MINNESOTA GEOLOGICAL SURVEY

PAUL K. SIMS, *Director*

Information Circular 7

SUMMARY OF FIELDWORK 1969

UNIVERSITY OF MINNESOTA

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1969

MINNESOTA GEOLOGICAL SURVEY

The Minnesota Geological Survey has the responsibility for conducting investigations of the geology of Minnesota for the benefit of the citizens and industries of the State. It carries out this responsibility by geologic mapping of the rock strata, by research on the occurrence, quality and usefulness of mineral resources, and by publication of the results.

A list of publications of the Minnesota Geological Survey is available upon request. The publications include a bulletin series, geologic map series, miscellaneous map series, reports of investigations, special publication series , educational series, information circulars, reprint series, summary reports, miscellaneous reports, and other maps and charts.

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SUMMARY OF FIELDWORK

1969

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INTRODUCTION

The purpose of this report is to summarize the status and results of field work and other research carried out by personnel of the Minnesota Geological Survey during the past year. In addition, summaries are presented for research financed mainly by other sources but supported by the Survey. The report supplements the annual newsletter, which contains outline maps showing the status of the State geologic (bedrock) map atlas and gravity programs and other data on Survey activities.

An index map that shows the status of detailed geologic mapping in northeastern Minnesota is included in the report (fig. 1).

Maps of areas of immediate interest to the mining industry will be placed in open files during the year, to make them available at the earliest possible time. A list of other maps and reports that are being prepared currently for publication is given in the 1969 Newsletter.

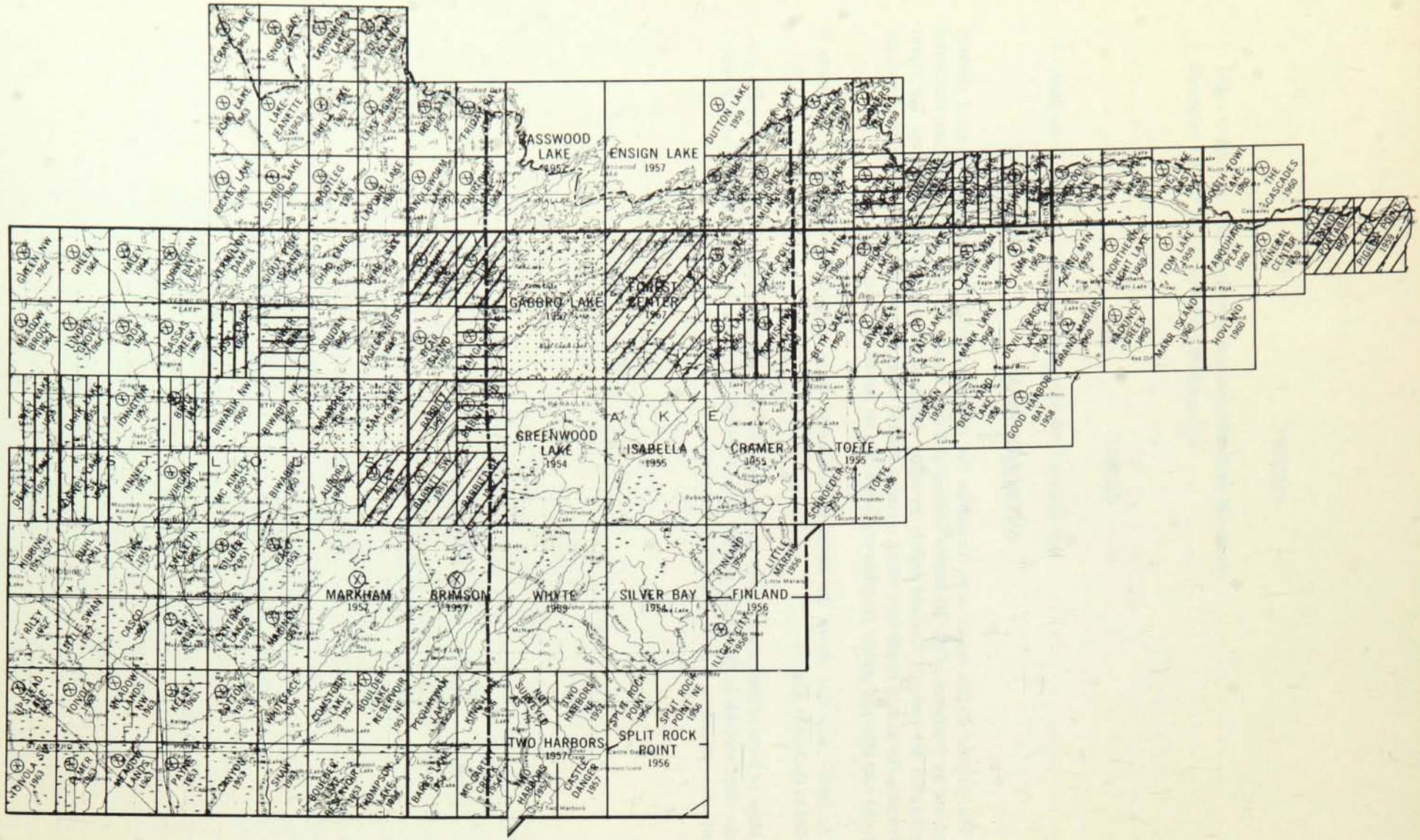

Figure 1 Index to geologic quadrangle mapping, northeastern Minnesota. (Stippled area, published; vertical-lined, mapping completed; diagonal-lined, mapping in progress; horizontal-lined, open-file maps available).

