

SIXTH ANNUAL MEETING
INSTITUTE ON LAKE SUPERIOR GEOLOGY

April 14 - 15, 1960

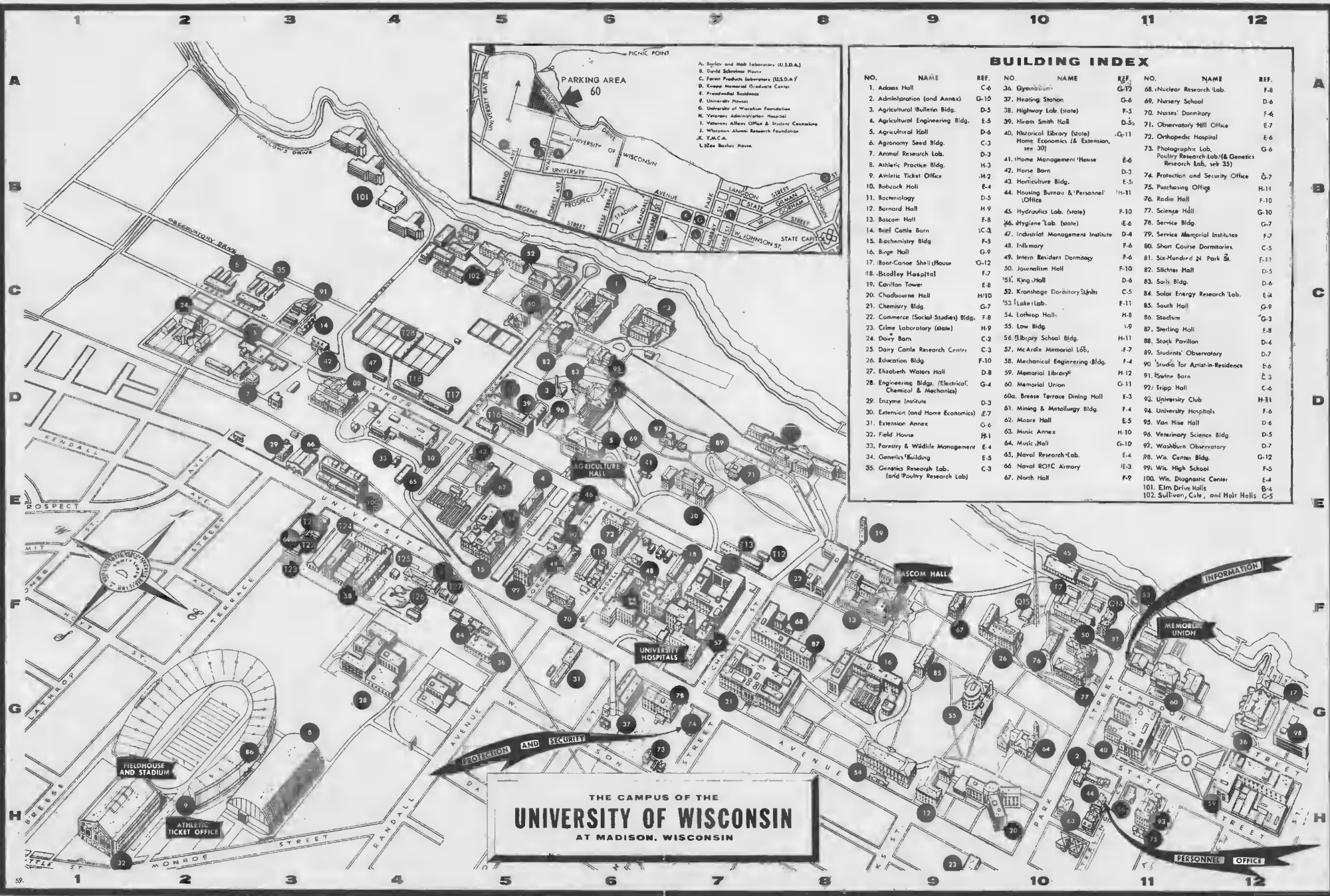
UNIVERSITY OF WISCONSIN
Department of Geology
and
WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY
Madison 6, Wisconsin

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B. David Schrieber House
C. Forest Products Laboratory (U.S.D.A.)
D. Kropf Memorial Graduate Center
E. University House
F. University of Wisconsin Foundation
G. Veterans Administration Hospital
H. Veterans Affairs Office & Student Counselors
I. Wisconsin Alumni Research Foundation
J. Y.M.C.A.
L. See Barker House

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THE CAMPUS OF THE
UNIVERSITY OF WISCONSIN
AT MADISON, WISCONSIN

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Department of Geology
and
WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY
Madison 6, Wisconsin

Institute on Lake Superior Geology

April 14 - 15, 1960

PROGRAM

Thursday, April 14, 1960

8:00 - 8:30 Registration - Wisconsin Center Auditorium Gallery

SESSION I**

Auditorium, Wisconsin Center

Co-Chairman: Lloyal Bacon, Josiah Royce

8:30 Call to order and welcome.....Eugene N. Cameron
8:35 Business meeting.....Ralph W. Marsden
9:00 RECENT STUDIES OF THE GUNFLINT RANGE,
ONTARIO.....Willard H. Parsons
9:20 STRUCTURE OF THE EAST GOGEBIC IRON RANGE....Thomas E. Hendrix
9:40 GEOLOGICAL INVESTIGATION SOUTHEAST OF THE PALMER AREA,
MARQUETTE DISTRICT.....Justin Zinn
10:00 Coffee Break, Snack Bar, Basement
10:30 SUBSURFACE GEOLOGIC STRUCTURE IN THE JACOBVILLE-GAY AREA
OF THE KEWEENAW PENINSULA AS INTERPRETED FROM GEOPHYSICAL
DATA.....Lloyal O. Bacon
10:50 GEOPHYSICAL INVESTIGATION IN THE WAUSAU AREA,
WISCONSIN.....John W. Allingham, Robert G. Bates
11:10 STRUCTURE OF THE EARTH'S CRUST IN WISCONSIN FROM EXPLOSION
SEISMIC OBSERVATIONS.....
.....Robert P. Meyer, J. S. Steinhart, George P. Woollard
11:30 A REGIONAL GRAVITY STUDY OF CRUSTAL STRUCTURE IN
WISCONSIN.....John W. Mack
11:50 Luncheon, Snack Bar, Wisconsin Center

