

FIFTH ANNUAL MEETING
INSTITUTE ON LAKE SUPERIOR GEOLOGY

April 13 - 14, 1959

UNIVERSITY OF MINNESOTA
Center for Continuation Study
of the
General Extension Division
Minneapolis 14

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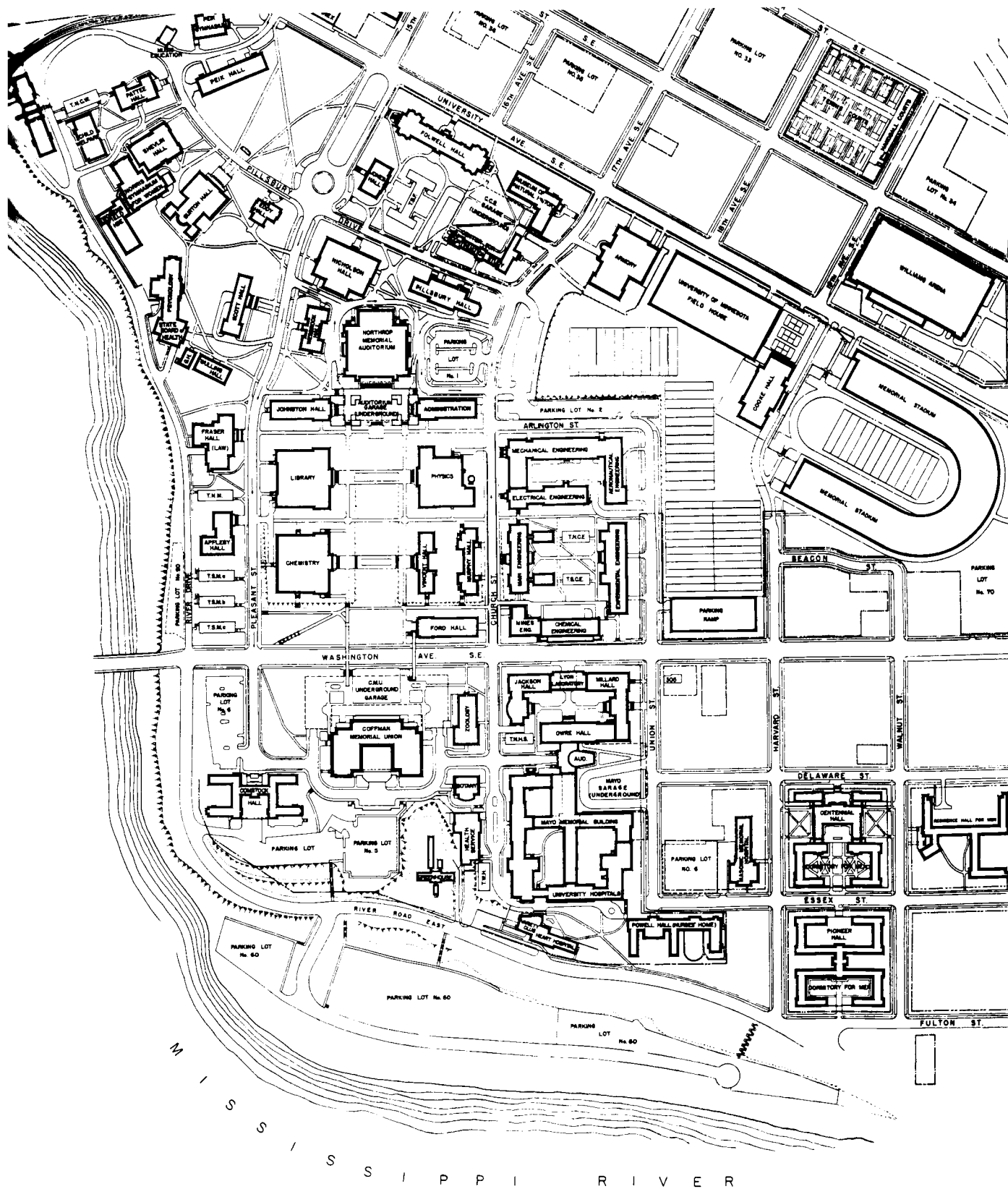
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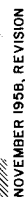
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MINNEAPOLIS CAMPUS



UNIVERSITY OF MINNESOTA
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Institute on Lake Superior Geology

April 13 - 14, 1959

PROGRAM

Monday, April 13, 1959

8:00 - 8:45 Registration and coffee hour, Center for Continuation Study

SESSION I**

Room 4, Mechanical Engineering Building
Co-Chairmen: E. N. Cameron, Richard A. Hoppin

9:00 Call to order.....Fred E. Berger
9:10 Welcome.....George A. Thiel
9:25 ELECTROMAGNETIC STUDIES OF THE LAKE SUPERIOR IRON
RANGES.....F. Frischknecht, E. B. Ekren*
9:50 THE GEOLOGY OF THE GREENWOOD MINE - A HARD ORE PRODUCER ON THE
MARQUETTE RANGE, MICHIGAN.....Alan T. Broderick
10:15 INVESTIGATIONS IN THE PRECAMBRIAN OF THE BIGHORN MOUNTAINS,
WYOMING R. A. Hoppin, R. F. Hudson*, K. A. Sargent
10:40 PRECAMBRIAN AGES IN THE NORTHERN CORDILLERAN REGION.....Paul W. Gast
11:00 POSSIBLE USE OF PRECAMBRIAN CALCAREOUS ALGAL COLONIA AS INDICATORS
OF POLAR SHIFTS.....Stephan C. Nordeng
11:25 SUMMARY OF RADIOACTIVITY DATING OF THE PRECAMBRIAN ROCKS OF
MINNESOTA.....S. S. Goldich*, A. O. Nier
12:00 Luncheon, Center for Continuation Study

SESSION II

Room 4, Mechanical Engineering Building
Co-Chairmen: Ralph W. Marsden, James Trow