BEDROCK GEOLOGIC MAP, STILLWATER SHEET

by

G. S. Austin

During the summers of 1968 and 1969 stratigraphic information from water wells in the area of the Stillwater 1:250,000 sheet was collected by Darryl Tharalson. The information, from several thousand wells, has been placed on cards and added to the Survey files. The data are being plotted and contacts on the Pre-Pleistocene bedrock surface are being drawn at the present time. Outcrops in the extreme eastern and western parts of the sheet will be examined during next field season.

BEDROCK GEOLOGIC MAP, NEW ULM SHEET

by

G. S. Austin

The bedrock geologic map of the New Ulm sheet is virtually completed. The collection of stratigraphic data from water well drillers was completed in 1968. Examination of outcrops in the Minnesota River Valley and in the smaller tributaries by J. A. Grant was finished during 1969. A preliminary simple Bouguer gravity map, completed in 1969 by R. J. Ikola, has been placed in open files. An aeromagnetic survey of most of the area was published by the U. S. Geological Survey in 1969 as Geophys. Inv. Map GP-560.

BEDROCK GEOLOGIC MAP, TWO HARBORS SHEET

by

J. C. Green

Reconnaissance mapping was continued on the Two Harbors map sheet in both the Lower Precambrian (vicinity of Ely) and Keweenawan (North Shore) areas. Several other Survey geologists (Bonnichsen, Davidson, Morey, Phinney, and Weiblen) were also mapping in this area, and their work is being collated and integrated. The new mapping constitutes both restudy of areas previously mapped and published (e.g., MGS Bull. 39) and mapping of areas for which no published information is available (as in certain parts of Lake and Cook Counties). This work is developing a picture of the Keweenawan rocks markedly different from that shown on the 1932 Geologic Map of Minnesota, particularly in bringing out the complex and abundant intrusive bodies, ranging in composition from troctolite to granite, which intrude the North Shore Volcanic Group; in breaking up the previously-shown linear band of "granophyre" at the southeastern margin of the Duluth Complex; and in outlining many internal contacts between anorthositic, gabbroic, and troctolitic masses within the Duluth Complex itself. Next summer's field studies should complete the map.

BEDROCK GEOLOGIC MAP, DULUTH SHEET

by

G. B. Morey

Geologic mapping in the 1:250,000 Duluth sheet was started July 1, 1968, and approximately 60 percent of the sheet has been completed. Emphasis has been placed on the eastern half where exposures, although not abundant, are fairly common.

Bedrock in the Duluth sheet ranges in age from Middle to Late Precambrian. The Thomson Formation of probable Middle Precambrian age is inferred to underlie approximately 40 percent of the Duluth sheet. The formation comprises a thick series of slates and graywackes that apparently accumulated in a relatively deep, quiet-water basin into which turbidity currents flowed (Morey and Ojakangas, 1969, in prep.) Subsequently the rocks have been strongly folded and are now intermittently exposed over an area of roughly 500 square miles in a belt trending southwestward from Duluth.

Although the structural relations of individual exposures can be determined, the regional structure of the Thomson Formation has remained obscure for lack of distinctive key beds. In general, the formation is folded into large, open anticlines and synclines, with many minor folds on their limbs. Evidence of gentle post- folding deformation is readily observable in the northeastern part of the Thomson outcrop area. Cleavage planes have been opened in places, the northeast joint set has been enlarged, "late" faults showing near vertical displacement are common, and a sub-parallel swarm of diabasic gabbro dikes have been emplaced parallel to and probably within the widened joint set.

The metamorphic grade of the Thomson rocks increases from the vicinity of Duluth toward the southwest to the vicinity of Denham, where the formation is intruded by a series of granitic rocks (Woyski, 1949) that were emplaced during the Penokean orogeny at around 1.7 b.y. ago (Goldich and others, 1961). The rocks in the northeastern part of the outcrop area are characterized by a mineral assemblage containing quartz-albite-chlorite-muscovite-calcite-dolomite.

From Atkinson to Moose Lake, where the formation consists of interlayered phyllite and metagraywacke, the dominant metamorphic mineral assemblage consists of quartz-plagioclase-chlorite-muscovite-biotite-calcite. Plagioclase ranges in composition from albite at Atkinson to oligoclase at Moose Lake.

From Moose Lake southward, beds of massive metagraywacke and biotite schist alternate. Garnet first appears at Moose Lake in the more quartzose and feldspathic metagraywacke beds. In addition, hornblende first appears in the more calcareous beds. Dominant mineral assemblages are: (1) quartz-oligoclase-chlorite-biotite- muscovite-garnet, or (2) quartz-oligoclase-chlorite-biotite-muscovite-hornblende- apatite.