SESSION II

Auditorium, Wisconsin Center

Co-Chairman: William Read, S. A. Tyler

1:00 BLACK SHALE FLYSCH FACIES OF THE OUACHITA MOUNTAINS,
SOUTHEASTERN OKLAHOMA.....Lewis M. Cline
1:20 PLEISTOCENE HISTORY OF WISCONSIN.....Robert F. Black
1:40 DIFFERENTIATION OF THE ST. CROIX AND EMERALD MORAINES IN
WEST-CENTRAL WISCONSIN.....Thomas E. Berg
2:00 A PHOTOLOGICAL STUDY OF A PART OF THE HURON MOUNTAIN
AREA OF MICHIGAN.....Richard C. Beard
2:20 Coffee Break, Snack Bar, Basement
2:50 QUANTITATIVE GEOMORPHIC ANALYSIS OF STREAM PATTERNS IN
WEST-CENTRAL WISCONSIN.....Elizabeth H. Kissling

** Five minutes for discussion are allowed after each paper throughout the program.

PROGRAM (Continued)

- 3:10 HOW MANY GRAINS SHOULD ONE COUNT IN PETROFABRIC
STUDIES?.....James Trow
- 3:30 LITHOFACIES AND BIOFACIES VARIATION IN THE PLATTEVILLE
FORMATION OF SOUTHEASTERN MINNESOTA.....Robert E. Sloan
- 3:50 GEOLOGY OF NORTHERN PART OF FLORENCE, WISCONSIN
AREA Carl E. Dutton
- 4:10 A CHANGE IN SEDIMENTARY FACIES IN THE LITTLE COMMONWEALTH
AREA, FLORENCE COUNTY, WISCONSIN.....Robert W. Johnson, Jr.
- 4:30 A LEPTOCHLORITE (?) FROM THE FLORENCE, WISCONSIN
AREA.....Gene L. LaBerge
- 6:30 Dinner, Main Dining Hall, Wisconsin Center Basement
Speaker: R. J. Anderson, Battelle Memorial Institute
Topic: "Journey into Ignorance. A Review of the Findings
of the International Geophysical Year"

Friday, April 15, 1960

SESSION III

Auditorium, Wisconsin Center

Co-Chairman: George Schwartz, Jack Everett

- 8:00 PETROGENY OF THE GRANOPHYRE AND INTERMEDIATE ROCK IN THE
DULUTH GABBRO OF NORTHERN COOK COUNTY,
MINNESOTA.....Russell C. Babcock, Jr.
- 8:20 THE SANGU CARBONATITE, KAREMA DEPRESSION, S.W. TANGANYIKA,
EAST AFRICA.....Gerrard L. Coetzee
- 8:40 PYROXENE PARAGENESIS IN A MAFIC-ULTRAMAFIC PLUTONIC
COMPLEX, BIGHORN MOUNTAINS, WYOMING.....W. C. Luth
- 9:00 ALLANITE OCCURRENCE IN THE HORN AREA, BIGHORN MOUNTAINS,
WYOMING.....K. A. Sargent
- 9:20 Coffee Break, Snack Bar, Basement
- 9:50 GEOLOGY OF THE SOUDAN MINE, NORTHEASTERN
MINNESOTA.....F. L. Klinger
- 10:10 MAGNETIC ANOMALIES AND MAGNETIZATION OF MAIN MESABI IRON-
FORMATION.....Gordon D. Bath, George M. Schwartz
- 10:30 MAGNETIZATIONS OF IRON-FORMATIONS AND IGNEOUS ROCKS OF
NORTHERN MINNESOTA.....Charles E. Jahren
- 10:50 THE OCCURRENCE OF CARBONATES OTHER THAN IRON AT DEPTH IN
LAKE SUPERIOR IRON FORMATIONS.....J. Royce
- 11:10 THE STRATIGRAPHY AND STRUCTURE OF THE MCCASLIN QUARTZITE
REGION OF NORTHEASTERN WISCONSIN.....Joseph J. Mancuso
- 11:30 INCREASING THE RESOLVING POWER OF GRAVITY AND MAGNETIC
OBSERVATIONS.....William J. Hinze
- 11:50 GEOLOGIC INTERPRETATION OF AIRBORNE MAGNETOMETER PROFILES
ACROSS LAKE SUPERIOR.....Edward Thiel
- 12:10 IRON DEPOSITS IN GABON, EQUATORIAL AFRICA.....Gilbert L. Hole

SPEAKERS

JOHN W. ALLINGHAM.....Geologist, U. S. Geological Survey,
Washington, D. C.

RUSSELL C. BABCOCK, Jr.....Geologist, Bear Creek Mining Company,
Aurora, Minnesota

LLOYAL O. BACON.....Associate Professor, Michigan College of
Mining and Technology, Houghton, Michigan

ROBERT G. BATES.....U. S. Geological Survey, Washington, D. C.

GORDON D. BATH.....U. S. Geological Survey,
Menlo Park, California

RICHARD C. BEARD.....Pickands Mather and Company, Duluth, Minnesota

THOMAS E. BERG.....Graduate Student, Department of Geology,
University of Wisconsin, Madison, Wisconsin

ROBERT F. BLACK.....Professor, Department of Geology, University
of Wisconsin, Madison, Wisconsin

LEWIS M. CLINE.....Professor, Department of Geology, University
of Wisconsin, Madison, Wisconsin

GERRARD L. COETZEE.....Graduate Student, Department of Geology,
University of Wisconsin, Madison, Wisconsin

CARL E. DUTTON.....Regional Geologist, U. S. Geological Survey,
Madison, Wisconsin

THOMAS E. HENDRIX.....Department of Geology, Indiana University,
Bloomington, Indiana

WILLIAM J. HINZE.....Assistant Professor, Michigan State University,
East Lansing, Michigan

GILBERT L. HOLE.....Geologist, Bethlehem Steel Company,
Bethlehem, Pennsylvania

CHARLES E. JAHREN.....Physicist, U. S. Geological Survey,
Austin, Minnesota

ROBERT W. JOHNSON, JR.....Geologist, U. S. Geological Survey,
Knoxville, Tennessee

ELIZABETH H. KISSLING.....Graduate Student, Department of Geology,
University of Wisconsin, Madison, Wisconsin

FREDERICK L. KLINGER.....Geologist, Oliver Iron Mining Division,
U. S. Steel Corporation, Virginia, Minnesota

GENE L. LABERGE.....Graduate Student, Department of Geology,
University of Wisconsin, Madison, Wisconsin

WILLIAM C. LUTH.....Graduate Student, Department of Geology, State
University of Iowa, Iowa City, Iowa

JOHN W. MACK.....Graduate Student, Department of Geology,
University of Wisconsin, Madison, Wisconsin

JOSEPH J. MANCUSO.....Graduate Student, Department of Geology,
Michigan State University, East Lansing,
Michigan

ROBERT P. MEYER.....Assistant Professor, Department of Geology
University of Wisconsin, Madison, Wisconsin

WILLARD H. PARSONS.....Professor and Chairman, Department of Geology,
Wayne State University, Detroit, Michigan