1:30 APPLICATION OF THE GRAVITY METHOD TO IRON ORE EXPLORATION..W. J. Hinze
2:00 GEOCHEMICAL SAMPLING OF LAKE BOTTOMS IN WINTER.....William F. Read
2:25 AMINO ACID DISTRIBUTION IN LAKE DEPOSITS.....Frederick M. Swain
2:50 Coffee Break
3:20 THE CHEMISTRY AND ORIGIN OF IRON FORMATION.....Henry Lepp
3:45 THE PETROGENETIC AND ECONOMIC IMPLICATIONS OF THE QUANTITATIVE
MINERALOGICAL VARIATION WITHIN A LARGE GRANITE
COMPLEX.....E. H. Timothy Whitten
4:10 THE GENETIC MEANING OF THE TERMS HYDROTHERMAL AND
REPLACEMENT.....G. C. Amstutz
6:30 Dinner, Junior Ballroom, Third Floor, Coffman Memorial Union Building
Presiding: Donald M. Davidson
Speaker: John W. Gruner
Topic: "40 YEARS IN COLD AND HOT WATER"

* Indicates Speaker

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

Tuesday, April 14, 1959

SESSION III

Room 4, Mechanical Engineering Building
Co-Chairmen: Jack L. Hough, Carl E. Dutton

- 9:00 TILLITE OR SUBAQUEOUS SLIDE?.....R. H. Dott, Jr.
9:25 GEOLOGY OF THE IRON FORMATION OCCURRENCE NEAR KAMINISTIKWIA,
ONTARIO.....John M. Ohlson
9:45 PLEISTOCENE POLLEN STUDIES IN MINNESOTA.....H. E. Wright, Jr.*,
Magnus Fries
10:10 Coffee Break
10:30 CURRENT RESEARCH IN GLACIAL GEOLOGY AND GEOMORPHOLOGY IN WEST-CENTRAL
WISCONSIN.....Robert F. Black
10:50 GEOLOGY OF THE LAKE ALBANEL IRON RANGE, MISTASSINI
TERRITORY, QUEBEC.....Terence T. Quirke, Jr.
11:15 MINERAL EXPLORATION IN SOUTHERN BAFFIN ISLAND, N.W.T....James M. Neilson
12:00 Luncheon, Center for Continuation Study

SESSION IV

Room 4, Mechanical Engineering Building
Co-Chairmen: Cedric L. Iverson, Donald W. Lindgren

- 1:30 PROBLEMS IN NORTHERN NEW ENGLAND STRATIGRAPHY.....John C. Green
1:55 THE GEOLOGY AND IRON DEPOSITS OF THE MOUNT WRIGHT MAP AREA,
QUEBEC - NEWFOUNDLAND, CANADA.....S. Duffell
2:20 THE CRETACEOUS SYSTEM OF MINNESOTA.....Robert E. Sloan
2:45 STRUCTURAL STUDIES IN THE THOMSON FORMATION, CARLTON COUNTY,
MINNESOTA.....Louis A. Mattson

* Indicates Speaker

SPEAKERS

- G. C. AMSTUTZ.....Department of Geology, Missouri School of Mines,
Rolla, Missouri
FRED E. BERGER.....Director, Center for Continuation Study,
University of Minnesota, Minneapolis, Minnesota
ROBERT F. BLACK.....Department of Geology, University of Wisconsin,
Madison, Wisconsin
ALAN T. BRODERICK.....Chief Geologist, Inland Steel Company, Ishpeming,
Michigan
EUGENE N. CAMERON.....Professor and Head, Department of Geology,
University of Wisconsin, Madison, Wisconsin
DONALD M. DAVIDSON.....President, E. J. Longyear Company, Minneapolis,
Minnesota
ROBERT H. DOTT, JR.....Department of Geology, University of Wisconsin,
Madison, Wisconsin
STANLEY DUFFELL.....Geological Survey of Canada, Ottawa, Ontario
CARL E. DUTTON.....Regional Geologist, U. S. Geological Survey,
Madison, Wisconsin
E. B. EKREN.....Geophysics Branch, U. S. Geological Survey,
Federal Center, Denver, Colorado

Lake Superior Geology

SPEAKERS (Continued)

MAGNUS FRIES.....Research Associate, Department of Geology,
University of Minnesota, Minneapolis, Minnesota

FRANK FRISCHKNECHT.....Geophysics Branch, U. S. Geological Survey,
Federal Center, Denver, Colorado

PAUL W. GAST.....Assistant Professor, Department of Geology,
University of Minnesota, Minneapolis, Minnesota

SAMUEL S. GOLDICH.....Professor, Department of Geology, University of
Minnesota, Minneapolis, Minnesota

JOHN C. GREEN.....Department of Geology, University of Minnesota,
Duluth, Minnesota

JOHN W. GRUNER.....Professor, Department of Geology, University of
Minnesota, Minneapolis, Minnesota

W. J. HINZE.....Assistant Professor, Department of Geology,
Michigan State University, East Lansing, Michigan

RICHARD A. HOPPIN.....Department of Geology, State University of Iowa,
Iowa City, Iowa

JACK L. HOUGH.....Department of Geology, University of Illinois,
Urbana, Illinois

R. F. HUDSON.....Graduate Student, Department of Geology, State
University of Iowa, Iowa City, Iowa

CEDRIC L. IVERSON.....Oliver Iron Mining Division, U. S. Steel
Corporation, Duluth, Minnesota

HENRY LEPP.....Associate Professor, Department of Geology,
University of Minnesota, Duluth, Minnesota

DONALD W. LINDGREN.....Chief Mining Geologist, Northern Pacific Railway
Company, St. Paul, Minnesota

RALPH W. MARSDEN.....Manager, Geological Investigations, Oliver Iron
Mining Division, U. S. Steel Corporation,
Duluth, Minnesota

LOUIS A. MATTSON.....Graduate Student, Department of Geology,
University of Minnesota, Minneapolis, Minnesota

JAMES M. NEILSON.....Department of Geology, Michigan College of
Mining and Technology, Houghton, Michigan

ALFRED O. NIER.....Head, School of Physics, University of Minnesota,
Minneapolis, Minnesota

J. M. NOLTE.....Dean, General Extension Division, University of
Minnesota, Minneapolis, Minnesota

STEPHAN C. NORDENG.....Assistant Professor, Department of Geology,
Michigan College of Mining and Technology,
Houghton, Michigan

JOHN M. OHLSON.....Assistant Geologist, Inland Steel Company, Iron
River, Michigan

TERENCE T. QUIRKE, JR.....Assistant Professor, Department of Geology,
University of North Dakota, Grand Forks,
North Dakota