At Denham, near the contact with the McGrath Granite Gneiss, staurolite and epidote also appear in the Thomson Formation.

West of Denham, intercalated coarse-grained muscovite-biotite schist and augen gneiss are exposed. The augen gneiss has been assigned to the McGrath Granite Gneiss although it is not clear whether this rock represents deformation of a pre-existing granite (Harder and Johnson, 1918), highly metamorphosed beds of the Thomson Formation with addition of potassium through metasomatism (Schwartz, 1942, p. 1014), or lit-par-lit injection of the Thomson Formation by a younger granite (Woyski, 1949). In any event, the gneiss is characterized by a mineral assemblage containing quartz-oligoclase-orthoclase-microcline-muscovite-biotite and chlorite.

Mapping indicates that the McGrath Granite Gneiss may contain two distinct rock units: a pink augen gneiss, similar to that at Denham, and a schistose granite with abundant biotite that occurs in thin laminae. Contact relations may be either conformable or disconformable to the foliation direction. It is hoped that laboratory studies presently underway will provide additional evidence pertaining to this problem.

The McGrath Granite Gneiss is intruded by the Warman Quartz Monzonite, a massive light-gray rock containing 60 percent feldspar, 25-30 percent quartz and 5-10 percent biotite. It contains numerous inclusions of biotite schist and biotite- bearing metagraywacke.

Contact relationships between the Warman Quartz Monzonite and the Hillman Tonalite which crops out west of the Warman outcrop area on the south shore of Mille Lacs Lake have not yet been defined. The Hillman Tonalite is a foliated rock containing abundant biotite schist inclusions. The rock is gray, medium-grained, and consists of approximately 45 percent plagioclase, 40 percent quartz, 10 percent biotite, and 5 percent hornblende.

Middle Keweenawan igneous rocks are exposed along the eastern edge of the Duluth Sheet. Lava flows and the Duluth Complex were originally mapped in the Duluth area by Taylor (1964) and no additional work has been done there. However, the Middle Keweenawan flows east of the Douglas fault were reevaluated as part of this study. These rocks are known to underlie about 500 square miles in an area that borders Wisconsin for about 75 miles. As such, the outcrop area lies almost wholly within the drainage basin of the St. Croix River; these rocks are the southwesterly extension of the lava flows exposed in northern Minnesota, Wisconsin, and Michigan within the Lake Superior syncline (White, 1957). The lava flows are predominantly basalt or basaltic andesite in composition, containing essential plagioclase (generally labradorite), augite, and minor olivine. Most of the flows have an ophitic, diabasic, or porphyritic texture. The uppermost part of many individual lava flows is conspicuously amygdaloidal and contains variable amounts of vesicles filled with secondary minerals. In a few flows, the vesicular crust is brecciated, and now consists of rubbly or fragmental material in which both amygdules within fragments and interstices between fragments are filled with secondary minerals. Secondary minerals include quartz, calcite, chlorite, epidote, laumentite, and prehnite. Native copper and malachite, when present, are intimately intergrown with prehnite.

Beds of conglomerate or sandstone lie between the lava flows and range in thickness from less than three feet to more than 300 feet. The conglomerates consist of decomposed pebbles to boulder-sized clasts of diverse origin cemented by a matrix of red or reddish-brown lithic sandstone. Locally the conglomerates are crudely graded and cross-bedded; they have many features indicative of fluvial deposition.

Intrusive rocks are rare. Small dikes averaging about five feet in width cut the lava flows at several localities. The dikes have a well-developed diabasic texture and are probably co-genetic with the lava flows.

Most of the structure within the area is obscure for want of good exposures. Gravimetric surveys have shown that these flows form a part of the St. Croix horst. The horst has been elevated several hundred to a few thousand feet above adjacent upper Keweenawan sedimentary strata. In Minnesota, the horst is bounded on the northwest and west by the Douglas fault, a high-angle reverse fault, the south side of which is upthrown. Outcrop data, drill-hole information, and aeromagnetic data (Marcellus, 1968) all strongly indicate that the Douglas fault is cross-faulted by at least two northwest-trending faults. However the geographic extent of these faults and their apparent displacement do not appear to be very large.

Upper Keweenawan sedimentary rocks flanking the St. Croix horst in Minnesota have been divided into the older Fond du Lac Formation and the overlying Hinckley Sandstone. The Fond du Lac Formation previously has been mapped and described by Morey (1967) and the Hinckley Sandstone is the subject of a current investigation by R. W. Ojakangas.

It is expected that geologic mapping will be completed during the 1970 field season. Special emphasis will be placed on the relationship between the Cuyuna range described by Schmidt (1964) and the Thomson Formation, and on the interrelationships between the various Penokean age igneous rocks that crop out within the Duluth Sheet.

BEDROCK GEOLOGIC MAP, ROSEAU SHEET

by

R. W. Ojakangas

Mapping of the northeastern part of the Roseau two-degree (1:250,000 scale) sheet was initiated this past summer. This area contains most of the outcrops within the map sheet. Thirteen 7-½ minute quadrangles were essentially completed; most known outcrops were visited and topographic highs were checked for additional exposures. Information furnished by mining companies and local residents was extremely helpful. Gravity data furnished by R. Ikola allowed for a more accurate placing of contacts. Aeromagnetic maps of the area, and areomagnetic and geologic maps of adjacent Canada were also utilized.