JOSIAH ROYCE.....Pickands Mather and Company, Duluth, Minnesota

KENNETH A. SARGENT.....Graduate Student, Department of Geology, State
University of Iowa, Iowa City, Iowa

SPEAKERS (Continued)

GEORGE M. SCHWARTZ.....Director, Minnesota Geological Survey,
Minneapolis, Minnesota

ROBERT E. SLOAN.....Assistant Professor, Department of Geology,
University of Minnesota, Minneapolis,
Minnesota

JOHN S. STEINHART.....Graduate Student, Department of Geology,
University of Wisconsin, Madison, Wisconsin

EDWARD G. THIEL.....Project Associate, Department of Geology,
University of Wisconsin, Madison, Wisconsin

JAMES TROW.....Professor, Department of Geology, Michigan
State University, East Lansing, Michigan

GEORGE P. WOOLLARD.....Professor, Department of Geology, University
of Wisconsin, Madison, Wisconsin

JUSTIN ZINN.....Professor, Department of Geology, Michigan
State University, East Lansing, Michigan

RECENT STUDIES OF THE GUNFLINT RANGE, ONTARIO

Willard H. Parsons
Wayne State University, Detroit, Michigan

The Gunflint iron-formation is located in Ontario north of Lake Superior. The range trends southwestward from near Port Arthur to the Minnesota boundary. Throughout most of its length the Gunflint is largely a carbonate iron-formation, but the western third carries appreciable quantities of magnetite and hematite. In this part of the range there are immense tonnages of low grade taconite. A number of studies have been carried out in recent years as to the economic possibilities of this taconite. Much of the earlier exploration has been confined to the lower Gunflint formation. The present investigation suggests that the upper Gunflint carries a higher concentration of magnetite. Magnetic tube tests of the upper 200 feet indicate that a concentrate carrying 58-60 per cent iron can be obtained, although it is somewhat high in silica (12-14 per cent).

STRUCTURE OF THE EAST GOGEBIC IRON RANGE

T. E. Hendrix

Department of Geology, Indiana University, Bloomington, Indiana

Structural analysis of the major and minor structures within the Keewatin and Huronian rocks shows there have been two periods of pre-Keweenawan deformation on the East Gogebic iron range. The older of the two deformations is post-Middle, pre-Upper Huronian in age. This deformation is local in extent and epeirogenic in nature. Fault block subsidence following outpouring of the Presque Isle volcanics has resulted in the shifting and tilting of successive blocks of Lower and Middle Huronian across an area 8 miles wide in the east half of T.47N., R.44W., and the west half of T.47N., R.43W. The subsidence was greatest towards the center of volcanism, causing part of the offset now apparent along the Presque Isle fault.

The second and more severe pre-Keweenawan deformation is post-Upper Huronian, pre-Keweenawan in age. It is regional in extent and orogenic in nature. This deformation appears to have folded also the southern iron ranges of Michigan and Wisconsin. The axis of apparent greatest principal stress is oriented northwest-southeast. The apparent intermediate principal stress axis is oriented northeast-southwest. The apparent least principal stress is essentially vertical.

The East Gogebic iron range was tilted to the north in Keweenawan time. This tilting does not appear to have extended east of Lake Gogebic because the Keweenawan flows of the southern trap ranges are practically horizontal. It is necessary, therefore, to postulate a "hinge" between the two areas. There is a suggestion, as yet unproven, that this hinge may be the southward extension of the Keweenawan thrust fault, displaced to the south by a late Keweenawan fault that now trends approximately north-south through the center of Lake Gogebic.

GEOLOGICAL INVESTIGATION SOUTHEAST OF THE PALMER AREA,
MARQUETTE DISTRICT

Justin Zinn
Michigan State University, East Lansing, Michigan

Thesis research on selected map areas southeast of Palmer during the past three years has been completed by Robert A. Vehrs, Armen Sahakian, and Richard A. Long. These studies have added some information that bears on several problems in this area, such as the questionable presence of post-Huronian granite, the nature of pre-Huronian rocks existing here, and the true nature of the Palmer gneiss. Most of the gneiss of this area is a contorted hornblende gneiss with a foliation trending mostly east-west. Its composition suggests metamorphosed basalt or andesite and it is believed to correlate with the pre-Huronian greenstones found along the north margin of the Marquette district. The gneiss is intruded by granite apophyses of possibly two ages, but most of the granite is of the pink to gray porphyritic type suggestive of Lamey's "Republic granite". Thin section studies indicate that the gneiss and at least most of the granite was sheared after their development, with some accompanying metamorphic alteration characteristic of the greenschist facies. This would indicate that the hornblende gneiss and the granite intruding it are of pre-Huronian age.

Associated with the gneiss and granite are small blocks of slate or phyllite near Palmer and a ridge of quartz rock farther southeast. The quartz rock, which looks like a quartzite ridge in the field, is actually metanovaculite and can not be correlated with any of the Huronian formations in the district. The phyllite is very similar to an argillite that occurs in pre-Huronian rocks north of the Marquette district. A pre-Huronian age for these metasedimentary rocks is suggested. Both the metanovaculite and the phyllite were intruded by granite.

This investigation failed to find any rocks of undoubted Huronian age in the gneiss area studied. Since the intruding granite itself shows shearing and crude foliations in many places along with the development of some chlorite and epidote, it appears that it was involved in the post-Huronian orogeny. Therefore this granite must be older than the Huronian. No undisputed post-Huronian granite bodies were discovered.

SUBSURFACE GEOLOGIC STRUCTURE IN THE
JACOBSTOWN-GAY AREA OF THE KEWEENAW PENINSULA
AS INTERPRETED FROM GEOPHYSICAL DATA

L. O. Bacon

Michigan College of Mining and Technology, Houghton, Michigan

Magnetic anomalies occur in the Gay-Jacobsville area of the Keweenaw Peninsula, an area composed of a thick section of Eastern or Jacobsville sandstone. Geophysical data indicate that depth to source is approximately 8,000 feet, which may be considered as probable thickness of the Jacobsville sandstone. Calculations indicate that one anomaly could be caused by material having a magnetic susceptibility of about 3000×10^{-6} cgs units which is in the range of some of the felsites and also of the basic flows of the Keweenaw Peninsula.

Spatial relationships indicate that the source of the anomaly is most likely a felsite which could then have been the southeastern source for the felsite conglomerate beds as postulated by W. S. White of the U. S. Geological Survey.

GEOPHYSICAL INVESTIGATION IN THE WAUSAU AREA, WISCONSIN

John W. Allingham and Robert G. Bates
U. S. Geological Survey, Washington, D. C.