W. F. READ.....Department of Geology, Lawrence College,
Appleton, Wisconsin

K. A. SARGENT.....State University of Iowa, Iowa City, Iowa

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

Lake Superior Geology

SPEAKERS (Continued)

F. M. SWAIN.....Professor, Department of Geology, University of
Minnesota, Minneapolis, Minnesota
GEORGE A. THIEL.....Professor and Chairman, Department of Geology,
University of Minnesota, Minneapolis, Minnesota
JAMES TROW.....Department of Geology, Michigan State University,
East Lansing, Michigan
E. H. T. WHITTEN.....Department of Geology, Northwestern University,
Evanston, Illinois
H. E. WRIGHT, JR.....Associate Professor, Department of Geology,
University of Minnesota, Minneapolis, Minnesota

ELECTROMAGNETIC STUDIES OF THE LAKE SUPERIOR IRON RANGES

F. C. Frischknecht and E. B. Ekren
U. S. Geological Survey, Denver, Colorado

In the past two years the U. S. Geological Survey has made experimental electromagnetic studies over several of the iron ranges in the Lake Superior region. The three principal objectives were to evaluate electromagnetic methods as a tool for locating directly oxidized iron ores, to test electromagnetic methods of tracing taconites that are known to have high electrical conductivity, and to determine if electromagnetic methods could be used to estimate the magnetic susceptibility and magnetite content of magnetic strata.

In the areas tested in the Cuyuna range it was not possible to locate directly oxidized iron ore beneath the 90 feet of drift present. It was possible to trace the contact of the hanging-wall and iron formation by following a graphitic or other conducting bed along the contact.

In the Gogebic range individual members of the iron formation were traced as conductors by conventional electromagnetic methods. The foot-wall quartzite and iron formation contact was readily located, but the hanging-wall iron formation and slate contact was difficult to locate because of conducting strata within the slates. Unless special electromagnetic techniques were used, some drilling control was necessary to define accurately the hanging wall contact of the iron formation.

A variable-frequency electromagnetic technique, which was tried on the Gogebic range, showed promise as a practical method for distinguishing between taconite, which has high electrical conductivity and high magnetic susceptibility, and graphite, which has high electrical conductivity, but low susceptibility. The same variable-frequency technique was also useful in estimating the magnetic susceptibility and magnetite content of magnetic strata.

THE GEOLOGY OF THE GREENWOOD MINE -- A HARD ORE PRODUCER
ON THE MARQUETTE RANGE, MICHIGAN

Alan T. Broderick
Inland Steel Company, Ishpeming, Michigan

The Greenwood Mine has been a small but steady producer of specularite and magnetite lump ores since 1932. The total production to date has been about two million tons.

All of this ore has come from relatively small, discontinuous bodies which lie in the hematite-chert facies at the top of the Negaunee iron formation and in the bottom of the overlying Goodrich conglomerate. The formation strikes east-west and dips about 70 degrees to the north. The rocks are in the garnet zone of metamorphism.

Structurally, the ore bodies are found in three environments: as irregular sheets along the hanging wall contact with the Goodrich conglomerate; as irregular, steeply dipping, rudely tabular masses ("droppers" in the local mine terminology) and as irregular pipes that follow inverted troughs formed by folds or by the intersections of faults and/or dikes and the hanging wall.

In textural and mineralogical detail, there are four distinct end member types of ore: conglomerate, i.e. pebble and sand-bearing hematite; "slaty", i.e. fine-grained, finely laminated, alumina-rich specularite; coarse specularite; coarse granular magnetite. The first two are found only along the hanging wall, the others are found in all locations.

The conglomeratic and "slaty" ores at the top of the formation are believed to have been concentrated by beach and/or stream winnowing during the erosion period which occurred before and during Goodrich time.

After folding, faulting and dike intrusion which left the rocks in about their present positions, the chert bands, in the iron formation were locally leached, leaving the iron-rich bands to form ore bodies. In other areas the volume-for-volume replacements of chert bands by iron minerals was the ore-forming process. At the same time, or possibly later, much of the hematite in irregular areas of iron formation, ore bodies and Goodrich conglomerate was reduced to equigranular magnetite. The magnetite areas contain vuggy quartz veins carrying tourmaline, pyrite, chalcopyrite and very coarse specularite.

The writer proposes that this chemical activity was accomplished by a fluid medium which entered the mine area from below along channels controlled in part, at least, by structural features.

This activity therefore took place after these structural features had been developed.

Since the platy hematite in such structurally controlled ore bodies is deformed around magnetite grains, the same period of deformation either continued during and followed mineralization or a later independent spasm of deformation occurred.

INVESTIGATIONS IN THE PRECAMBRIAN OF THE BIGHORN MOUNTAINS, WYOMING

R. A. Hoppin, R. F. Hudson, K. A. Sargent
State University of Iowa, Iowa City, Iowa

In order to better understand the structural evolution of the Bighorn Mountains detailed structural, petrographic, and petrologic investigations, under the direction of the senior author, are being carried out in the Precambrian crystalline rocks.

The investigations are directed toward the solution of three intimately related problems: one, to what extent do Precambrian structures control the local Laramide faulting evident along the margins of the range; two, is the regional trend of the range due to the presence of a major Precambrian structural feature or does the trend reflect the prevailing Laramide stress pattern; three, is the uplift due dominantly to vertical tectonics or to folding by horizontal compression.

Initial field investigations have been completed along the marginal portion of the east-central part of the range. As a necessary complement to the detailed study of the crystalline rocks, the minor structural features of the adjacent sedimentary rocks were mapped. Preliminary results indicate: a local control of Laramide tear faults, in a N10-15E direction, by strong Precambrian shearing; no apparent Precambrian structure controlling the trend of the range; an intimate relations of petrography and petrology to structure; and, a difference in the nature of deformation during the early Precambrian and the Laramide.

The field work for two investigations, which have the same objectives as the present studies, will begin this summer. One is an east-west section across the range, beginning in the vicinity of the North Fork of Crazy Woman Creek then west approximately parallel to Highway 16. The second is a study of the Precambrian structures of the Horn, where a striking mineralogical layering occurs.

