

NINTH ANNUAL

INSTITUTE ON LAKE SUPERIOR GEOLOGY

MAY 2 - 3, 1963

UNIVERSITY OF MINNESOTA, DULUTH

Department of Geology

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INSTITUTE ON LAKE SUPERIOR GEOLOGY

University of Minnesota, Duluth

May 2-3, 1963

P R O G R A M

Thursday Morning - May 2, 1963

Science Auditorium, University of Minnesota, Duluth

9:00 General Meeting of the Institute Chairman, H. Lepp
Secretary, D. H. Hase

SESSION I

Co-chairmen: J. C. Green, J. S. Owens

9:30 D. W. Pollock & S. C. Nordeng: PRELIMINARY INVESTIGATION OF A
PORTION OF THE NORTHERN COMPLEX, BARAGA CO., MICH.

9:55 George Moerlein: STRUCTURE AND STRATIGRAPHY OF THE KEWEENAWAN IN
NORTHWESTERN MICHIGAN

10:20 Isidore Zeitz & P. K. Sims: BURIED EXTENSION OF THE KEWEENAWAN
BASIN IN MINNESOTA - A GEOPHYSICAL STUDY

10:45 P. K. Sims & Isidore Zeitz: GEOLOGIC INTERPRETATION OF AERO-
MAGNETIC ANOMALIES OVER PRE-KEWEENAWAN ROCKS
IN CENTRAL MINNESOTA

11:10 S. C. Nordeng, C. O. Ensign & M. E. Volin: THE APPLICATION OF
TREND SURFACE ANALYSIS TO THE WHITE PINE COPPER
DISTRICT

11:35 GENERAL DISCUSSION

12:00 LUNCH - MAIN BALLROOM, KIRBY STUDENT CENTER

SESSION II

Co-Chairmen: F. D. Effinger, T. E. Stephenson

2:00 W. C. Phinney: STRUCTURE WITHIN THE DULUTH GABBRO COMPLEX IN THE
GABBRO LAKE AND GREENWOOD LAKE QUADRANGLES,
MINNESOTA

2:25 G. N. Hanson, W. C. Phinney & P. W. Gast: THE THERMAL EFFECT OF
THE DULUTH GABBRO UPON THE SNOWBANK GRANITE

- 2:50 N. W. Jones: THE RELATIONSHIPS BETWEEN THE DULUTH GABBRO AND THE DIKES AND SILLS NEAR HOVLAND, MINNESOTA
- 3:15 COFFEE BREAK
- 3:45 G. B. Morey: THE STRATIGRAPHY AND STRUCTURE OF THE ROVE FORMATION, GUNFLINT LAKE AREA, MINNESOTA
- 4:10 Paul Wieblen: STRUCTURES OF CONCRETIONS IN THE THOMSON FORMATION, CARLTON AND PINE COUNTIES, MINNESOTA
- 4:35 GENERAL DISCUSSION
- 6:30 DINNER - MAIN BALLROOM, KIRBY STUDENT CENTER

Speaker: Dr. R. L. Heller, Director, Earth Science Project;
Head, Department of Geology,
University of Minnesota, Duluth

Topic: EARTH SCIENCE AND THE SECONDARY SCHOOL CURRICULUM

Friday Morning, May 3, 1963

SESSION III

Co-Chairmen: P. C. Tychsen, I. L. Reid

- 9:00 R. L. Blake, T. Z. Zoltai & R. E. Hessevick: REFINEMENT OF THE HEMATITE CRYSTAL STRUCTURE
- 9:25 G. L. Laberge: CARBONATE MINERALS IN THE IRON FORMATION AND THEIR SIGNIFICANCE
- 9:50 R. E. Randolph: SUSCEPTIBILITY MEASUREMENTS OF EMPIRE MINE MAGNETIC MATERIAL
- 10:15 COFFEE BREAK
- 10:45 R. A. Hoppin, J. C. Palmquist & L. O. Williams: CONTROL BY PRE-CAMBRIAN BASEMENT STRUCTURE ON THE LOCATION OF THE TENSLEEP - BEAVER CREEK FAULT, BIGHORN MOUNTAINS, WYOMING
- 11:10 C. M. Gallick: CLAY MINERALOGY OF THE DECORAH SHALE, MINNESOTA
- 11:35 M. A. Rogers: BIOGEOCHEMISTRY OF MINNESOTA LAKES: CARBOHYDRATES
- 12:00 LUNCH - MAIN BALLROOM, KIRBY STUDENT CENTER