Contacts and regional structural relations between major rock units in the Wausau area of central Wisconsin are defined by airborne geophysical data. Interpretation of data from a survey made in June 1956 shows that magnetic and radioactivity patterns can materially assist geologic mapping.

The Precambrian rocks of the Wausau area consist of a complex of volcanic and sedimentary rocks metamorphosed to the greenschist and amphibolite facies and intruded by granite and associated granophyre, and by syenite, diorite, gabbro, and diabase. Bedrock is covered by residual soil, glacial debris, and loess, and the area is now a plain of low relief except for resistant hills of quartzite.

Areas of granite, diorite, hornblende gabbro, and diabase can be delineated by distinctive aeromagnetic patterns that are directly related to the magnetite content of these rock units.

Arcuate patterns of high-amplitude magnetic anomalies are associated with skarn and intrusive diorite in the central area of red granite and in the adjoining complex of aplitic syenite. The skarn and diorite are closely associated with pendants of quartzite and chlorite schist, the distribution of which indicates that they are remnants of a large fold.

Adjacent to the red granite the structural grain of diabase dikes, hornblende gabbro, and diorite is indicated by the northeasterly trend of associated magnetic anomalies. Across the central part of the area individual diabase dikes of easterly trend can be traced for as much as 12 miles. In these dikes, which contain accessory titaniferous spinel, the remanent magnetization is reversed and is much greater than the induced magnetization, and a sharp continuous low is produced.

Well-defined medium-amplitude anomalies on radioactivity profiles clearly outline the syenite. Radioactivity lows are associated with the quartzite of Rib Mountain as well as smaller nearby quartzite beds. Rivers and swamps complicate the correlation of radioactivity units with the geology, particularly in Weston township.

The Wausau region can be divided on the basis of radioactivity and magnetic data into areas characterized by (a) high-amplitude radioactivity features and low-amplitude magnetic features, (b) medium-amplitude radioactivity and magnetic features, and (c) low-amplitude radioactivity features and high-amplitude magnetic features. These areas correspond respectively to red granite, aplitic syenite, and diorite or gabbro.

STRUCTURE OF THE EARTH'S CRUST IN WISCONSIN
FROM EXPLOSION SEISMIC OBSERVATIONS

R. P. Meyer, J. S. Steinhart, G. P. Woollard
University of Wisconsin, Madison, Wisconsin

A series of seismic observations of blasts have been made to determine crustal structure in Wisconsin. A reversed profile 300 km long extends from the Apostle Islands southeast to Wisconsin Rapids and an unreversed profile 230 km long extends from the tip of Keweenaw Peninsula southwest into Wisconsin. These results together with the earlier work by Schlichter and consideration of the gravity anomalies allow the structure and physical properties of the crust to be deduced. Velocities in the major portion of the crust are in the range 6.2 to 6.5 km/sec, and formal solutions for the depth to M discontinuity yield average depths of 36 to 38 km.

A REGIONAL GRAVITY STUDY
OF
CRUSTAL STRUCTURE IN WISCONSIN

John W. Mack
University of Wisconsin, Madison, Wisconsin

A regional gravity study of Wisconsin was conducted for the purpose of finding if gravity information would lead to a better understanding of large-scale geologic features and of crustal structure.

The data was statistically analyzed using a method developed by R. A. Haubrich (University of Wisconsin) of least squares fitting a two dimensional power series to the actual data points. A seventh degree polynomial fit of the data was assumed to be the regional effect. The residual map was formed by subtracting the regional values from the original data.

The results of the residual maps and profile lines indicate a thickening of the low density (2.67) granitic or acid igneous layer in parts of the State. The gravity picture also indicated the Moho is deeper under the central portion of the State than it is near the edges. The Mid-Continent gravity high, which extends from Lake Superior into central Kansas, may be explained by changes in mass distribution above the mantle.

BLACK SHALE FLYSCH FACIES OF THE OUACHITA MOUNTAINS,
SOUTHEASTERN OKLAHOMA

L. M. Cline

Geology Department, University of Wisconsin, Madison, Wis.

The sedimentary features of the upper Mississippian and lower Pennsylvanian Stanley-Jackfork-Johns Valley-Atoka stratigraphic sequence of the Ouachita Mountains of Oklahoma are comparable to the typical black-shale flysch facies of the Eocene and Cretaceous of the Alps and Carpathian Mountains of Europe. The conclusion is reached that a predominately deep-water black-shale and radiolarian-chert environment was periodically interrupted by turbidity currents which debouched quartzose sands derived from a nearby shelf environment. The presence of convolute bedding, graded contacts of sandstones and overlying shales, abundant flow casts, flute casts, and groove casts on the under surfaces of the sandstones, the general lack of cross-bedding and ripple marks, and the scarcity of fossils except for planktonic and nektonic forms support this thesis. The most characteristic feature of the Stanley-Jackfork sequence is the repeated alternation of unfossiliferous dark shales and gray sandstones. The boulder-bearing Johns Valley shale represents what Alpine geologists call wild flysch; most of its limestone erratics are depositional rather than tectonic in origin.

The cherts and the graptolitic shales of the lower Paleozoic represent a period of very slow sedimentation in a deep and starved arcuate trough. The 22,000 feet of post-Arkansas novaculite sediments represents a period of rapid sedimentation during active tectonism.

The Johns Valley shale lies stratigraphically above the Jackfork group, and it contains late Mississippian marine invertebrates indigenous to the lower part of the formation; thus, the entire Stanley-Jackfork sequence is pre-Pennsylvanian.

PLEISTOCENE HISTORY OF WISCONSIN

Robert F. Black
University of Wisconsin, Madison, Wisconsin

Reconnaissance in all counties in Wisconsin, local detailed studies, and radiocarbon dates on deposits of the Wisconsin stage provide data that necessitate a review of the Pleistocene history of Wisconsin. It now seems relatively certain that no Pleistocene deposits at the surface or buried are older than the Wisconsin stage, with the possible exception of some gravels assigned to the Windrow formation. According to workers outside Wisconsin, the Wisconsin stage began between 50,000 and 70,000 years ago. The earliest dated advance in Wisconsin, about 30,000 years ago, was synchronous in the Lake Michigan and Superior lobes. This advance is here designated the Rockian after the Rock River which traverses much of the area of deposition in southern Wisconsin and in Illinois. Subsequent deglaciation during the Farmdalian substage, 22,000 to 28,000 years ago according to data from Illinois, was incomplete--ice blocks remained in the deep valleys until after the readvances of the ice during Cary time in southern Wisconsin and during Valdres time in northern Wisconsin. These ice blocks subsequently produced many of our large lakes such as Mendota, Green, and Geneva in the south and Cedar, Twin, and Pelican in the north. Unfortunately, the chronology in Wisconsin of the Farmdalian deglaciation and subsequent readvances and retreats of the ice up to the Two Creeks substage 11,000 to 12,500 years ago has no support of radiocarbon dates and is imperfectly known. Permafrost was present for a time according to casts of ice-wedge polygons and to well-developed solifluction and other frost phenomena. Primitive man was in the State during Two Creeks time and possibly somewhat earlier.