Pillowed greenstone, mixed felsic to intermediate metasedimentary and metavolcanic rocks, pink and gray granites, granitic gneisses, amphibolitic gneisses, and diabasic diorite constitute the rocks of the area.

Most bedding and foliation measured in the area trends northeastward and dips steeply, and apparently reflects the limbs of major folds. Lineations in the metavolcanics and metasediments generally plunge steeply either to the southwest or northeast; lineations in the gneisses in the northwestern and southwestern parts of the area and in four intrusive granites within the area, on the other hand, are differently oriented.

Outcrops exist on two pillowed greenstone belts. One belt, exposed three to five miles southwest of Birchdale, is about 3 miles wide and appears to lie within a northeast-trending syncline. The other belt, one mile east of Clementson, is about half a mile wide and appears to be on the southeastern flank of another northeast-trending syncline. A third greenstone belt crops out in the International Falls 1:250,000 sheet in the vicinity of Indus and Manitou, within eight miles of the Roseau sheet; this belt probably enters the Roseau sheet three to four miles south of the Rainy River. The greenstones appear to be gradational with and largely interbedded with felsic to intermediate metasediments (mostly chloritic and biotitic schists) and metavolcanics.

The diabasic diorite dikes, the youngest rocks in the area, trend north- northwest and generally range in width from 125 to 400 feet. Parts of the same dikes have been mapped in Canada, and individual ones apparently are exposed intermittently over a total length of 65 miles.

BEDROCK GEOLOGIC MAP, HIBBING SHEET

by

P. K. Sims

Mapping was completed during the summer and final compilation is in progress. A preliminary geologic map of the northeastern part of the sheet, which includes the western part of the Vermilion district and the eastern part of the Mesabi range, was published in 1968 as MGS Miscellaneous Map M-5. The comments that follow apply to the western part of the sheet.

Exposures are sparse in the western half of the sheet, except locally in areas of mafic volcanic rocks, and delineation of rock units is dependent to a substantial degree on interpreting aeromagnetic (U.S. Geol. Survey Geophysical map GP-472) and gravity (MSG Misc. Map M-3) data. A major greenstone body composed dominantly of mafic-intermediate volcanic rocks trends northeastward across the northwestern part of the map sheet. It is estimated to be about 25 miles wide; the southeastern margin extends from the vicinity of Ball Club Lake (T.145N., R.26W) northeastward to the Linden alkalic pluton (T.62N., R.21W). The body is bordered on the north by metagraywacke and on the south by the Giants Range batholith. A granitic pluton centered at Effie, which has an areal extent of about 100 square miles, cuts the mafic volcanic unit; another granitic pluton that trends northeastward and is at least 20 miles long is inferred to intrude the mafic unit in the area south of Big Fork. Both granitic bodies are marked by conspicuous gravity "lows."

Another mafic volcanic unit, which may connect with the major body, trends northwestward from the vicinity of Day Lake to the Bear River. It is cut by several northwest-trending gabbroic dikes.

The lithologies of the greenstone belts are poorly known. Banded iron- formations occur sporadically; felsic rocks have not been observed and cannot be distinguished with certainty from available geophysical data.

The western part of the Mesabi range crosses the southwestern part of the sheet. Some prominent faults that are known to be present on the range, and are the loci of natural ores, are aligned with lineaments in the older rocks. Tentatively we conclude that many of the faults in the Middle Precambrian rocks of the Mesabi range represent rejuvenated, older faults.

Sulfides, mainly pyrite, are widely dispersed in the strata within the greenstone belts. A few sulfide-bearing quartz veins were observed in the mafic rocks in T.62N., R.22W., west of the Linden pluton.

BEDROCK GEOLOGIC MAP, INTERNATIONAL FALLS SHEET

by

D. L. Southwick

Semi-reconnaissance geologic mapping was carried south and east from the vicinity of Kabetogama Lake to the vicinity of Loon Lake on the Minnesota-Ontario border during the past field season. Shoreline outcrops were examined along the Minnesota side of the Border lakes from Kabetogama Narrows to Loon Lake, except for a three-mile stretch east of Junction Bay on Namakan Lake. In addition, some traverses were made in the Johnson Lake, Marion Lake, Elephant Lake, Myrtle Lake, Kabustasa Lake, Echo Lake, Jeanette Lake, and Buyck 7-½ minute quadrangles, generally south and west of Crane Lake.

The principal rocks throughout this area are various phases of the Vermilion Granite "batholith" of Grout. It is more accurate, however, to think of these rocks as a migmatite-granite massif rather than as a classical intrusive batholith, for all possible mixtures and gradations between massive granite, migmatite, gneiss, and wallrock schist, amphibolite, and greenstone occur. A complex history of deformation, mobilization, and injection is indicated.

