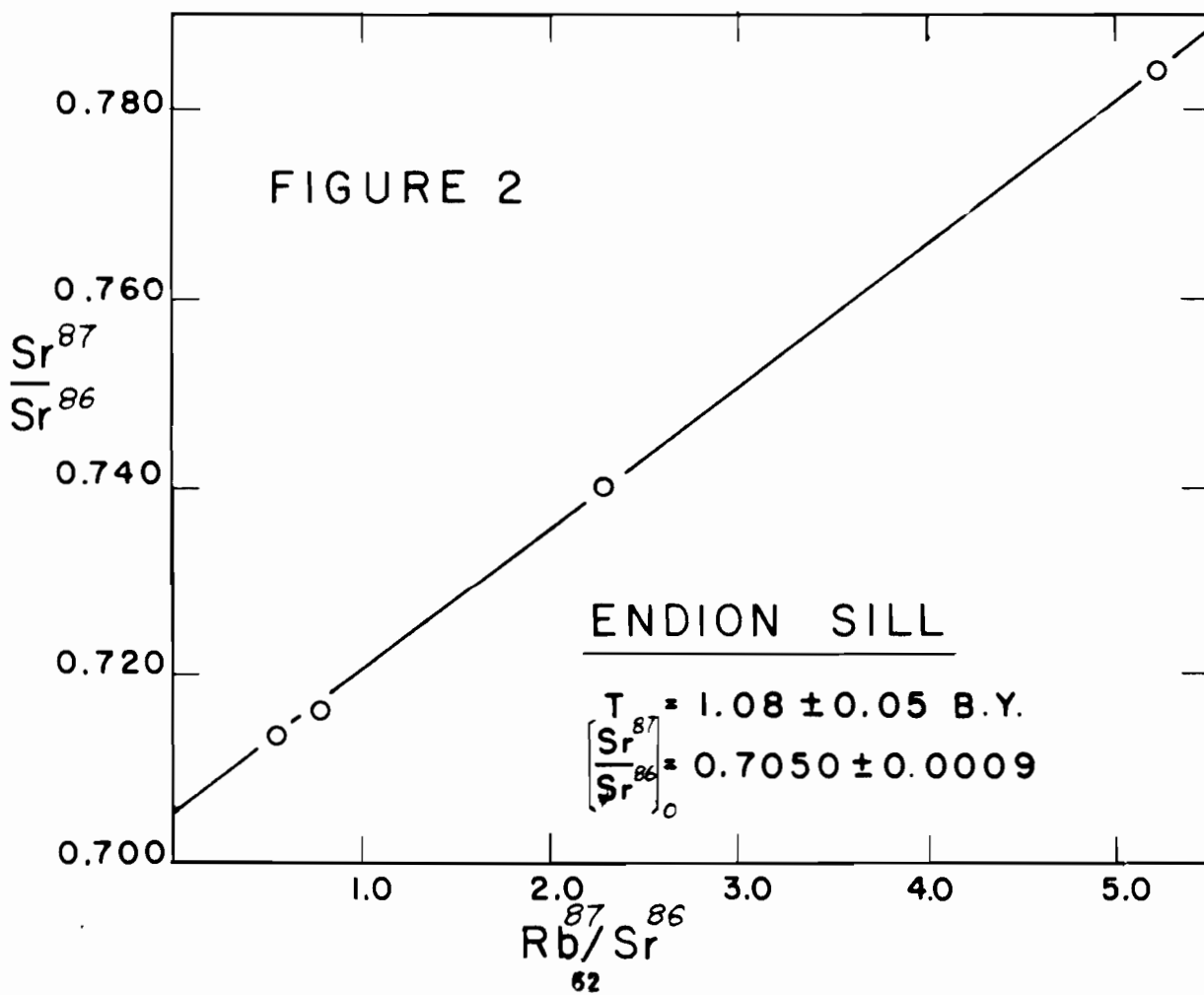
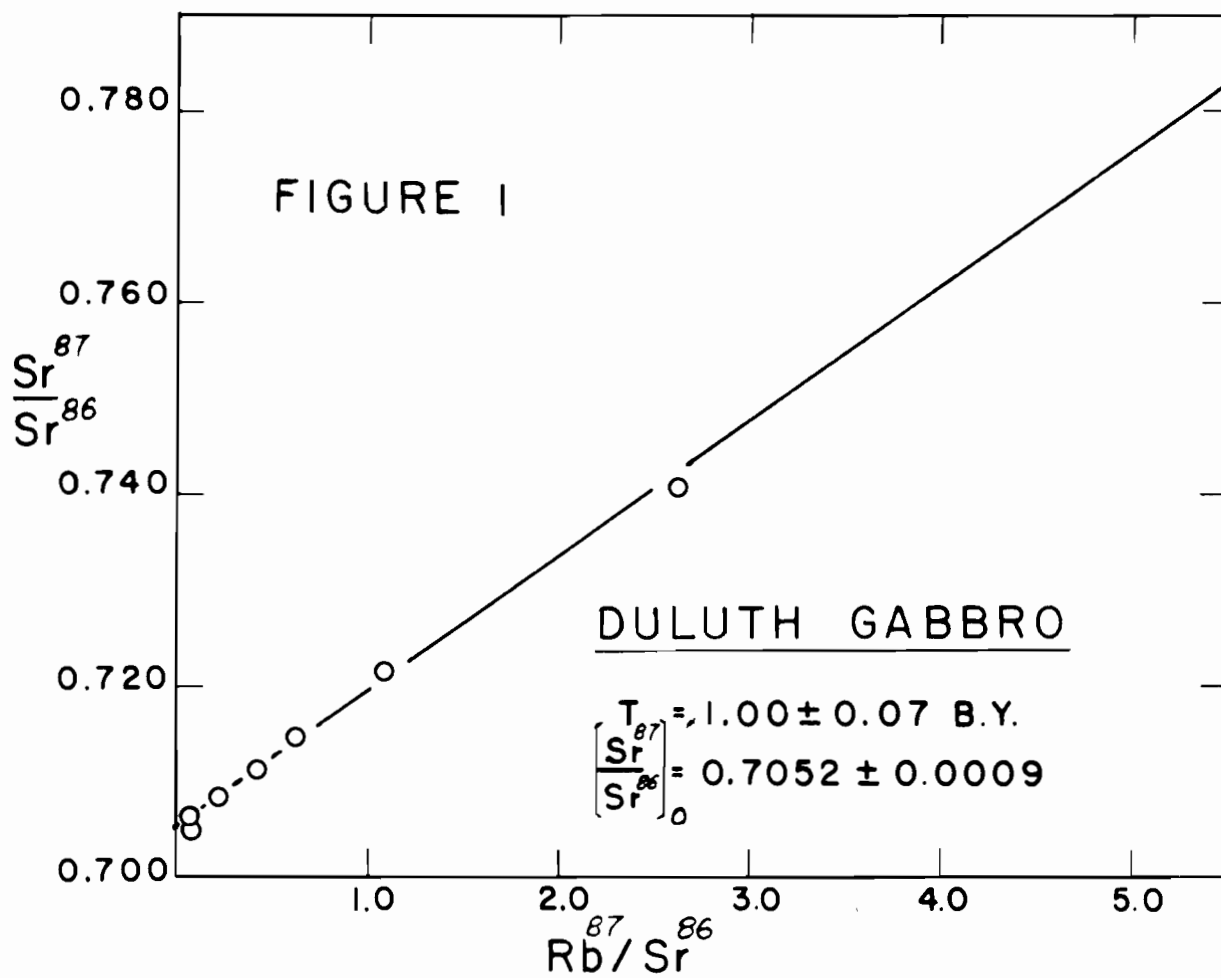
M.I.T. Sample	Rock Type	$\left[\frac{\text{Sr}^{87}}{\text{Sr}^{86}} \right]_N$	$\frac{\text{Rb}^{87}}{\text{Sr}^{86}}$
4364	Granophyre	0.7408	2.62(2)
4361	Granophyre	0.7218	1.07(2)
4363	Granophyre	0.7146	0.63
4365	Granophyre	0.7114	0.42
4362	Anorthositic Gabbro	0.7087	0.23
4366	Gabbro, Layered Series	0.7049(3)	0.07
1231	Gabbro	0.7065(2)	0.06