DIFFERENTIATION OF THE ST. CROIX AND EMERALD MORAINES
IN WEST-CENTRAL WISCONSIN.

Thomas E. Berg
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Deposits of three distinct glacial advances of Wisconsinan age are present in west-central Wisconsin. Because of their lithologic similarity, the three drifts are distinguishable most easily on a geomorphic basis. The youngest deposit, the St. Croix moraine, trends SW-NE across the area. The main moraine is characterized by well-developed knob-and-kettle topography, unconnected drainage, numerous inwash areas, and lakes. The limit of advance is distinguished by reworked outwash, outwash channels, and thin ice-stagnation features about 4 miles in front of the main moraine.

In the northeast corner of St. Croix County outside the St. Croix moraine, slightly older drift, here named the Emerald moraine from deposits near Emerald, Wisconsin, is characterized by subdued topography, numerous boulder piles scattered over the surface, and poorly integrated drainage. Subdued kettles are present; some are filled and others have been drained. Kames are present on the uplands. The east boundary of the moraine is approximated by the drainage divide separating the Willow River from the Cedar River.

The oldest drift is distinguished by well-integrated drainage, fossil frost phenomena, absence of kettles, and a more strongly eroded topography.

The basal till in the oldest drift has been radiocarbon dated at approximately 30,000 years before the present, or late Altonian. The Emerald moraine is, therefore, tentatively assigned an Early Woodfordian age and the St. Croix moraine a Late Woodfordian age.

A PHOTOGEOLOGICAL STUDY OF
A PART OF THE HURON MOUNTAIN AREA
OF MICHIGAN

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A study was made of the uses and limitations of photo-geology in the mapping of an area of moderately thick glacial cover and relatively complex structure. A part of the Precambrian shield area of Michigan was chosen for this study and the procedure employed was one that made full utilization of aerial photographs in all three phases of geological investigation: planning, field use, and compilation.

It was found that the regional structure is quite easily interpreted from the aerial photos. It consists of several plunging folds, which were easily traced by a sharp escarpment between more resistant basement rocks and softer overlying slates.

Thin and discontinuous bands of other sedimentary rocks occur stratigraphically between the basement and the overlying slates. While not easily recognized in the photos, these bands were located by field checks concentrated along the escarpment.

Some local folding in the slate area could also be traced thru the blanket of glacial material, without any visible outcrops.

Topography and drainage reflects a prominent fracture pattern, especially in the areas underlain by basement; and where these fractures intersect contacts, the relative movement was often evident.

Numerous basic dikes, although observed in the field, show little topographic expression and are therefore not recognizable in the photos.

QUANTITATIVE GEOMORPHIC ANALYSIS OF STREAM PATTERNS IN
WEST-CENTRAL WISCONSIN

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In a quantitative study of first-order streams in west-central Wisconsin the lengths of streams, basins, and divides, the areas of the basins, the angles at which the streams enter others, and the direction of stream flow were measured in eight areas. Drainage density was calculated and the shapes of the basins analyzed. The data and the calculated quantities were tested statistically to determine whether they were normally distributed, and the groups were compared and tested for significant differences. Histograms and graphs representing the data allow no definite conclusions. Plots of the probabilities that the data for each group were normally distributed suggest the presence of three types of streams. The tests for significant differences also show three different groups, but the members of these groups do not always coincide with the members of the probability types. The results are therefore inconclusive in attempting to differentiate various ages of tills in this area.

HOW MANY GRAINS SHOULD ONE COUNT IN PETROFABRIC STUDIES?

James Trow

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In an effort to determine the minimum number of grains that one must count to achieve reliable results in a U-stage analysis of quartz orientation in the Sturgeon quartzite, the following students measured the crystallographic orientation of 2,300 quartz grains from one thin section with a maximum concentration of $3\frac{1}{2}\%$ per 1% of the area of the hemisphere of projection. The students participating in the study were David Cummings, Michael Gorycki, Martin Horowitz, David Hutchison, Roger Kirkpatrick, Thomas Manley, Richard Thompson, and James Wallace.

The observations were subdivided into 100-, 200-, and 300-grain small samples for comparison to the distribution in the total 2,300-grain sample. A chi-square test for goodness of fit showed that from 120 to 180 grains must be counted to attain the conventional 95% confidence limit of classical statistics.

LITHOFACIES AND BIOFACIES VARIATION IN THE PLATTEVILLE
FORMATION OF SOUTHEASTERN MINNESOTA

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The variation in facies of the Middle Ordovician Platteville in southeastern Minnesota is related to the major structural features of the area, the south edge of the Twin City Basin and the Red Wing-Rochester anticline, and shows that these structures were formed during the deposition of the Platteville formation. Individual beds of limestone and shale partings are traceable for distances up to 100 miles, and a precise lithostratigraphic correlation network has been established for the entire area.

The principal source for the clastic component is the landmass Siouxi to the northwest. This landmass had a maximum possible width of about 250 miles. Bottom faunas were controlled principally by bottom sediment type, and observed faunal changes are the result of changes in sedimentation. The only fossils that occur in all lithofacies are the conodonts, which are most numerous in shallow water or shoal facies. The density of conodonts per gram of limestone can be used as an important rock parameter and, when contoured, reflects the structural features of the basin.

GEOLOGY OF NORTHERN PART OF FLORENCE, WISCONSIN, AREA

Carl E. Dutton

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The northern part of the Florence area contains strata of Middle Precambrian age. The rocks strike northwesterly, are steeply inclined, and are folded and faulted.

The northernmost part of the area is underlain by iron-formation, slate, graywacke, and greenstone that are the southeastward continuation of part of the Paint River and Baraga groups of Iron County, Michigan. These strata are in a northwestward-plunging syncline, but most of the southwest limb is missing because of truncation by a fault. Rocks in this syncline are in chlorite grade of metamorphism, but those elsewhere in the northern part of the area are in biotite or garnet grade.

Another sequence is exposed southwest of the fault, and a prominent unit is quartzite with excellent cross bedding that indicates top toward the southwest. Sericitic slate is older than the quartzite; slate, graywacke, and some silicate-magnetite iron-formation are younger.

A third sequence, farther southwestward, has two thin discontinuous members of iron silicate-magnetite rock separated by gray slate that locally has graded bedding; massive and ellipsoidal greenstone is also present. This sequence is in a northwestward-plunging anticline, is probably younger than the quartzite-slate sequence, and is apparently separated from it by a fault. Somewhat similar rocks that are probably repetition of the third sequence occur to the west in what is apparently a southeastward-plunging anticline.