Within the migmatite-granite massif a coherent structural picture is preserved. Foliations and lineations measured in the more gneissic rocks clearly indicate broad, gently east-plunging regional folds that have been disrupted to some degree by late-phase granite injection and post-granite faulting. A northwest- trending left-lateral fault having a half-mile horizontal separation passes through Hammer Bay of Namakan Lake. A larger fault may pass through Grassy Bay of Sand Point Lake and continue southeastward under Little Vermilion Lake, but its existence has not been proved unequivocally.

Deposits of valuable minerals were not found in the area in economically significant amounts. Pyrrhotite and chalcopyrite are disseminated in biotite gneiss at an old gold mine site in the SW ¼ of sec. 36, T. 67 N., R. 18 W., and sparsely disseminated in amphibolite in sec. 33, T. 66 N., R. 17 W. At both localities the mineralized rock appears to be a local "inclusion" a few feet or tens of feet in size, surrounded by barren pink granite. Small concentrations of pyrite were noted in migmatitic biotite gneiss south, east, and northeast of Myrtle Lake.

SURFICIAL GEOLOGIC MAP, DULUTH AND STILLWATER SHEETS

by

E. J. Cushing

The surficial deposits in the Duluth and Stillwater 1:250,000-scale sheets are largely the result of the activity of the Superior Lobe and the Grantsburg Sublobe of the late-Wisconsinan ice sheet, and a major purpose of the project is to investigate the history of that activity and explain its effects on the landscape. The study to date has concentrated on the stratigraphy of the deposits as exposed in the field and the geomorphology of the region as interpreted in the field from aerial photographs and the large-scale topographic maps that are now becoming available. Field compilation of maps of the surface lithologic and geomorphic units is essentially complete for most of the area. Yet to be completed are the collection and interpretation of available subsurface data and the analysis of the lithology of the drifts to supplement the field and initial laboratory descriptions. When completed, the maps will cover all of the Minnesota portions of the Stillwater and Duluth sheets except the area north and west of Mille Lacs Lake; interpretation of the complex glacial geology of that region must wait for extensive reconnaissance of the area covered by the St. Louis Sublobe in adjoining sheets to the north and west.

The map units include complex till sheets whose highly variable lithology is interpreted as the result of erosion and mixing of older drifts by the advancing glacier lobes. This interpretation makes possible a simpler explanation of the geomorphic features, which include tunnel valleys and associated eskers formed by subglacial drainage as well as extensive drumlin fields, moraines, tills, outwash, and lake plains. The interaction of active glaciers and their deposits with extensive masses of older stagnant ice is a unique feature of the history of the area. The mapping of terraces and other drainage features along the St. Croix, Kettle, Snake, and Rum Rivers and their tributaries, now possible with the completion of topographic mapping in those watersheds, is proving essential to the correlation of glacial events over the area.

Three weeks were spent in the field during the summer of 1969. The work included the collection of drift samples for lithologic analysis; detailed reconnaissance in the Cambridge quadrangle, a complex area that contains important clues to the behavior of the Grantsburg Sublobe; and field checking of several critical areas in Mille Lacs and Kanabec Counties for which topographic maps have just become available.

SURFICIAL GEOLOGICAL MAP, NEW ULM SHEET

by

Charles L. Matsch

This mapping project has a two-fold aim; (1) to produce a more detailed map of the surficial materials than now is available for land use planning as well as for economic exploitation of the new deposits themselves, and (2) to expand our knowledge of the Quaternary history of southwestern Minnesota.

Although at least five distinct glacial episodes are recorded in the Quaternary deposits of the New Ulm sheet, the greatest volume of sediments is attributable to two glacial depositional events that occurred after 34,000 years B.P. The sediments consist mainly of till, in association with a wide variety of sorted glacier-derived sediments of various origins.

The oldest of these glaciations is represented by massive deposits of till and outwash, herein informally called the "older formation", which comprise the bulk of the subsurface Quaternary sediments in the entire area. They are extensively exposed in the sheet only along the Minnesota River. The surface deposits on the uplands flanking the valley, herein called the "younger formation", consist of glacial till of the last ice advance, along with glaciofluvial and lacustrine deposits associated with the stagnation and melting of glacier ice. Alluvial deposits underlie terraces and the modern floodplain in the Minnesota River Valley.

The "older formation" consists of both till and outwash deposits. It is exposed extensively along the valley walls of the Minnesota River throughout the entire sheet. At Morton, North Redwood Falls, and New Ulm this formation lies disconformably upon a soil horizon containing wood fragments that have been C^{14}-dated as 34,000 years old. The major facies is a buff (oxidized) to gray (unoxidized) calcareous, silty to clayey till that contains about 50 percent carbonate pebbles; crystalline rock types make up most of the remaining pebbles. Cretaceous shale is absent or present in small quantities (1% to 3%). Outwash bodies, which are well-sorted sand and gravel deposits that generally lack shale, are irregularly distributed at both the base and the top of the formation. In the subsurface these porous and permeable lenses are important local aquifers, and at the surface they are extensively mined for construction materials. The formation generally is more than 30 feet thick and commonly is more than 100 feet thick. Where the base of the formation is exposed, it is seen to lie nonconformably at many places on regolith of the Precambrian crystalline rocks. The top of the formation is marked by an extensive boulder pavement, generally only one-stone thick, produced by subaerial erosion. The upper contact of this important stratigraphic marker with the superjacent till is planed and striated.