SESSION IV

Chairman: R. W. Marsden

- 2:00 J. H. Zumberge & W. R. Farrand: LAKE SUPERIOR CORES AND BOTTOM TOPOGRAPHY
- 2:25 C. E. Carson: ORIENTED LAKES IN NORTHERN ALASKA
- 2:50 G. M. Schwartz: THE SUBDIVISIONS OF THE BIWABIK FORMATION ON THE EASTERN MESABI
- 3:15 GENERAL DISCUSSION

Saturday, May 4, 1963

7:30 - Hotel Duluth

FIELD TRIP TO THE MESABI IRON RANGE

Field trip leaders:

F. D. Effinger, Pickands Mather & Company

J. W. Emanuelson, Reserve Mining Company

C. L. Iverson, Oliver Iron Mining Division

Richard Strong, Oliver Iron Mining Division

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REFINEMENT OF THE HEMATITE CRYSTAL STRUCTURE

R. L. Blake^{1/}, T. Z. Zoltai^{2/}, and R. E. Hessevick^{1/}

The crystal structure of hematite has been refined as an initial phase of studies involving atomic positions and vacancies in hematite during reduction to magnetite. Three-dimensional diffraction intensities were collected on a spherical single crystal of hematite with both manual and automated Buerger single crystal diffractometer. The structure has been refined with a least squares program and the final structure gave an R factor of 7.1 percent. The structure model of Pauling and Hendricks has been confirmed with essentially no change in the iron coordinates and approximately a 5 percent change in the oxygen coordinates. The interatomic distances and bond angles were also calculated.

^{1/} Minneapolis Metallurgy Research Center, Bureau of Mines

^{2/} Department of Geology & Geophysics, University of Minnesota

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ORIENTED LAKES IN NORTHERN ALASKA

C. E. Carson
University of Minnesota, Duluth

Study of numerous thaw-lakes in the permafrost of the Arctic Coastal Plain has revealed that basin shape and orientation is controlled by wind-driven waves and currents with associated thermal effects.

The lakes range in size from mere puddles to basins 8 or 9 miles long, and all possess a similar basin morphology. This morphology consists of wide sub-littoral shelves and bars on the east and west sides, with the deeper central basin extending uninterrupted to the north and south ends. The basins are elongated in a north-south direction, and have length-width ratios ranging from 1 to 5.1. Few basins are over 8 feet deep. In the Point Barrow area, most basins taper toward the north.

Analysis of wind data from the Barrow weather station has revealed that summer winds are bimodal, being either easterly or westerly, average some 15 m.p.h., and are remarkably steady from one direction for several days at a time. Their average directions are nearly perpendicular to the axes of orientation. Investigation has shown that wind-driven wave action on the east and west sides, and the presence of circulation cells in the north and south ends, has produced the characteristic basin morphology; therefore, orientation.

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CLAY MINERALOGY OF THE DECORAH SHALE, MINNESOTA

Cyril M. Gallick
University of Minnesota, Minneapolis

The Middle Ordovician Decorah Shale is exposed sporadically in a 20-mile wide band, extending from St. Paul to the southwestern corner of Houston County. It is a green-gray or less commonly a blue-gray shale that contains thin (generally 0.1 to 0.2 foot) interbeds and lenses of limestone and coquina. The limestone layers are widely separated in the basal 10 to 20 feet, but increase in number irregularly upwards. In the middle of the formation, there are two or more zones, 3 to 5 feet thick, which contain limestone beds separated by less than 0.4 feet of shale; near the top, the limestone beds become thicker and more widely separated. A few of the uppermost beds are one to two feet thick. The formation is 89 feet thick at St. Paul and thins progressively to 25 feet at the Minnesota-Iowa border.

The minerals in the grade size less than $1/512$ mm were determined with the X-ray diffractometer to be: "illite" (a 10\AA layered silicate with interlayers of a 14\AA mineral), kaolinite, orthoclase, and calcite. Where all minerals are present, peak intensities indicate that orthoclase and illite predominate. The material sized greater than $1/512$ mm is mostly fossil hash and rare quartz grains. At St. Paul, illite and orthoclase are present throughout the formation, apparently in constant proportions; kaolinite and calcite are sparse in the basal part but occur in significant amounts in the middle and upper part of the section. At Rochester, the basal shale contains illite, orthoclase, and calcite in proportions similar to that in the upper part of the St. Paul section and sparse kaolinite; the middle shales consist entirely of illite; beds in the upper part contain either kaolinite or orthoclase or both, but apparently only in minor amounts. The orthoclase in the Decorah Shale has been presumed to be the result of authigenesis.