Between the two anticlines repetition of part of the Paint River group occurs in a southward-plunging syncline that is cut off to the south by a fault.

A few outcrops in the southwestern part of the area are sericitic slate and probably are repetition of part of the Michigamme slate of the Baraga group.

A CHANGE IN SEDIMENTARY FACIES IN THE LITTLE COMMONWEALTH
AREA, FLORENCE COUNTY, WISCONSIN

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The Little Commonwealth exploration area is underlain by highly ferruginous slate and graywacke that are closely associated with and extend about 2,000 feet beyond the southeast end of a cross-bedded vitreous quartzite. The close association of these rocks and the numerous occurrences of breccia have been attributed to faulting or erosional unconformity. These conditions may exist locally but they are of minor significance; the character and distribution of the rocks at Little Commonwealth are primarily the result of a change in sedimentary facies.

Stratigraphic equivalence of the ferruginous clastic rocks with the vitreous quartzite appears to be established by adjacent through-going older sericitic phyllite on the north and younger distinctive slate and graywacke on the south.

Strata that underlie the villages of Florence and Commonwealth are the southeastern continuation of the Paint River group of Iron County, Michigan, and are in the northeast limb of a syncline. The ferruginous rocks and vitreous quartzite are located on the apparent continuation of the southwest limb of the syncline, but direction of cross bedding refutes this possibility. The ferruginous clastic rocks in the Little Commonwealth area are not distinguishable lithologically from the ferruginous slate of the Paint River group, but structural relations suggest that the former are of pre-Paint River age and are upfaulted.

A LEPTOCHLORITE(?) FROM THE FLORENCE, WISCONSIN, AREA

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An unusual iron-rich chlorite occurs in the Huronian rocks west of Florence, Wisconsin. The principal occurrence is stratigraphically just above the quartzite at Keyes Lake. The mineral occurs locally as the almost exclusive constituent of a heavy, massive chlorite rock; however, it generally occurs as metacrysts or veins in the conglomerate, graywacke, and slate at the top of the quartzite. Its association with garnet, tourmaline, biotite, normal chlorite, magnetite, pyrite, and stilpnomelane also attest to its metamorphic origin.

Chemical analysis and thin section studies indicate that the mineral is different from other chlorites in composition and optical properties. The total iron content is about the same as for thuringite, but the ferric iron content is much higher than it would be in a normal chlorite. The birefringence and pleochroism are much more pronounced than in normal chlorites. In fact, the mineral could be mistaken in thin section for a pale green biotite.

X-ray analysis, however, gives a powder photograph that is almost identical with a thuringite from the Soudan mine at Ely, Minnesota.

PETROGENY OF THE GRANOPHYRE AND INTERMEDIATE ROCK
IN THE DULUTH GABBRO OF NORTHERN COOK COUNTY, MINNESOTA

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The relationship between the granophyre and the gabbro within the northeastern projection of the Duluth gabbro complex was studied to determine the origin of both the granophyre and the associated "intermediate" rocks. To best understand these relationships between rock types the transition from gabbro to granophyre was investigated in detail. The variation in abundance of the common minerals was determined with point counter analyses, and the sequence of mineral formation was determined on the basis of textural features. These were then related to both major and minor structural features of the complex.

The presence of two distinct rock types, gabbro and granophyre, within the northeastern projection of the Duluth complex is thought to be a result of fractional crystallization and differentiation through gravity settling and structural activity. Upon emplacement of magma, the gabbroic minerals plagioclase and pyroxene crystallized, and, owing to their greater density, accumulated in the lower portions of the magma chamber where they were knit together by continued crystallization. The liquid which remained in the interstices reacted slightly with the crystalline phase and then solidified in the form of intergrown quartz and potassium feldspar. The resulting rock is a gabbro with minor amounts of interstitial granophyre.

The essentially complete crystallization and accumulation of the gabbroic constituents caused the residual liquid to become more acidic in composition and to crystallize as a granophyre. The texture of the granophyre is the result of crystallization of intergrown quartz and potassium feldspar from the liquid surrounding scattered euhedral plagioclase crystals. The mafic minerals which are disseminated throughout this rock are fine, scattered alteration products of pyroxene crystals which formed earlier.

The intermediate rock represents the gradational separation of gabbro and granophyre. Upward from the gabbro the amount of interstitial granophyre and alteration of mafic minerals increases, forming a rock which has a diabasic texture as does the gabbro but which contains abundant interstitial granophyre. As the granophyre becomes more abundant, the corresponding decrease in gabbroic minerals causes the diabasic texture to disappear and the rock appears as a mafic granophyre.

Structural activity has complicated the expected distribution of rock types, causing amounts of granophyre to be concentrated both locally and regionally in excess of that which could have formed from fractional crystallization and gravity settling alone.

THE SANGU CARBONATITE, KAREMA DEPRESSION
SOUTHWESTERN TANGANYIKA, EAST AFRICA

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The basement rocks of the Karema Depression consist of quartzofeldspathic gneisses, amphibolites, metasediments and various intrusives that occur in a large synclinorium which plunges northwest. Patches of post-basement sediments of several ages occur in the area.

Two major subparallel faults in the Depression link the Rukwa Rift Valley on the southeast to the Great Tanganyika Rift to the west.

Three lenses of carbonate rock, all aligned on the same north-westerly trend, occur over 16 miles of strike along the northernmost fault and on the south limb of the synclinorium. These are the Sangu carbonate rocks, previously regarded as basement metasediments, but shown by detailed mapping to be discordant to the basement rocks which are locally tightly overfolded. The post-basement Ifume series sedimentary rocks are intruded by vein-dikes of the various carbonate rock types.

The carbonate rocks comprise white and red calcitic units and a dolomitic unit. These occur as narrow bands, lenses, and irregular masses that commonly trend oblique to the main body. Fine-grained feldspathic and siliceous rocks are closely associated with the carbonate rocks. "Intrusive" contacts prove the siliceous and feldspathic rocks oldest, followed by the dolomitic, the white calcitic, and then the red calcitic rocks.

Apatite and magnetite are ubiquitous in the carbonate rocks but phlogopite, tremolite, quartz, pyrite, and feldspar are common. Soda amphibole, barite, and serpentine occur in small amounts and accessories include zircon, baddeleyite, pyrochlore, rutile, titanite, chalcopyrite and fluor-apatite.

Field relationships prove that the carbonate rocks are not basement limestones. These rocks have a typical carbonatite mineralogy. The fine-grained feldspathic rocks closely resemble fenites, usually associated with carbonatites. The lack of associated undersaturated igneous rocks and the presence of fissure rather than the ring structure are unusual but not unique for carbonatites.