The surface deposits over most of the New Ulm sheet consist of till, glacial outwash, and lacustrine sediments, herein called the "younger formation". The till is buff, calcareous, and generally silty. A distinctive feature is its content (10-30 percent) of Cretaceous shale fragments. As much as 50 percent of the pebbles are carbonates. Sorted sediments are in the form of outwash fans, crevasse fillings, braided valley trains, deltas, and lake sediments. The geometries of the sedimentary units vary according to their origin. Sand and gravel deposits associated with this formation are not suitable for many uses because of the high percentage of fissile shale generally present. The formation thickens in both directions transverse to the Minnesota Valley. Along the valley axis it is commonly just a veneer of till a few feet thick. Toward the outer margins of its exposure, the formation thickens to many tens of feet. Shale content of the till also decreases away from the valley.

Scattered exposures of glacial drift along the valley sides of the Minnesota River stratigraphically lower than the "older formation" of this report indicate that the area had a complex glacial history prior to 34,000 years ago. Some exposures northeast of Montevideo consist of as much as 40 feet of red sandy till that contains erratics of a Lake Superior aspect, which lies directly beneath till of the "older formation". In the valley between Redwood Falls and Mankato, a black, calcareous till lies beneath the "older formation".

Alluvial deposits are common in the Minnesota River Valley as a number of terraces underlain by boulder and cobble gravel. The modern floodplain is composed of fine sand and silt. Colluvial aprons of silt and sand and eroded slump blocks also are a part of the present valley fill.

The wide and deep Minnesota River Valley follows the northwestward trending axis of a topographic trough that is more than 100 miles wide. This trough on the present landscape apparently reflects a similar configuration of the underlying bedrock. The flanks of the trough are rimmed by massive moraines and ice stagnation complexes of both the "older" and "younger formations". The detailed interrelations of these features will be documented in a later report.

The broad central part of the trough is characterized by a distinctive topography consisting of oriented positive landforms (mainly crevasse fillings), and by linear depressions that appear to be abandoned meltwater channels. Previously many of the crevasse fillings were interpreted as recessional moraines.

The Quaternary history can be summarized as follows. Multiple glaciation is proven by the superposition of several glacial tills having intervening weathered zones, including paleosols and boulder pavements. Erosional episodes between glacial events have removed most of the deposits that were left by earlier Quaternary glaciers. The sediments exposed in the New Ulm sheet belong for the most part to the Wisconsin Stage of the Pleistocene Epoch. The important events represented are:

1. A glacial advance before 34,000 years ago from the Lake Superior Basin that reached the northwest corner of the sheet.
2. A second advance (older formation) after 34,000 years ago that covered the entire sheet from a northern direction, and retreat of this ice sheet to a temporary position north and east of the sheet, accompanied by the concentration of a boulder lag as the result of subaerial erosion.
3. Advance of a glacier from the northwest that deposited a veneer of till over the boulder pavement (younger formation), followed by stagnation and retreat of this ice lobe from the area before 11,300 years ago.
4. Drainage of Glacial Lake Agassiz through a southern outlet at Browns Valley that eroded the present Minnesota River Valley.
5. Recent modifications of the landscape by the development of drainage networks.

GRAVITY INVESTIGATIONS IN MINNESOTA

by

R. J. Ikola

Progress continued during 1969 toward completing a Bouguer gravity map of Minnesota. The areas surveyed during the past field season are shown in Figure 2. A La Coste-Romberg geodetic gravimeter was used to make the gravity measurements, and U.S.G.S. topographic maps were used to establish vertical and horizontal control. Readings were taken on a one- or two-mile grid, depending on local variations in the gravity field.

It is tentatively concluded from the unreduced gravity data that several greenstone belts occur in northwestern Minnesota. The smallest of these enters Minnesota in the vicinity of Birchdale, in Koochiching County. It continues approximately 15-20 miles southwestward where it apparently is cut off by a large granitic pluton that extends northward from Upper Red Lake. A second possible greenstone belt occurs along the Minnesota-Manitoba border west from Roseau. A large belt of coextensive metavolcanic and metasedimentary rocks crosses Rainy River at the city of Baudette. This belt continues southwestward to the vicinity of Grygla in Marshall County, where it appears to widen substantially. The present gravity survey has delineated this belt to the vicinity of Thief River Falls and Newfolden.

A north-south gravity anomaly, believed to be caused by a dike-like basic igneous body as much as two miles wide, enters Minnesota at the west edge of Lake of the Woods, passes through the city of Warroad, and extends at least 10 miles farther south. A residual gravity anomaly of 15-20 milligals occurs over this body. Water wells at Warroad over this anomaly are reported to have penetrated "black granite."

A grid of gravity stations with a half mile spacing is being established over the Roseau Lakebed northwest of Roseau. The Roseau Lakebed occupies a nearly circular depression three miles in diameter which could possibly be a meteor impact crater.