Table 2
Analytical Data for Endion Sill

4373	Granophyre	0.7839	5.22
4372	Granophyre	0.7402	2.29(2)
4371	Intermed. Rock	0.7163	0.78
4369	Diabase	0.7136(2)	0.55

All $\text{Sr}^{87}/\text{Sr}^{86}$ ratios have been corrected for fractionation by normalizing to $\text{Sr}^{86}/\text{Sr}^{88} = 0.1194$.

Numbers in brackets indicate the number of measurements made.



THE PENOKEAN FOLD BELT NORTH OF LAKE HURON

G. G. Suffel

Since the discovery of uranium in the basal quartzites (1952), detailed mapping of the type Huronian in Ontario has been continuous. Much of the ground between Sault Ste. Marie and Sudbury has been re-mapped. Enough information is now available to assess the changes made and the problems remaining.

The classic work of Collins and Quirke (1914-1930) has withstood re-examination remarkably well. Their conception of the Huronian as a miogeosyncline folded by orogeny and "the disappearance of the Huronian" to the southeast due to granitization along a transecting front has been amply verified.

Important new developments stem from absolute dating. The work of Goldich and associates in Minnesota established the minimum age of deformation as 1700 m.y. and revived the term Penokean for the orogeny, a name already applied by some to the fold belt in Canada since 1948. Killarnean orogeny was finally discredited and identified with Grenville metamorphism at about 900 to 1000 m.y. Dating of the Penokean in Ontario has been difficult due to superimposed events but since 1959 it has become clearer that a similar minimum of about 1600 m.y. applies.

However, some confusion still exists and important problems remain. Some recent reports refer to the Huronian sediments north of Lake Huron as part of a Grenville geosyncline. J. E. Thomson and others question the correlation of some or all of the sediments of the "Panache" block south of the Murray fault with the Huronian; they maintain that the Wanapitei quartzite south of Sudbury is not equivalent to the Mississagi but pre-Huronian. These conclusions are questioned. Work in progress by both the Ontario Department of Mines and the Geological Survey of Canada should resolve these and other problems within the next few years.

No developments have yet denied the probability that the type Huronian sediments were deposited in the same geosyncline as the Animikie of Michigan and Minnesota. New stratigraphic studies in Ontario, partly published already, should encourage renewed efforts to correlate these rocks.