PYROXENE PARAGENESIS IN A MAFIC-ULTRAMAFIC
PLUTONIC COMPLEX, BIGHORN MOUNTAINS, WYOMING

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The complex that lies within the Precambrian para-(?)gneiss core of the Bighorn Mountains is 9.5 miles west of Buffalo, Wyoming, on U. S. Highway 16. It has an elongate subelliptical outcrop pattern trending N.60°E. and enclosing an area of 1.2 square miles.

The rock types of the complex may be categorized under the broad headings of peridotite, pyroxenite, norite, diorite, and amphibolite. Major constituents present in varied amounts include orthopyroxene (Ofs₁₇₋₄₈), olivine (Fa₁₂₋₂₈), diopsidic augite, pigeonite, various amphiboles (cummingtonite, actinolite, anthophyllite, and hornblende), biotite, quartz, and plagioclase. Minor constituents include chromite, magnetite-ilmenite, pyrite, and apatite. Alteration products in the ultramafic rocks characteristically are antigorite, chrysolite, serpophite, talc, magnetite, hematite, calcite, tremolite and iddingsite.

Of particular interest is the anomalous (Hess, 1941) presence of pigeonite in the coarse-grained ultramafic rocks. The intimate association of the three pyroxenes, diopsidic augite, pigeonite, and bronzite, causes very peculiar textures. Textural evidence suggests that diopsidic augite formed in part prior to, and in part contemporaneously with pigeonite and bronzite. Pigeonite-bronzite relationships are exceedingly complex and appear to result primarily from incomplete inversion of pigeonite to bronzite. The available physico-chemical data derived from the quaternary system MgO-FeO-CaO-SiO₂ also suggests the early and contemporaneous formation of diopsidic augite with respect to pigeonite, and later inversion of pigeonite to bronzite.

ALLANITE OCCURRENCE IN THE HORN AREA,
BIGHORN MOUNTAINS, WYOMING

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The Horn area of the Bighorn Mountains is approximately 35 miles southwest of Buffalo, Wyoming. It is readily accessible by secondary roads from U. S. Highway 16.

Quartzo-feldspathic gneiss covers most of the 18 square miles of the Horn and shows a distinct layering throughout the area. Feldspathic rock (albite-biotite), amphibolite, and calcite marbles are less common. Shearing is common in the more competent rocks; contortion, flowage and lensing are common in the carbonate layers. Recent areal work suggests that these rocks are metasediments of the staurolite-quartz subfacies of the almandine amphibolite facies.

Allanite is fairly common in gneisses throughout the Bighorn Mountains. In the Horn area it is found in greatest abundance along zones adjacent to the carbonate rock. These zones, ranging in width from zero to about four feet, also contain diopside, tremolite-actinolite, epidote, and garnet. They resemble typical skarn; however, no igneous rock is apparent. Tabular allanite grains range from submicroscopic to 3 cm in length, they carry 5-10% Ce, 3-5% La and notable amounts of Nd and Th. Most grains show metamictization; zoning is common. Some of the allanite is believed to have formed by replacement of epidote; however, the source of the rare-earth elements is unknown.

Prospect pits and trenches dug in search of radioactive minerals are common throughout the Horn area. Staking was done in 1954-55, along a zone parallel to and including the carbonate rock, mostly on the basis of geiger-counter investigation and the great abundance of vitreous black minerals. A radiometric survey made by the author in the area of greatest trenching revealed low readings. Further work showed the presence of thorium-bearing allanite, but the largest percentage of black minerals is andradite garnet.

GEOLOGY OF THE SOUDAN MINE, NORTHEASTERN MINNESOTA

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The Soudan mine is located in the western part of the Vermilion district, 20 miles north of the Mesabi range. In this area deposits of massive hematite are found in steeply dipping rocks of Earlier Precambrian age. The hematite deposits are associated with the Soudan iron-formation, which occurs as lenticular beds within the Ely greenstone. The ore deposits are found in a belt of greenstone and iron-formation that is flanked on the north and south by sedimentary rocks correlated with the (Medial Precambrian) Knife Lake group. The rocks of the area strike E-W to N, 80° E, and dip 75-85° N.

The greenstone is made up of a complex group of chloritic and sericitic schists derived from flows, intrusives, fragmental rocks and sedimentary rocks. Despite strong alteration and the development of schistosity, primary textures and structures are retained in the greenstone and indicate that these rocks are not extensively sheared. The rocks range in composition from basic to acidic, and the basic varieties are notably deficient in lime; this contrasts with the basaltic composition of greenstone from other parts of the Vermilion district. A zone of siliceous and sericitic rocks, resembling tuffaceous sediments, is found adjacent to the main belts of iron-formation.

The iron-formation shows mappable changes in lithology, which appear in a regular order as chert, lean jasper, and jaspilite. The distribution of lithologies is interpreted as vertical and lateral facies changes. A stratigraphic sequence is proposed, consisting of basal chert succeeded upwards by lean jasper and jaspilite. The main bodies of iron-formation in the Soudan mine appear to be related to a series of complex folds developed in a single belt of iron-formation. Strong folding in the iron-formation is in contrast to the scarcity of recognizable folds in the greenstone.

The ore occurs in the iron-formation as replacement deposits of hematite. The occurrence of ore shows stratigraphic control by the jaspilite facies, and other controls include intrusive contacts and structurally thinned portions of the iron-formation. The origin of the ore is suggested as hydrothermal.

MAGNETIC ANOMALIES AND MAGNETIZATION
OF MAIN MESABI IRON-FORMATION

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It has long been known that the magnetic effects of the Biwabik iron-formation are complex. It was not, however, until the district, along with most of northern Minnesota, was mapped with the airborne magnetometer that the full import of the complexity was realized. Large negative anomalies appear where positive effects were expected and positive anomalies appear offset with respect to the geologic map of the formations.

As a result of the problems of interpretation encountered, the United States Geological Survey with the cooperation of the Minnesota Geological Survey started a detailed research project to attempt to explain the anomalies not only over the iron-formation but over all the igneous and metamorphic complex of northern Minnesota. Following are some of the results over the Biwabik iron-formation.

Negative magnetic anomalies over magnetite-rich Biwabik iron-formations have been explained as resulting from the low angle of dip which places the formation almost at right angles to the earth's magnetic field. The strength of the earth's field is reduced by the demagnetizing effect of the formation to a degree that the induced magnetization is less than the remanent magnetization. A direction of remanent magnetization, one that is generally along the bedding planes of the formation, produces the magnetic lows found over the tops of the strongly magnetized members.

Ground magnetic traverses show the effects of this near-horizontal direction of remanent magnetization. The magnetic lows are much greater in ground and air traverses over the magnetic taconites of the East Mesabi range.