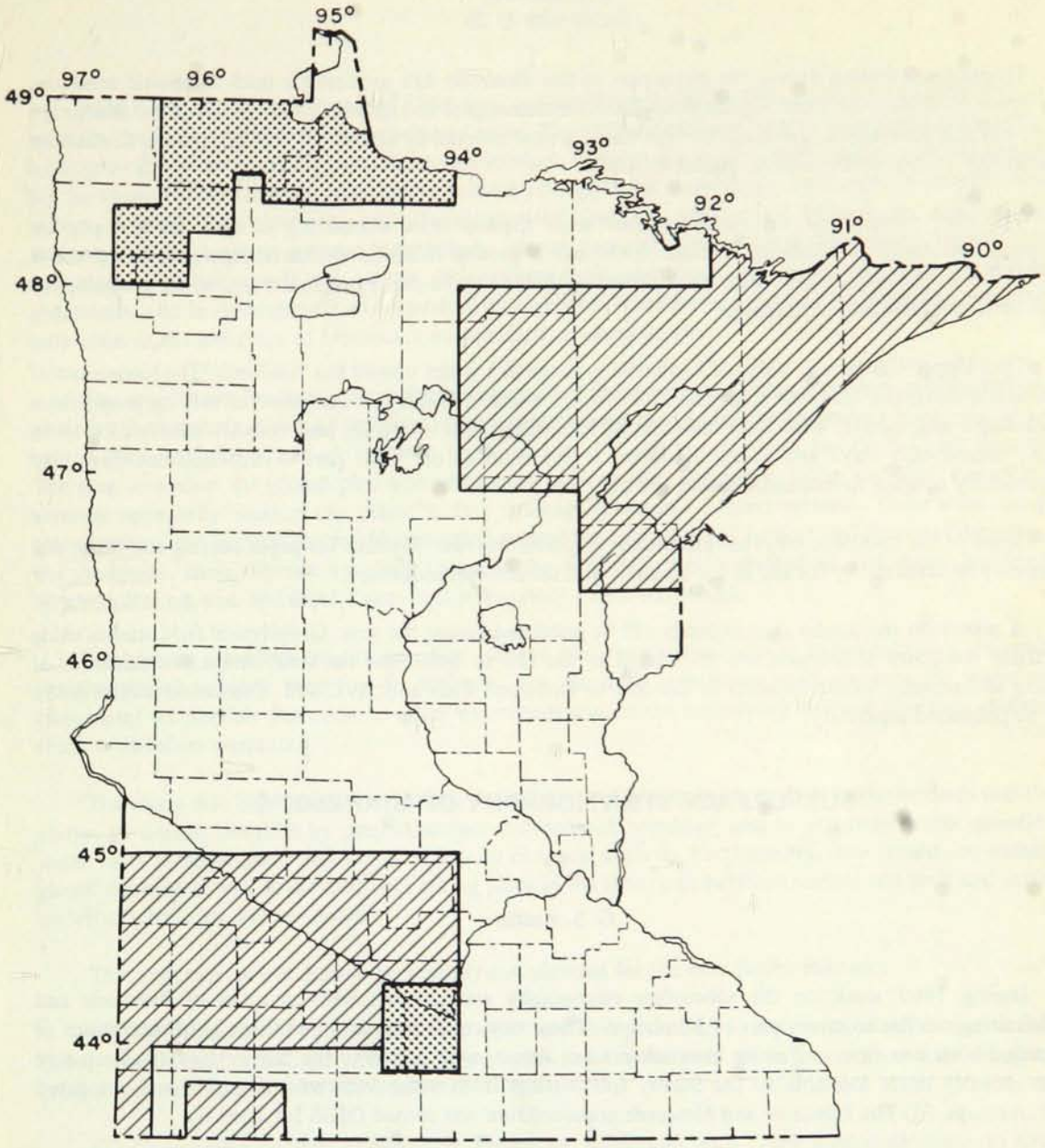

Figure 2 Status of gravity surveying in Minnesota. (Lined area surveyed previously; stippled area surveyed in 1969.)

GEOLOGY AND MINERALOGY OF MINNESOTA KAOLIN CLAYS

by

W. E. Parham

Tropical weathering during the latter part of the Mesozoic Era produced a thick kaolinitic residuum over much of Minnesota, mainly from Precambrian metamorphic and igneous rocks. Much of the weathered zone, which is generally as much as 100 feet thick, is now covered by at least 25 feet of younger Cretaceous sedimentary rocks and Pleistocene glacial deposits.

The clay minerals of the residuum that were formed from weathering of felsic rock types are composed primarily of kaolinite. Tubular halloysite is present in minor amounts, especially in the lower part of the weathering profile. Mafic rock types weathered first to montmorillonite and under progressively more intense weathering to kaolinite.

Two Upper Cretaceous units of kaolinitic sedimentary rocks overlie the residuum. The lowermost of these has a maximum observed thickness of 45 feet, is white or tan, and is composed of varying proportions of kaolinite and quartz, with trace amounts of halloysite. The overlying unit consists mostly of gray to black, organic-rich clays and shales. Kaolinite is abundant in the basal part of this unit but gives way progressively upward to montmorillonite and illite.