To date six Master's theses, dealing with the complicated marginal sedimentary structures, have been completed. Four of these, together with the area of the University of Iowa field course, extend continuously from Little Goose Creek south to the Horn region. The remaining two deal with the northwestern portion of the range in the Five Springs area. A new project is to begin this summer in the southwestern part of the range.

Additional projects now in progress include petrologic studies of a Precambrian rare earth deposit in the Horn region, and of several small ultrabasic bodies, exposed along Highway 16 close to the eastern margin of the range.

PRECAMBRIAN AGES IN THE NORTHERN CORDILLERAN REGION

Paul W. Gast
University of Minnesota, Minneapolis, Minnesota

The ages of rocks and minerals in a number of occurrences of Precambrian rocks in Wyoming, Montana and Utah have been determined. Detailed investigation of a small area in the Beartooth uplift indicates a period of rock formation 2750 m.y. ago. Preliminary studies in the Wind River, Bighorn and Owl Creek-Bridger uplifts suggest that this event may also be represented there.

Other studies in the Medicine Bow and Wasatch uplifts indicate another rock forming event 1600 m.y. ago. Precambrian rocks in southeastern Montana are also younger. One occurrence of 1350 m.y. old rocks has been found in central Wyoming.

POSSIBLE USE OF PRECAMBRIAN CALCAREOUS ALGAL COLONIA
AS INDICATORS OF POLAR SHIFTS

Stephan C. Nordeng
Michigan College of Mining and Technology, Houghton, Michigan

This paper presents some preliminary results of investigations on calcareous algae recently undertaken at the Michigan College of Mining and Technology.

Collenia kona Twenhofel, 1918, is briefly redescribed.

Study of the literature on calcareous algae and of numerous occurrences besides those in the Kona dolomite in Northern Michigan have led the writer to certain conclusions concerning the mechanisms by which the colonial growth forms are controlled. The most important of these is believed to be sunlight. The activity of the algae would be greatest on those portions of the colony receiving the greatest amount of sunlight and therefore colonial growth should be a maximum in the direction from which the maximum amount of sunlight is received. Thus, the vertical axes of the majority of colonies in a bioherm or biostrome should point toward the equator.

Measurements made on Collenia kona indicate the equator was 27° North 20° West in Kona time. This is essentially in agreement with measurements made on algae in the Iron Mountain-Loretto, Michigan, area in beds of the same age.

If the theories of many prominent workers in the field of tectonophysics can be given any credence, changes in position of the poles and equator have been frequent, if not constant, throughout geologic time. It is, therefore, very likely that algae colonies from widely separated areas growing at the same time may have different axial inclinations but should be in close agreement as to the location of the equator, thus furnishing a possible means of correlation.

Time permitting, methods of study and proposed future work will be discussed.

SUMMARY OF RADIOACTIVITY DATING OF THE PRECAMBRIAN
ROCKS OF MINNESOTA

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

Radioactivity dating supports a three-fold division of the Precambrian rocks of the Lake Superior region rather than a two-fold division as is advocated by Canadian geologists for the Precambrian of Canada; however, a considerable revision of the three-fold division used by the Minnesota Geological Survey is suggested.

Two major periods of orogeny, accompanied by granitization and granite intrusion that have been dated at approximately 2.6 b y and 1.7 b y are the basis of the three-fold division. Keewatin rocks and the Knife Lake group, older than 2.6 b y, are assigned to the Early Precambrian. The Animikie group, formerly placed with the Keweenawan group in Later Precambrian, is assigned to the Middle (Medial) Precambrian. The Keweenawan group is retained in Late Precambrian.

The suggested classification makes the Early Precambrian, terminated by the Algoman orogeny, equivalent to the Archean of the two-fold classification commonly used in Canada; Middle and Late Precambrian are equivalent to the Proterozoic. The magnitude of the orogeny at 1.7 b y has not been fully appreciated in the past, because of the uncertainty of the age of many granite intrusions.

Metamorphism and igneous activity at 1.3 - 1.4 b y have been dated in Wisconsin, Michigan, and the Sudbury region, and elsewhere. Similarly the Grenville orogeny (1.0 b y), although apparently not of a mountain-building scale in the Lake Superior region, is represented in lesser structural disturbances and in igneous activity.

Radioactivity dating promises to be of great assistance in solving the problems of the Precambrian, although the limitations of analytical procedures and the difficulties of interpretation may not be fully appreciated or known. The major challenge, however, is to geologists, and a satisfactory solution of many of the problems will result only from the application of all available techniques. Fundamental geologic investigations, including mapping, petrologic and stratigraphic studies, are needed.

Results of radioactivity dating of Precambrian rocks of Minnesota and adjacent areas that have been presented at past meetings of the Institute are summarized. Rb-Sr dating now in progress appears to support earlier conclusions drawn from K-A dating. Development of a useful terminology for the Precambrian poses many problems.

APPLICATION OF THE GRAVITY METHOD TO IRON ORE EXPLORATION

W. J. Hinze

Michigan State University, East Lansing, Michigan

The gravity method has played an increasingly important role in the search for new reserves of iron ore since the development of highly portable gravimeters capable of a high degree of precision. This method has been used in the search for and study of direct shipping ores, but it has proven to be especially useful in the study of large tonnage, wide, near surface, "taconite type" ore bodies which have been the primary concern of the iron ore industry during the past decade.

The gravity method was first applied to iron ore exploration as a tool for detecting non-magnetic ores, but advantages of this method over other exploration methods also have made it useful under certain geological conditions in the study of magnetic ores and regional structures favorable for the occurrence of iron ore. However, the gravity method is restricted by several limitations which must be realized and understood if the application of the method is to be successful. In addition, the full utilization of the method is dependent on a complete understanding of the density relationships of ores and their contrast with the country rocks. This is made particularly difficult by the wide range of densities of iron ores which can lead to the association of both positive and negative gravity anomalies with iron ore bodies. The result is that the amount and quality of information interpreted from the results of gravity surveying is a direct function of the auxiliary geological information available either through geological or other geophysical studies.