All illite (001) peaks on the diffractometer from the St. Paul section and from the basal part of the Rochester section are very asymmetrical, extending from 9.8\AA to slightly more than 14\AA , possibly indicating a considerable amount of interlayer 14\AA mineral in the structure. In the middle and upper parts of the Rochester section, the illite (001) peaks are nearly symmetrical.

X-ray analysis of a shale which had been weathered for possibly more than five years showed only a change of the illite (001) peak. This peak was lower in relation to the (002) illite peak, broader and much more asymmetrical than that of any other shale analyzed. It extended from 9.8\AA to a little more than 17\AA .

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THE THERMAL METAMORPHIC EFFECT OF THE DULUTH GABBRO
UPON THE SNOWBANK GRANITE

G. N. Hanson, W. C. Phinney, and P. W. Gast
University of Minnesota, Minneapolis, Minnesota

The effect of the thermal metamorphism of the 1.0 billion-year Duluth Gabbro on the 2.5 billion-year Snowbank Granite can be seen in the changes of the Rb-Sr ages of the biotites and the changes in the degree of triclinicity of the potassium feldspar in the granite. In both cases, the transition zones parallel the granite-gabbro contact.

Biotites from the granite within 2.0 kilometers of the contact (map distance) have Rb-Sr ages of less than 1.2 billion years. At distances greater than 2.0 kilometers, the successive biotite ages increase regularly to 2.55 billion years. The change in the ages exhibited by the biotite is shown to result from the loss of radiogenic strontium from the biotite structure. The mechanism for this loss is assumed to be either recrystallization of the biotite structure or volume diffusion of the radiogenic strontium out of the structure. By a trial and error process of fitting theoretical curves to the data, an activation energy of about 50 kilocalories for recrystallization by a zero-order rate process and an activation energy of 85 kilocalories for volume diffusion are proposed.

Potassium feldspars at distances greater than 2.0 kilometers from the contact are maximum microcline (maximum triclinicity) as determined by measurement of the $131\text{-}\bar{1}\bar{3}1$ spacing by x-ray diffraction. Within 2.0 kilometers of the contact, the potassium feldspars are primarily orthoclase (monoclinic feldspar) except for several samples near the contact which show mixed orthoclase and microcline.

The albite content of the potassium feldspar tends to be only a function of the facies of the stock and ranges from Or59-Or96.

The above data raise several questions which as yet are unanswered:

- (1) Why is microcline the potassium feldspar at distances greater than 2.0 kilometers? Could this be explained by regional metamorphism of the stock during the Algoman orogeny about 2.5 billion years ago?
- (2) Why did the potassium feldspar within 2.0 kilometers of the contact change to orthoclase upon thermal metamorphism by the gabbro and then not revert back to microcline upon cooling? Could this be a result of a lowering of water pressure in the stock at the time of the intrusion of the gabbro?

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CONTROL BY PRECAMBRIAN BASEMENT STRUCTURE OF THE LOCATION OF
THE TENSLEEP-BEAVER CREEK FAULT, BIGHORN MOUNTAINS, WYOMING

Richard A. Hoppin - University of Iowa, Iowa City, Iowa
John C. Palmquist - Monmouth College, Monmouth, Illinois
Lyman O. Williams - The California Company, Pensacola, Florida

The Tensleep-Beaver Creek Fault (Laramide in age) is a high angle fault, 32 miles in length, trending E-W across the Bighorn Mountains. The north side has moved up a maximum of 1350' in the axial portion of the range. The fault is a major transcurrent fracture but is the only such feature presently known that crosses the whole range. Why the fault formed and has this trend, has been a puzzle. This investigation was restricted to the eastern 12 miles along which the Precambrian rocks are exposed. The Precambrian rocks were examined to see if there was any structural anisotropy that might have been responsible for the localization of the fault.