The tendency of alignment of magnetization direction along bedding planes suggests that changes in dip angle would make significant changes in the character of the magnetic anomaly. A ground profile over the Ironwood formation near Mellen, Wisconsin, shows an anomaly that is similar to the one that would be expected for a steeply dipping Biwabik iron-formation with a near-vertical direction of magnetization.

MAGNETIZATIONS OF IRON-FORMATIONS AND IGNEOUS ROCKS OF
NORTHERN MINNESOTA

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Measurements of the physical properties of oriented rock samples collected in northern Minnesota show irregular magnetizations for iron-formations and granites, and more regular magnetizations for the gabbros, diabase, and flow rocks of the Duluth gabbro complex. The directions of remanent magnetization of the iron-formation are irregular in azimuth but have an average inclination that is close to the plane of the bedding of the formations. Mesabi iron-formations with high magnetite contents have remanent moments several times their induced moments, but Soudan-type iron-formations have induced moments that are greater than their remanent moments.

The majority of the gabbro, basalt, diabase, and granophyre samples from the Duluth area have a remanent magnetization with an azimuth of about 290° and an inclination downward of about 35° . Twenty-nine samples from seven strongly magnetized diabase outcrops have an average moment of 0.01 cgs with 288° azimuth and 36° inclination. Their average susceptibility is 0.003 cgs. Fifty-eight samples of Giants range granite collected southeast of Ely show a downward but scattered direction of remanent magnetization ranging in intensity from 0.0001 to 0.001 cgs.

THE OCCURRENCE OF CARBONATES OTHER THAN IRON AT DEPTH
IN LAKE SUPERIOR IRON FORMATIONS

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Widely separated, steeply pitching Lake Superior iron ore bodies encounter an increase in calcium and magnesium carbonates at depth. These carbonates fill voids in the iron ore, lowering the grade of the iron with a corresponding rise in lime and magnesia. When these contaminants become sufficiently abundant, the iron formation no longer contains ore even though well oxidized and leached.

On the Gogebic range there is evidence that these carbonates have been replaced by iron oxides at depths of more than 3,000 feet. This would seem to indicate that, after the ore was formed, calcium and magnesium carbonates were emplaced. At some later time the contaminants were removed from the top downward.

Apparently, in several localities, this removal was accompanied by replacement in which iron oxides were substituted for the carbonate minerals. At such places very rich oxide ore bodies result, cut off at depth by interstitial carbonates as yet unremoved from the ore.

STRATIGRAPHY AND STRUCTURE OF THE McCASLIN QUARTZITE REGION OF NORTHEASTERN WISCONSIN

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The McCaslin Mountain district lies along the parallel 45°22' north latitude and between the meridians 88°11' and 88°48' west longitude in northeastern Wisconsin. The district occupies parts of Marinette, Langlade, Forest, and Oconto Counties and contains the McCaslin Mountain quartzite, the Thunder Mountain quartzite and the complex of border rocks associated with the quartzites. The district covers an area of approximately 375 square miles.

The rock formations and their succession beginning with the youngest are shown in the following table:

Pleistocene	Glacial drift
	Unconformity
	High Falls granite
	Intrusive contact
	Hager rhyolite porphyry
Precambrian	Unconformity
	McCaslin quartzite
	Unconformity
	Waupee volcanics and basement complex

The broad regional structure of the McCaslin district can best be described as the north limb of a large synclinal trough, the south limb of which rises in the vicinity of Mountain, Wisconsin, approximately 15 miles south of the main McCaslin range of hills. The axial line of the regional structure trends east-west to N.60°E. and plunges slightly to the west. The High Falls granite terminates the structure to the north and northeast. It exhibits intrusive relationships to the rocks of the McCaslin district, showing evidence of invasion by a combination of the processes of forceful injection, stoping, and assimilation.

INCREASING THE RESOLVING POWER OF GRAVITY AND MAGNETIC OBSERVATIONS

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Observed gravity and magnetic anomalies normally consist of the superposition of effects from two or more sources. This may seriously hamper the location and quantitative study of interesting anomalies. As a result the first and most important step in gravity and magnetic analysis is to separate the anomaly into its component parts. One method of increasing the resolving power of gravity and magnetic anomalies, and thus of separating anomalies into their component parts, is to project analytically the observed anomaly to what it would be at a horizontal level closer to the sources of the anomaly. This downward continuation method is based on the general rule that gravity and magnetic anomalies decrease in areal extent and increase in magnitude as their source is approached.

Standard methods of downward continuation are difficult and time-consuming to apply to most mining and regional geophysical surveys. However, an approximation method, based on Peters' solution of the upward continuation problem and a method of finite difference approximation to Laplace's equation assuming two-dimensional anomalies, greatly simplifies the problem. Calculations on ideal examples suggest that the accuracy of this approximation method compares favorably with standard methods.

The usefulness of the method in increasing the resolving power of gravity and magnetic observations is illustrated by theoretical examples and a case history dealing with an iron-formation in the Lake Superior region.

GEOLOGIC INTERPRETATION OF AIRBORNE
MAGNETOMETER PROFILES ACROSS LAKE SUPERIOR

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A Varian proton precessional airborne magnetometer scheduled for use in Antarctica during the 1959-60 field season was test flown in the Lake Superior region during October 1959. Four magnetic profiles across Lake Superior were obtained. Two additional profiles were run over the Lake Superior syncline to the southwest of the Lake. The correlation of magnetic variation and geology obtained over this known geological structure on these two profiles served as a guide to interpretation of the four profiles across the water-covered region.

The magnetic pattern obtained over the basic Keweenawan lava flows differs sharply from that of the adjacent sandstone formations. On this basis it is possible to infer the location of geological contacts beneath Lake Superior.

IRON DEPOSITS IN GABON, EQUATORIAL AFRICA

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The iron deposits in Gabon are associated with Precambrian sedimentary iron-formation that, through the leaching of silica and the solution and redeposition of iron oxides, has been enriched to large concentrations of high-grade iron ore. The unweathered iron-formation is for the most part a laminated rock called itabirite containing hematite, magnetite, and quartz. There is a little silicate material, but carbonate minerals have not as yet been found. The formation is strongly folded, and steep dips to the east are generally the rule. The ore bodies are related to the surface rather than to the structure of the underlying rocks, the ore zones commonly transecting the bedding of the itabirite at steep angles. Exploration to date has indicated a reserve of several hundred million tons of direct-shipping, open-pit ore running 62 to 64% Fe and 2 to 3% SiO_2 , and it is anticipated that an additional significant amount will be proved through further exploration. The ore is friable and soft and will require agglomeration. Eventual development of these deposits will require construction of approximately 450 miles of railroad through rough jungle country, much of which is wild and uninhabited.