GEOCHEMICAL SAMPLING OF LAKE BOTTOMS IN WINTER

William F. Read
Lawrence College, Appleton, Wisconsin

In recent years, mining companies have carried out numerous investigations of the heavy metal content of soils and stream sediments in an effort to locate concealed ore bodies. Little attention has been paid to lake sediments. If mineralization is present beneath a lake, heavy metals from this source may reach the lake bottom by groundwater circulation, or, under exceptional circumstances, by direct upward diffusion. Anomalies produced in this manner should be distinct from anomalies due to inflowing streams, which are definitely concentrated around points of inflow.

Winter sampling from an ice cover offers definite advantages in (1) precise determination of location, and (2) relative ease in handling of equipment. Severe cold can cause trouble, but this problem may be largely avoided by sampling either early or late in the winter season. The necessary equipment can conveniently be mounted on a small fleet of toboggans. It includes (1) a power ice drill; (2) stainless steel sampling tube, rope, and winch; and (3) a supply of suitable sample containers. A modified camp stove may be used to de-ice the sampling tube in very cold weather.

AMINO ACID DISTRIBUTION IN LAKE DEPOSITS

Frederick M. Swain
University of Minnesota, Minneapolis, Minnesota

The bottom sediments of a wide variety of lakes were studied for their amino acid content. Free amino acids are rare or absent in the lake sediments, but amino acids ranging from less than 2 ppm to more than 4000 ppm were obtained in acid hydrolyzates of the sediments. The amino acids probably occur as glutelin or scleroprotein types of proteins, as peptides or tie to humic acid substances in these sediments.

Neutral peat deposits and well humified organic lake deposits yield neutral and acidic amino acids in approximate proportions of 85:15; alkaline bogs and well humified organic marls yield neutral and onliamino acids in proportions of about 75:25; acid peats contain basic amino acids in addition to neutral and acidic types. Incompletely humified lake deposits yield variable proportions of all three amino acids. The stable proportions of amino acids in well humified deposits are believed to be related to the zwitter ion properties of amino acids.

Lake sediments of low organic content generally yield small amounts of neutral amino acids. There is little or no evidence of a relationship between type of lake sediment and individual amino acids.

In deep, well humified lake and bog deposits, study of the amino acids should help to reveal the depositional environment and history.

THE CHEMISTRY AND ORIGIN OF IRON FORMATION

Henry Lepp
University of Minnesota, Duluth, Minnesota

Unaltered sedimentary iron formations of all ages are remarkably uniform in iron content. Calculations based on 200 analyses of scattered samples of iron formation from various parts of the Mesabi and Cuyuna ranges show that 67% fall in the range of from 25 to 32.5% Fe. Similarly of 136 analyses of the Liassic Cleveland ironstone of England 85% contain between 25-30% Fe. Published average compositions for other iron formations, be they Keewatin, Huronian or post-Cambrian type, almost invariably show from 25 to 30% Fe.

Although appreciable quantities of leaner than normal iron formation are known to exist, it is significant that of the many billions of tons of geologically explored iron formation there are no (or at least very few) examples of mineable primary concentrations of more than 40% Fe. This marked uniformity of composition is an important property of iron sediments, and it may be a significant clue to their origin. It suggests that pre- and post-Cambrian iron formations are, in the main, the result of the same geologic processes.

The marked uniformity of composition points to a complete sedimentary origin for the iron sediments. It is inconsistent with hypotheses involving direct magmatic (exhalative) sources for the iron.

Attempts to explain the regularity of composition in terms of relative solubilities and/or abundances of iron and silica are unsatisfactory, and, moreover, they do not account for the carbonate iron formations. At present the most likely explanation is that iron was available at the site of deposition as $\text{Fe}(\text{HCO}_3)_2$ and that the resulting sediments formed by coprecipitation of CaCO_3 and FeCO_3 . This should produce a sediment with about 24% Fe. Diagenetic replacement of CaCO_3 by SiO_2 would slightly upgrade the iron content as would any precipitation of $\text{Fe}(\text{HCO}_3)_2$ as oxide.

THE PETROGENETIC AND ECONOMIC IMPLICATIONS OF THE QUANTITATIVE MINERALOGICAL VARIATION WITHIN A LARGE GRANITIC COMPLEX

E. H. Timothy Whitten
Northwestern University, Evanston, Illinois

A new and very powerful analytical technique has been used to study the mineralogical variation within a large inhomogeneous granitic mass. This quantitative modal study was made possible by detailed sampling (two specimens per 1/4 square mile) of an entire complex and the use of an IBM 650 electronic computer. In this paper the petrogenetic significance of the mineralogical variation is emphasized, but the success obtained with analyses of accessory minerals suggests potentialities in economic prospecting.

The methods are general and applicable to any area, but are illustrated by reference to the extremely well-exposed 'older granite' of Donegal, Eire, because the entire Donegal Granite has been mapped recently on the scale of 6"/mile. The nature of the complex is outlined so that the significance of the analytical work can be appreciated.

The 'older granite', the oldest component of the Donegal Granite, is a single structural unit measuring some 24 miles from north to south. In the southeast it is characterized by dioritic migmatites which contain innumerable metasedimentary rafts; these relics comprise a well-defined ghost-stratigraphy. Northwards and westwards the rafts are lacking and the granite changes to a typical two-feldspar granite and thence to highly quartzose (quartz > 40%) leucocratic granite (colour index < 1%). Contact relationships and flow patterns indicate that away from the migmatitic area homogenization was accompanied by magmatic flow and stopping. Concomitant with the gradual compositional change to quartzose granite (taking place over 5-10 miles), unusual micro-textures increase, and these suggest that microcline and quartz partially replaced minerals crystallized previously. All of these relationships imply the operation of two successive petrogenetic rhythms. Firstly, chemical processes created granodioritic magma at the expense of metasediments now represented by relics within the migmatitic diorite; this essentially homogeneous magma was intruded into adjacent areas. Secondly, another chemical metasomatic phase generated more quartzose granite at the expense of part of the virtually solidified granodiorite. Eventually such end-products became mobile and were intruded as minor transgressive plutons within the 'older granite' parent (see Whitten 1957a - Proc. Royal Irish Acad. vol. 58B, pp. 245-92; 1957b - Geol. Mag. vol. 94, pp. 25-39).