Two strong foliations were discovered. One is best developed near the fault. This foliation varies from N.80°E. to N.80°W. in strike and dips 50° to 70°N. Several zones of pervasive foliation up to 300 feet wide were mapped. As one goes north away from the fault, the foliation is less well developed although local zones of a few inches to five feet in width are present. In the field, the foliation looks like closely spaced shear surfaces; however, thin sections indicate complete recrystallization except for occasional deformed relict plagioclase augen. Later, pegmatitic masses cut this foliation. In the fault zone, these foliated rocks, and the sedimentary rocks, are brecciated and crushed. Quartz veins and quartz cementation are characteristic. The crushed zone is only about 50 feet wide.

The second foliation trends N.50°-65°W. and dips 60° to 70°NE. This foliation is dominant to the north of the fault but is absent near the fault. It is also the main foliation in the Horn area south of the fault. This fabric is also completely recrystallized with only a few relict deformed plagioclases. Later, zones of crushing, mylonitization and quartz veining have this trend. A particularly strong cataclastic zone is followed by a straight portion of the valley of the North Fork of Powder River. This same zone continues southeast into the fault and is probably responsible for a small deflection of the fault.

It seems reasonable, therefore, that the Tensleep-Beaver Creek fault was formed along an E-W zone of pervasive foliation and deflected in one area along another zone of northwesterly foliation. These foliations were formed under deep-seated conditions of plastic deformation followed by recrystallization. The later deformation during the Laramide took place at shallow depth and was of a brittle nature.

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THE RELATIONSHIPS BETWEEN THE DULUTH GABBRO AND THE DIKES
AND SILLS NEAR HOVLAND, MINNESOTA

Norris W. Jones
University of Minnesota, Minneapolis, Minnesota

It is tentatively concluded from reconnaissance geologic mapping in the vicinity of Hovland, Cook County, that the Duluth gabbro complex does not extend as far eastward as Lake Superior, as suggested earlier by Grout and others (1959). Instead, the gabbro appears to terminate at the Brule River. The mafic rocks along the shore that previously were called Duluth gabbro are the lower part of the Hovland diabase sill. Three other diabase or gabbro units are recognized in the area.

Petrographic and x-ray studies show systematic changes in the Hovland sill. Silica, alkalis, and iron gradually increase upward from the base. As in the Skaergaard intrusion of East Greenland, an olivine gap is present and the two pyroxene boundary is crossed. The compositional changes are inferred to indicate that the sill formed by crystal fractionation.

The relations of the intrusive units in the area can be explained as the result of emplacement of Logan intrusives, followed by intrusion of the Duluth gabbro complex. The Logan intrusives were emplaced along a dominantly northeast-trending fracture system, whereas the Duluth gabbro complex in this area strikes essentially east-west. The Hovland area represents the intersection of these two major structural trends.

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CARBONATE MINERALS IN THE IRON-FORMATION AND THEIR SIGNIFICANCE

Gene L. LaBerge
University of Wisconsin, Madison, Wisconsin

To allow more rapid identification, a staining technique was used in studying the carbonate minerals in the iron-formation. The procedure is outlined in an article by Warne in the Jour. of Sed. Pet., March, 1962. In addition to simplifying the identification of the carbonate species, the stain showed beautifully the relationship of the various carbonates to one another, and the association of particular carbonate species with certain other minerals.

Some generalizations to which there certainly are many exceptions which may be made, are as follows: Most of the siderite is primary material. The extremely fine-grained carbonate which comprises up to 75 per cent of some slaty layers in the iron-formation is almost certainly primary. This material is siderite and/or very iron-rich ankerite. Textures indicate that the siderite granules, which are not uncommon, are probably primary. Unquestionably, secondary siderite is not common.

In contrast, most of the ankerite, ferroandolomite, and dolomite are secondary. Much of this secondary carbonate is probably a by-product of the decomposition of the iron-rich ankerite to form magnetite, with which it is usually associated. However, primary ankeritic carbonate in both the slaty material and in granules does occur.

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STRUCTURE AND STRATIGRAPHY OF THE UPPER KEWEENAWAN
ROCKS IN NORTHWESTERN WISCONSIN

George Moerlein
Bear Creek Mining Company, Anchorage, Alaska

Between the summer of 1955 and the winter of 1960, Bear Creek Mining Company explored the western tip of the Lake Superior Syncline in quest of possible copper-bearing Nonesuch formation. The area covered includes portions of Ashland, Bayfield, Douglas, Washburn, and Burnett Counties, Wisconsin. Field mapping, extensive magnetic and gravity surveys, some refraction seismic work, and diamond drilling each played a part in outlining the geology of the area.

The normal sequence of Keweenawan sediments, Copper Harbour, Nonesuch, and Freda formations was recognized, and the stratigraphy of each formation will be discussed.

The structure of the area is essentially that shown on the 1948 edition of the Geologic Map of Wisconsin, a northeast plunging syncline. This, however, is locally complicated by faults of major importance.

Evidence will be presented which indicates that the formation of the Lake Superior Syncline, at least in Wisconsin, began in very late Keweenawan time.

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THE STRATIGRAPHY AND STRUCTURE OF THE ROVE FORMATION,
GUNFLINT LAKE AREA, MINNESOTA

G. B. Morey
University of Minnesota, Minneapolis, Minnesota

Geologic mapping of Animikie Group rocks in the South Lake Quadrangle, near Gunflint Lake in Cook County, was completed in 1962. The area is on the north limb of the Lake Superior structural basin; accordingly, the strata strike eastward and dip consistently five to 15 degrees south, except adjacent to the Duluth Complex where the dips increase to as much as 65 degrees.

The Rove Formation overlies the Gunflint Iron Formation, apparently conformably, and is truncated by the Duluth Complex; approximately 1,800 feet of Rove are exposed. The formation consists of two recognizable lithologic units. The lower unit, about 400 feet thick, consists mainly of a black, very fine-grained, thin-bedded or fissile argillite with abundant graphitic or carbonaceous material and pyrrhotite, interbedded with lesser amounts of gray, medium-grained, massive graywacke. Calcareous concretions are locally abundant. The upper unit, about 1,400 feet thick, consists of interbedded argillites, graywackes, and quartzites; the latter two rock types become more abundant upward in the section.

Graded bedding, sole marks, intraformational argillite fragments, convolute and small-scale cross-laminations and clastic dikes suggest a subaqueous flow origin for much of the upper unit. A south-southwestward movement of material is suggested by many of these structures.

The Animikie Group rocks contain several east-trending sill-like bodies, mainly of diabasic gabbro, which range from less than 100 to more than 1,000 feet in thickness. The sedimentary rocks adjacent to the sills are metamorphosed to mineral assemblages characteristic of the hornblende-hornfels facies. The sills are correlated with the Logan Intrusives; they are older than and are truncated by the Duluth Complex.

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THE APPLICATION OF
TREND SURFACE ANALYSIS TO THE WHITE PINE COPPER DISTRICT

S. C. Nordeng¹, C. O. Ensign, Jr.², M. E. Volin³

Over one hundred sets of drill hole data were taken from the files of the White Pine Company and coded on IBM cards. The section was divided into upper and lower halves and linear, quadratic and cubic surfaces of best fit were computed for each half for average copper percentage, thickness, and ounces of silver per ton, utilizing a taped multiple regression program on a medium speed digital computer.

The linear surface for the upper half accounted for one-half or better of the departures from the mean and showed slight improvement for higher order surfaces, suggesting that the trends of the quantities under consideration are essentially planar in nature. The best fit was found for copper, the poorest for silver. The surfaces show an increase in thickness to the north and northeast, and in copper content to the southeast.

The lower section showed maximum improvement in the sum of squares for the cubic model for both percent copper and thickness. Maps of the cubic surfaces successfully predict the location of a known ore body for which no data was entered in the program. Departures of observed values from computed values for the lower half are interpreted as resulting from relative thickening and thinning of the upper part of the lower section which is relatively barren, and the lower part of the lower section in which most of the ore is found.

1

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STRUCTURE WITHIN THE DULUTH GABBRO COMPLEX, GABBRO LAKE AND
GREENWOOD LAKE QUADRANGLES, LAKE COUNTY, MINNESOTA

William C. Phinney
University of Minnesota, Minneapolis, Minnesota

Mapping and petrologic studies of the Duluth gabbro complex in the Gabbro Lake and Greenwood Lake quadrangles during the summers of 1961 and 1962 have indicated a complex series of gabbroic intrusions associated with anti-form and basin-like structures. A major intrusion in the southeast quarter of the Gabbro Lake quadrangle and the north-central part of the Greenwood Lake quadrangle is roughly elliptical in plan, has a long axis of at least nine miles, and is inferred to be cone-shaped. It intrudes anorthositic gabbro and has concentric layers that dip nearly vertical at the border and nearly horizontal at the center. Regular variation in mineral assemblages from olivine rich at the border to pyroxene-rich at the center indicate a normal differentiation sequence. Numerous smaller gabbroic intrusions as well as zones of intrusions have been mapped.