A Swift automatic electrical point counter enabled accurate modal analyses to be made rapidly. By the method of least squares linear, quadratic, and cubic areal trend surfaces have been computed for each major and most accessory minerals within the 'older granite'. Strong

and consistent gradients (trends) are apparent. The residuals (difference between the observed and computed surface values) for each phase clearly define palimpsestic ghost-stratigraphy. In some areas the pattern of the residuals can be directly related to metasedimentary rafts visible within the granitoid rocks. In other parts of the complex, the residuals constitute the only detected relics of the metasediments which were extant prior to emplacement of the 'granite'; that is, the residuals reveal previously unsuspected ghost-stratigraphy which is harmonious with the regional structure. This discovery is of considerable petrogenetic significance.

THE GENETIC MEANING OF THE TERMS
HYDROTHERMAL AND REPLACEMENT

G. C. Amstutz

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The term hydrothermal has been defined in many different ways which reflect the schools of thought represented by the authors using it. A cross section through many different definitions of "hydrothermal" given during the last one hundred and fifty years shows that practically all authors assume hydrothermal solutions or fluids to be hypogene; most of them assume magmatic origin. There is much disagreement or confusion however with regard to the syngenetic or epigenetic nature of hydrothermal deposits and processes.

It is here shown and proposed that the term hydrothermal should not be given a priori a connotation of epigenetic origin. Hydrothermal is a physico-chemical concept which also includes the concept of hypogene origin; but it does not involve any time concept. Hydrothermal rocks, deposits, alterations, etc. may be epigenetic or syngenetic (autohydrothermal processes, exhalations, etc.). Hydrothermal nature is thus per se no proof for epigenetic origin.

Much the same can be said for the term replacement. This term has been somewhat a magic word in the past and was often loosely used as a synonym for epigenesis. Epigenetic replacements are possible and take place. They require however many more assumptions than syngenetic replacement. Also, in many cases, an assumption of replacement is not justified, since simple contemporaneous crystallization offers a physico-chemically and geometrically sound explanation of origin. Thus also with regard to this term it must be said that a compositional change in time may fall within the time of formation of a rock and has to be classified as syngenetic.

Examples are abundant: e.g. autohydrothermal changes in igneous rocks; dolomitization or other changes in sediments which often take place during diagenesis; etc. Various geometric and geochemical criteria from the Lake Superior copper deposits, from the Mississippi Valley deposits, and from other ore deposits are used to illustrate the genetic meaning of the terms hydrothermal and replacement.

TILLITE OR SUBAQUEOUS SLIDE?

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Recent studies of turbidity current and associated slide deposits have opened new vistas to understanding many ancient sediments. Notably, the mechanisms of suspension and mass flow of sediments moving under influence of gravity provide means of transport of shallow marine or terrigenous clastics and organic remains to deeper water. Traditionally, geologists have insisted that all geosynclinal sediments were deposited in shallow water because of abundant clastics. Furthermore, repetitious graded bedding was not satisfactorily explained until these mechanisms were evaluated. Rhythmically-laminated sandstone, siltstone and mudstone associated with unsorted pebble and boulder beds have been rather universally interpreted as glacial varves and tillites respectively, and elaborate theories of ancient climatology and geotectonics were (and are) erected upon this foundation.

Concepts of turbidity current and slide deposition can best be demonstrated in Mesozoic and Cenozoic strata of geosynclinal belts such as the Pacific coast and the Alps. However, the interpretations can also be extended to certain more obscure and less fossiliferous older rocks. Newell (1957) reinterpreted Permian "tillites" of northern Mexico, and Sanders (1957) challenged glacial interpretation for Cretaceous boulder beds in Chile. Other examples were questioned long ago, but dissenters were little-heeded in the "glacial enthusiasm" of the early twentieth century.

By analogy with well-documented turbidity and slide deposits of California and Oregon, it is reasoned that the famous Paleozoic Squantum "tillite" near Boston, Massachusetts possesses so many similarities as to make the glacial interpretation suspect. Submarine sliding of rapidly deposited, volcanic-rich sediments is proposed as an alternate hypothesis. Absolute criteria for distinction of the two mechanisms of deposition are difficult to discover. Both processes produce very poor sorting of fragment size and both can conceivably produce faceting and striation of pebbles. Only a preserved glacial pavement overlain by extensive, poorly-sorted till-like material (as in South Africa) seems unequivocal. General stratigraphic relations and tectonic setting serve as secondary factors in judging probability of sliding in many geosynclinal sequences. Extending the reasoning, it appears that all ancient "tillites" must be regarded with suspicion until critically re-analyzed (as suggested by Crowell, 1957). Because of striking similarities of many Precambrian sediments and associated "tillites" to younger geosynclinal deposits, a re-evaluation of Precambrian glaciations seems in order.

GEOLOGY OF THE IRON FORMATION OCCURRENCE
NEAR KAMINISTIKWIA, ONTARIO

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The iron formation near Kaministikwia, Ontario, outcrops within the valley of the Kaministikwia River, 18 miles northwest of Port Arthur, Ontario.

Three vertically dipping strands of magnetite iron formation strike east-west to northeast-southwest. The rocks above and below the iron formation are volcanic flows, volcanic breccias, agglomerates, bedded and massive tuffs. The iron formation is highly magnetic and consists of beds 1/4" to 3" thick of red stained chert, hematitic magnetite and white laminated chert with scattered beds of tuff. The iron formation averages 600 feet in thickness.

There is not sufficient evidence to determine the structural pattern in the Kaministikwia area at present. The three iron formations are either three stratigraphic units, one stratigraphic unit broken into segments by faulting, or two stratigraphic units, one of which is broken into two segments by faulting.

The mineralogy of the iron formation together with the size of the quartz crystals in the recrystallized chert suggest that the iron formation is an original magnetite iron formation.

PLEISTOCENE POLLEN STUDIES IN MINNESOTA

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A program of study of the pollen content of the sediments of selected Minnesota lakes and bogs has been initiated in the Geology Department of the University of Minnesota with the aid of a grant from the Hill Family Foundation, for the purpose of working out the late-glacial and post-glacial vegetational and climatic history of the region. Sites have been selected with respect to the distribution of glacial drifts of different substages of the Wisconsin glacial stage and with respect to the present major vegetational provinces (conifers, hardwoods, prairie).

Preliminary analyses for a buried peat layer near North Branch, Chisago County, suggest that the vegetation in this area during the Two Creeks interstadial interval about 12,000 years ago was marked by spruce with many openings of grass, shrubs, and herbs.