Olivine gabbro with well defined layers having graded olivine concentrations in rhythmic succession forms a broad, shallow basin in the southwest quarter of the Gabbro Lake quadrangle. Within the basin, there are many anorthosite lenses that contain numerous one- to two-inch patches of olivine, apparently concentrated from the interstitial fluid. The eastern boundary of the basin is in sharp contact (apparently intrusive) with the anorthositic gabbro intruded by the cone-like intrusive mentioned above. The relative ages of the cone-like gabbro intrusion and basin-shaped gabbro intrusion are not known.

Southeast of Gabbro Lake, a marker zone in the gabbro can be traced around an antiformal structure that is elongated subparallel to the basal contact of the gabbro and has an anorthositic gabbro core. In the same area, a very coarse-grained pyroxene- and ilmenite-magnetite-rich dike, that is as much as one-fourth mile wide, can be traced for several miles.

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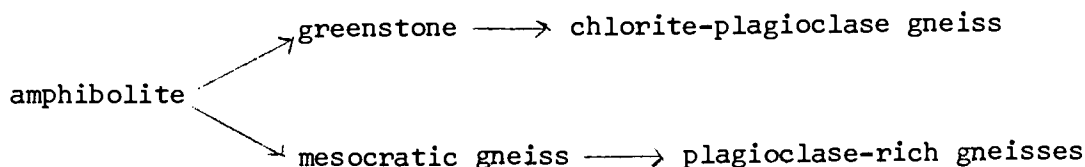
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PRELIMINARY INVESTIGATION OF A PORTION OF THE
NORTHERN COMPLEX, BARAGA COUNTY, MICHIGAN

D. W. Pollock and S. C. Nordeng
Michigan College of Mining and Technology, Houghton, Michigan

During the summer of 1962, the writers initiated a study of a portion of the "Northern Complex" which lies in Baraga County, Michigan. Some results of this study are reported herein.

Several lithologic groups have been mapped. These are: (1) amphibolite; (2) greenstone; (3) mesocratic gneisses and (4) plagioclase-rich gneisses. Each of these groups can be subdivided into more specific varieties. The groups occur in definite belts and the following gradations were observed in the field:



A thin "infolded" belt of Michigamme (?) phyllite has been located west of Clear Lake in Sec. 14, R 49 N, R 32 W.

The broad structural trend is an arc, convex to the west. In detail, the structure is more complex. Poles to foliation (W 5 diagrams) were plotted, but with poor results. The most useful approach was to outline the structure on the basis of vertical foliation trends. The origin of the foliation remains in doubt as the origin of the rocks is not yet known. Mesoscopic lineation is only feebly developed.

Investigation of some of the many problems raised during this study is continuing.

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SUSCEPTIBILITY MEASUREMENTS OF EMPIRE MINE MAGNETIC MATERIAL

E. Richard Randolph
Cleveland Cliffs Iron Company, Ishpeming, Michigan

The Negaunee Iron-Formation at the Empire Mine on the Marquette Range in Michigan consists, briefly, of magnetic cherty iron-formation, magnetic cherty carbonate iron-formation, magnetic cherty silicate iron-formation and a hanging wall member containing many large clastic facies interbedded with the precipitate iron-formation.

The common criterion for grading ore at the mine is on the basis of per cent weight recovery. The ore type which presents the greatest problem in grade control is the clastic facies of the iron-formation which can vary in weight recovery from 10% to 41%. It is very difficult to distinguish rich, moderate and poor clastic ore material by macroscopic means. Close order magnetometer surveying is an aid to localizing large zones, but a more definitive procedure is desirable for day-to-day control. It was suggested that susceptibility measurements on the cuttings from blast hole drilling might indicate the grade of the ore in that hole more cheaply and reliably than crude Fe analyses or streamlined Davis tube testing.

Susceptibility is the ratio of the intensity of magnetization acquired by a substance to the strength of the magnetizing field acting on the body. In a rock containing magnetite as the principal magnetizable constituent, susceptibility is, for practical purposes, the measure of the amount of magnetite present. Because per cent weight recovery of magnetite is the criterion for the cut-offs between rock, lean ore and ore in the hanging wall clastic zone, a program relating susceptibility measurements to per cent weight recovery was started.

The conclusions are as predicted: measurements show a broad range of values for the general area but within a limited area correlate sufficiently well to offer a rapid, cheap, reliable method for sampling blast hole cuttings for grade control.

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BIOGEOCHEMISTRY OF MINNESOTA LAKES: CARBOHYDRATES

M. A. Rogers
University of Minnesota, Minneapolis

Fossil carbohydrates have been found in typical sedimentary rocks; carbonaceous organic rocks such as peat, coal and lignite; fossilized wood; insect remains; modern lake sediments; modern and ancient marine sediments; and in lake waters. Carbohydrate materials were studied in the aquatic plants, lake waters and lake sediments of two eutrophic-alkalitrophic lakes of central Minnesota. Both free sedimentary sugars and sugars liberated on hydrolysis were recovered.

Glucose, galactose, xylose and arabinose are the dominant sugars in order of decreasing abundance in aquatic plants of the two lakes. Maxima and minima in these sugars, as well as in the content of cellulose and hemicellulose, show little relation to season of collection and appear to be characteristic of individual plant species.

Acid hydrolysis of lake bottom sediments recovered the eight sugars, arabinose, xylose, galactose, glucuronic acid, glucose, rhamnose, mannose and ribose, in concentrations ranging from 19.1 to 0.1 mg/gm of dry wt. sediment. The variety and amount of these sugars is believed to demonstrate the importance of microorganisms in altering the carbohydrate fraction prior to stabilization and preservation within the sediment.

Acid hydrolysis of lake sediments from a deep core from Blue Lake, Minnesota, recovered in order of decreasing abundance the eight sugars, xylose, glucose, arabinose, galactose, mannose, rhamnose, ribose and glucuronic acid.

A natural stability series for carbohydrates in the lacustrine environment is: fairly stable: xylose, glucose, rhamnose, arabinose; moderately stable: ribose, mannose; fairly unstable: galactose; very unstable: glucuronic acid.

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GEOLOGIC INTERPRETATION OF AEROMAGNETIC ANOMALIES OVER PRE-
KEWEENAWAN ROCKS IN CENTRAL MINNESOTA

P. K. Sims, Minnesota Geological Survey, Minneapolis, Minnesota
Isidore Zietz, U. S. Geological Survey, Washington, D. C.

An aeromagnetic survey completed by the U. S. Geological Survey in 1961 has clarified our knowledge of the Pre-Keweenawan rocks in an area of about 3,000 square miles in central Minnesota, extending from the latitude of Little Falls, in Morrison County, south to the vicinity of Gaylord, in Sibley County. In the northern part of the area, sources of the anomalies have been identified from scattered outcrops and separate rock units have been extended, based on geologic considerations and magnetic data.

The aeromagnetic data indicate that the igneous rocks of the Penokean orogeny (Woyski, 1949), which have been quarried extensively for building and monumental stone in a broad area centered at St. Cloud, extend in the subsurface south at least to latitude $45^{\circ}15'$ N. and eastward beneath overlapping upper Keweenawan sedimentary rocks. Northwestward from St. Cloud, schist appears to be the dominant bedrock.

In the southern part of the area, outcrops are lacking and interpretation of the magnetic patterns is more equivocal. Except for an anomaly at Lake Washington in Meeker County, which probably is above igneous rocks of intermediate or mafic composition, interpretation of the magnetic anomalies is not attempted. South of Hutchinson, a change in the trend of the basement rock, as indicated by the magnetic pattern, suggests a marked discontinuity, possibly a fault or an unconformity, in the Pre-Keweenawan rocks at this latitude.

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STRUCTURES OF CONCRETIONS IN THE THOMSON FORMATION
CARLTON AND PINE COUNTIES, MINNESOTA

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Calcareous concretions in the Thomson Formation found in the vicinity of Carlton are of two types. The concretions in graywacke and graywacke-slate beds consist of massive calcite, are ellipsoidal, and lack a distinctive internal structure other than bedding, which conforms to the enclosing rock. Those in finer-grained slate beds are zoned; they contain an inner core of slaty material, surrounded by well-crystallized calcite or by quartz with sutured grain boundaries. The outer zone has a pseudo cone-in-cone structure, defined by bands of slaty material. The calcite in both types of concretions replaces quartz and feldspar.