Analyses have also been made for a lake between drumlins about 30 miles north of Two Harbors in Lake County. The drumlins were formed during the Cary subage of the Wisconsin glaciation, and the region was approached but not reached during two subsequent ice advances (Mankato and Valders). The first vegetation indicated after recession of the Cary ice was grass with perhaps both tundra and prairie plants and some spruce and willows on sheltered slopes. A pronounced but temporary influx of birch along with a reduction of spruce may record the warming of the Two Creeks (Mankato/Valders) interstadial, but the earlier Cary/Mankato interstadial is not recognizable in the pollen diagram. Subsequent changes involved increase of pine to a maximum about halfway through the post-glacial succession, along with a slight increase of oak, elm, and ash, suggesting a larger number of outliers of warmth-demanding deciduous trees than at present in this region. The latest horizons are marked by a decrease of hardwoods and a corresponding increase of spruce, fir and tamarack.

Glacial studies in the area indicate that the fluctuations of the Superior lobe and other ice lobes during the Cary, Mankato, and Valders subages of the Wisconsin glaciation probably exceeded 150 miles. Distinct climatic fluctuations are thereby implied, but the fact that only one of the two possible interstadial intervals is suggested in the pollen diagram implies either that the pollen studies are not yet sufficiently precise to reveal all the climatic changes or that fluctuations of the ice fronts were controlled not by gross climatic changes near the margin but by changes in conditions of snow accumulation or ice flow far back from the ice front. Continued studies will be directed particularly towards these problems of the late-glacial vegetational and climatic changes.

CURRENT RESEARCH IN GLACIAL GEOLOGY AND GEOMORPHOLOGY
IN WEST-CENTRAL WISCONSIN*

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A program of research on glacial deposits of Wisconsin and their modification by geomorphic processes was begun in the fall of 1956. The program is carried on part time during the school year. Research assistant L. A. Bayrock has completed one academic year and Elizabeth H. Kissling and Thomas E. Berg are on their first and second academic years respectively. It is yet premature to draw definite conclusions from many aspects of the various studies so this abstract must cover essentially the nature of the program.

Airphoto mapping of glacial deposits in Pepin, Pierce, St. Croix, Dunn, Polk, and Barron counties has yielded information on the distribution of various erosional and depositional features such as pro-glacial and marginal channels, pre-glacial drainage ways, outwash and inwash deposits, kames, crevasse fillings, eskers, kettles, terraces, loess, moraines, and areas of thin drift. Field checking during the winter months has established the reliability and usefulness of this approach. Quantitative geomorphic studies of the development of the drainage network in representative parts of the area are underway. It is anticipated that they will aid in correlation of the older drifts. Bottom sampling of kettle lakes and drained lakes has just been started.

Youthfulness of Cary-age features in northern and western parts of the area readily distinguish them from subdued forms of Tazewell and Farmdale age to the south and east. The Farmdale has been confirmed by two carbon-14 dates of $29,000 \pm 1000$ (W-747, U. S. Geological Survey) and $30,650 \pm 1640$ (Y-572, Lamont Laboratory) years B. P. from Hammond and Woodville respectively. Deposits in southeast Pierce County and in Pepin and Buffalo counties have eluded positive correlation, but are also thought to be Farmdale in age.

Widely scattered pebble and heavy mineral counts, which have just been started, and depths of oxidation and leaching of drift have not been reliable measures of age or correlation. Much old weathered drift obviously is incorporated in young deposits. Modification of glacial deposits by gravity movements under climates that produced permafrost is diagnostic of Tazewell and older drifts. Tazewell ice-wedge casts have been identified in a kame north of Richmond and in a kame at River Falls. Thawing of buried Farmdale ice beneath younger deposits was not completed until after Cary deglaciation.

In addition to furthering our knowledge of the Pleistocene, results of the study will aid in determining buried bedrock from indicator erratics, in mapping of soils, in locating and evaluating supplies of ground water and construction aggregates, and in analysing foundation problems.

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GEOLOGY OF THE LAKE ALBANEL IRON RANGE,
MISTASSINI TERRITORY, QUEBEC

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The Lake Albanel iron district of the Mistassini Territory is located about 400 miles north of Montreal and comprises between 150-175 square miles. Since 1952 the area has been under intensive investigation; geophysical, geologic, diamond drilling, and laboratory investigations have been carried out.

All consolidated rocks in the area are of Precambrian age. The oldest rocks are sediments and volcanics of the Sam Gunner group to the north of the Lake Albanel iron range. These sedimentary rocks have been intruded by granites and gneisses of the Takwa Mountains complex. Resting with angular unconformity upon the Takwa Mountains complex are rocks of the Papaskwasati group, and they in turn are conformably overlain by the Mistassini group. All these groups lie to the northwest of the Mistassini (Grenville) fault zone. The Grenville metamorphic complex to the southeast of the fault consists of acidic and basic intrusions, orthogneisses and paragneisses.

The Mistassini group consists of five formations. From oldest to youngest these are the Lower and Upper Albanel dolomites, Boulder Bay quartzite, Temiscamie iron-formation and Kallio slate. The Temiscamie iron-formation has been divided into six members.

Minerals of the iron-formation are thought to have formed from an original silica gel rich in iron and carbonate. The first minerals to form were chert, siderite and in some cases hematite, magnetite and perhaps minnesotaite. Due to the incorporation of iron into the early minerals there was a subsequent enrichment of magnesium, manganese and calcium. These three crystallized into a dolomite structure.

Chemical analyses have been made of each of the members of the Temiscamie iron-formation. These analyses are compared with similar rocks of other Precambrian iron-formations. Because of the general similarity of these iron-formations it seems probable that they were formed under similar circumstances.

MINERAL EXPLORATION IN SOUTHERN BAFFIN ISLAND, N.W.T.