The zoned concretions on the limbs of folds in the slate and graywacke succession are rotated out of the plane of bedding. The c axis of the calcite in the pseudo cone-in-cone structures is oriented parallel to the direction of maximum compression and a cleavage, which is well developed, parallels shear directions. These features afford a promising means for further study of structural relations in the formation.

Remnants of concretions are found in the more intensely metamorphosed phases of the Thomson Formation southwest of Carlton, in phyllite, metagraywacke, and mica schist. Quartz has replaced the calcite in phyllite. Well-zoned concretions occur in the metagraywacke. The outer zones of these consist principally of hornblende, garnet, quartz, and andesine; the cores contain mainly epidote, quartz and andesine. Sections of the cores show that they are deformed into boudins. They also contain characteristic S-shaped structures formed by shearing and defined by heavy mineral concentrations. Structures similar to these occur in the slate and phyllite. These similarities indicate that further sampling may show that the concretions can be used as stratigraphic marker beds in the Thomson Formation.

Remnant calcite is found in the concretions in the mica schist, metagraywacke and phyllite. The (211) spacing of the calcite ranges from 3.04 angstroms in the slate to 3.02 angstroms in the schists, indicating the occurrence of relatively pure calcite (less than 5 percent Fe, Mg) throughout the entire formation. Plagioclase coexisting with calcite ranges from An_5 in the slate and graywacke to An_{40} in the mica schist and metagraywacke.

It has been found that radiographs afford a practical method for studying the internal structures of the concretions. Fluorescence excited by electron bombardment provides a mean of distinguishing calcite from dolomite.

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BURIED EXTENSION OF THE KEWEENAWAN BASIN IN MINNESOTA - A
GEOPHYSICAL STUDY

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Approximately 30,000 linear traverse miles have been flown aeromagnetically by the U. S. Geological Survey across the "mid-continent gravity high". This is, perhaps, the most outstanding gravity feature in the United States, extending from near Lake Superior in a southwesterly direction to the Salina basin in Kansas. Coupled with the gravity measurements and meager drill hole records, the aeromagnetic data strongly, if not unequivocally, imply the existence of a several-mile-thick accumulation of Keweenawan lava flows, extending uninterruptedly for 800 miles, flanked by Pre-Cambrian sandstones which locally may be more than a mile thick. Total thicknesses of lava flows and neighboring sandstone can be estimated from the gravity data, whereas the aeromagnetic data supply the details of the configuration of the upper surface of the flows. In Minnesota, the magnetic data clearly outline the Twin Cities artesian basin, an elliptical trough 60 miles long in a northeast direction and 30 to 35 miles wide. At the eastern margin of the basin and north of latitude $44^{\circ}35'$ N., the magnetic data suggest that the basin is bounded by a narrow northeast-trending horst of mafic volcanic rocks, probably elevated at least 1,000 feet above the adjacent rocks. The horst is the basement manifestation of the Hudson-Afton anticline, a northeast-trending Paleozoic fold. In southern Minnesota, south of latitude $44^{\circ}15'$ N., the mafic lavas are at considerable depths, but the surface of the flows rises to within 1,500 feet at the Iowa border.

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LAKE SUPERIOR CORES AND BOTTOM TOPOGRAPHY

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Cores were recovered from eleven drill holes in water depths of 500 to 1,130 feet in Lake Superior in 1961 and 1962. A shipboard, rotary drilling rig was used to penetrate the unconsolidated Pleistocene sediments and to locate the bedrock surface. The sediments were recovered by gravity and piston coring -- continuously in the upper 30 feet and intermittently below that depth.

The longest core penetrated 686 feet of sediments without reaching bedrock, and it shows at least four alternations of glaciolacustrine sediments and red, clayey till. The other cores penetrated only 47 to 156 feet and the typical sequence was gray, lacustrine clay (lower part varved), red lacustrine clay (some varved), and red clay till. Below the till, well-washed sand (outwash?) was found in three holes, and in four other holes red and white (Cambrian?) sandstone was reached.

A sub-bottom depth recorder was used in combination with the drill logs for the interpretation of stratigraphy and sub-bottom topography. Near the Minnesota coast, more than 700 feet of drift lies in a broad bedrock valley. In the eastern part of the basin, strong north-south trending valley-and-ridge topography appears to be a submerged, glacially modified stream system, rather thinly covered with glacial drift. Also, the possibility of strong east-west faults between Keweenaw Peninsula and Sault Ste. Marie is indicated.