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The paper presents an account of the regional geology of the southernmost part of Baffin Island. The main physiographic features from the Kingaita Peninsula to the Foxe Peninsula are described and related to the rock types examined in the course of mineral exploration. The lithology and stratigraphy of the Precambrian and Paleozoic rocks are considered in general terms, and the age of certain rocks is discussed on the basis of radioactivity dating. The effects of glacial erosion are described together with the effects of deglaciation which resulted in features indicative of both submergence and emergence. The geomorphic processes active in this region produce conspicuous examples of frost action and surface weathering, fluvial and lacustrine phenomena, mass wasting, patterned ground, etc.; these are described and illustrated. Mineral exploration procedures suitable to this part of Baffin Island are discussed with particular reference to photogeologic interpretation, prospecting techniques, climatic conditions, transportation facilities, communications, and other matters that affect operations. It is concluded that mineral exploration in this Arctic region possesses certain definite advantages and also some obvious disadvantages.

PROBLEMS IN NORTHERN NEW ENGLAND STRATIGRAPHY

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The "New Hampshire and Vermont sequences" of metamorphosed Paleozoic geosynclinal rocks are separated by a contact of uncertain significance called the Monroe fault. Because very few geologists have worked in both sequences, correlation of the two has been a problem. This problem was increased by the establishment in 1942 of the Orfordville formation beneath the Albee formation, hitherto the lowest in the standard New Hampshire sequence of Billings (1937): many geologists believe that the Orfordville is the equivalent of several formations higher in the New Hampshire sequence. This interpretation is supported by the recent discovery by the writer in northern New Hampshire of a different group of rocks (Aziscohos formation) in the supposed position of the Orfordville. The Aziscohos is stratigraphically beneath the Albee, as determined by graded bedding in several localities; the position of the Orfordville was determined by plunges of minor folds alone.

If the Orfordville formation is thus removed from the column, correlation between the two sequences is made much easier, and such a correlation is now accepted by many New England geologists. The establishment of the Aziscohos formation beneath the Albee agrees better with this correlation, since the Aziscohos resembles the formations of the Vermont sequence immediately below the Moretown, which is correlated with the Albee of New Hampshire.

THE GEOLOGY AND IRON DEPOSITS OF THE MT. WRIGHT MAP AREA
QUEBEC - NEWFOUNDLAND, CANADA

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The Mt. Wright map area has been prominent in recent years because of the active exploration by major iron and steel companies of the large deposits of concentratable iron ore that lie within its boundaries. The iron formation includes a number of facies of which the most important is an oxide facies that consists of granular quartz, specular hematite and magnetite. It is noticeably banded with iron rich and quartz rich bands and resembles the itabirite formation of Brazil. Friability and coarseness of grain of the material are important assets in the separation and concentration processes required for marketing.

The area covers part of the southwestern extension of the Labrador Trough and lies in the Grenville subprovince of the Canadian Shield but close to the Grenville Front.

Rocks involved are gneisses that represent metamorphic equivalents of units of the Labrador Trough that 50 miles to the north are relatively unmetamorphosed. The gneisses may be divided roughly into three bands that transverse the area in a southwesterly direction. The central and southern bands may both be included in the amphibolite facies of metamorphism. They differ in that the iron formation is associated only with rocks of the central band.

The southern band consists of graphitic gneisses, hornblende-biotite garnet gneisses and their migmatitic equivalents. These structurally overlie the iron formation and are believed to also stratigraphically overlie it. They occur in a synclinal structure between the central band of acid to intermediate biotite-hornblende gneisses and similar rocks in the southwest corner of the area. The gneisses with which the iron formation is associated form broad anticlinal structures in which folding about two sets of axes has taken place.

The northern band of gneisses is composed of rocks of the granulite facies of metamorphism that strongly resemble in mineralogy and physical characteristics the charnockite rocks of Precambrian terrains of other continents. The lower grade amphibolite facies of metamorphism appears to have been emplaced on the higher grade granulite facies and is interpreted as being younger.

Gravity surveys in the area by the Dominion Observatory proved the existence of a phenomenally low gravity anomaly extending across the area in a southwesterly direction just south of the transition zone between the two facies of metamorphism. This gravity low is interpreted as being due to the presence of a granitic batholith not far below the surface.

THE CRETACEOUS SYSTEM OF MINNESOTA

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Cretaceous rocks in Minnesota are Cenomanian to Coniacian age and are referred to the Coleraine formation in northern Minnesota and the Windrow formation in southern Minnesota. An Early Cretaceous interval of deep weathering under humid subtropical to warm temperate climate produced a variety of regoliths on the underlying rocks of Precambrian to Devonian age. Paleotopographic, paleogeologic, and two paleogeographic maps are presented. The Cretaceous sediments are predominantly sandstones and shales with a few beds of lignite. They were deposited on the eastern edge of the western epicontinental sea and include fluviatile, lacustrine, estuarine, and marine shelf facies. Out crops are scattered and exposures are poor.

STRUCTURAL STUDIES IN THE THOMSON
FORMATION, CARLTON COUNTY, MINNESOTA

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The Thomson formation is a thick series of slates and graywackes that apparently accumulated in a relatively deep, quiet basin into which turbidity currents periodically flowed. Subsequently the series has been strongly folded and is now exposed intermittently over an area of roughly 500 square miles in a belt trending south-westward from Duluth. Geologic evidence and radioactivity ages indicate that the major deformation and metamorphism are pre-Keweenaw.

Although the structural relations of individual exposures can be determined, the regional structure of the formation has remained obscure for want of distinctive key beds. During this detailed study of an area of about 35 square miles around the town of Carlton a 19 foot "marker" member was discovered and allowed the determination of the larger structural pattern in this area. A 3 mile north-south cross-section reveals 3 large synclines and 2 anticlines with many minor folds on their limbs. Although earlier thickness estimates in excess of 20,000 feet may prove correct for the entire outcrop area of the Thomson formation, the thickness of exposed beds in this restricted area is approximately 3,000 feet.

The Thomson formation has been intruded by a parallel swarm of "diabase" dikes. One of these dikes contains numerous anorthosite and anorthositic gabbro inclusions. These inclusions range in diameter from a few inches to 3 feet and are believed to be related to the Duluth gabbro complex. If so, they represent the southwesternmost known occurrence of such rocks.

Throughout the area evidence of gentle post-folding deformation is well exposed. Cleavage planes have been slightly opened in places, the "NE" joint set has been enlarged, "late" faults show near vertical displacement, and the dike swarm has been emplaced parallel to and probably occupying the widened joint set. These features are probably related to the subsidence of the Lake Superior syncline.