Some of the kaolinitic clays are potentially important as raw materials for paper coating and filler, and some may be satisfactory for use in the ceramics and refractories industries.

A report on the kaolin clay deposits will be published during the year. Geophysical field studies using electrical resistivity techniques will be started in the fall to determine the areal extent and thickness of certain sedimentary kaolin deposits in the area of Redwood Falls and St. Cloud. The results of this study will be published separately.

SUBSURFACE STRATIGRAPHY OF MINNESOTA

by

G. S. Austin

During 1969 work on the subsurface stratigraphy was concentrated on rocks of Paleozoic and Mesozoic age in the southern part of Minnesota. Three objectives were accomplished: (1) Descriptions of outcrops, both new ones and older ones taken from theses, were added to the Survey files. (2) Deep core holes recently made available to the Survey and cuttings from water wells were described and compared with outcrops. (3) The Paleozoic and Mesozoic nomenclature was revised (MGS Inf. Circ. 6).

Several papers concerned with the subsurface stratigraphy of southern Minnesota will be published in the near future (see 1969 Newsletter). A paper concerned with the interface between rocks of Late Cretaceous age and the underlying Precambrian Sioux Quartzite near New Ulm, Minnesota, "WEATHERING OF THE SIOUX QUARTZITE NEAR NEW ULM, MINNESOTA, AS RELATED TO CRETACEOUS CLIMATES," will be published in the March 1970 issue of the Journal of Sedimentary Petrology.

HYDROGEOLOGIC STUDIES OF GROUNDWATER IN SELECTED AREAS OF THE TWIN CITIES METROPOLITAN AREA

by

H. O. Pfannkuch

Field work during the summer of 1969 was conducted to survey the Twin Cities metropolitan area and to study the hydrogeology of certain selected areas. The ultimate purpose of the study is (1) to describe the hydrogeology of the area, (2) to establish relationships between the general geology and geohydrology, and (3) to show the distribution and characteristics of significant hydrologic units such as buried bedrock valleys, ancient river terraces, and glacial contact features. Of special interest are the hydrologic interconnections between present morphology, glacial deposits, and bedrock. Knowledge of the natural hydrological situation will aid in the development and protection of water resources, in pollution abatement, and in development of watershed management procedures. Continued observation will give an indication of the influence of urbanization on watershed characteristics.

The area chosen for study, the southwestern part of the urbanized Minneapolis area, is bounded on the north by the southern divide of the Minnehaha watershed, on the east by the Mississippi River, on the south by the Minnesota River, and on the west tentatively by the western divide of the Bluff Creek Watershed. The area comprises the geomorphic watershed areas of Nine Mile, Purgatory, Riley, and Bluff creeks as well as areas apparently lacking any major surface drainage connected to river systems. These areas comprise among others the eastern part of Bloomington around the International Airport and the areas draining into the Anderson, Bush, Hyland and Neil Lakes in the Nine Mile Creek watershed, and those draining into Mitchell, Round, and Red Rock Lakes in the Purgatory Creek watershed.

In choosing a subject area, it was soon evident that comparatively fewer hydrologic data are available for the glacial deposits than for the bedrock. Yet the drift constitutes both a source for water and a transmitter of possible pollution to other watersheds and to the underlying bedrock aquifiers. A detailed study is therefore warranted.

The study will be organized to identify logical units of investigation such as the watersheds mentioned above, to delimit the drift by present surface and bedrock topology, and to inventory water quantity by water table measurements and water quality by chemical analysis. Furthermore, flow conditions within the glacial deposits as well as the exchange taking place at the interfaces between surface and drift and drift and underlying bedrock will be studied.

The work carried out during the summer and planned for the near future follows:

(1) Identification of sources for information and data-gathering. Contact was established with federal, state, county, and municipal units of government and institutions, as well as with watershed districts, private industry, contractors, and landowners.

(2) Geomorphic analysis of Nine Mile, Purgatory, Riley, and Bluff Creek watershed basins, to arrive at form elements of the basins for comparison and possible relationships of topographic forms to the general hydrology and geology of the area.

(3) Detailed geological and hydrogeological mapping. Outcrops were mapped, samples taken, and well records analyzed for correlation and detailed geologic understanding of both the glacial deposits and the bedrock topography. Significant hydrogeological data were obtained, such as location of wells and springs, surface flow rates, surface water, and groundwater temperatures.

(4) Hydrogeochemical analysis. Water samples of lakes, rivers, springs, and wells were taken for analysis of resistivity, pH, alkalinity, hardness, and basic ions (Ca, Mg, Na, K, Cl). Results will be used both to describe quality of the water and to indicate inflow and mixing patterns of natural waters.

(5) Samples of unconsolidated drift material were collected at various localities. Mechanical grain size analyses and laboratory flow measurements are being performed to determine transmissivity and permeability. These samples will also be used to determine the glacial history of the deposits (Des Moines or Superior Lobe).

(6) Establishing an observation network. The secretary of the Purgatory-Riley Watershed District has been contacted for cooperation in planning the observation network of wells, stream and lake gauges, and precipitation measurements. Also, Rich-Carroll-Muller-Contractors have tentatively agreed to put in an observation well on the property of R. Welter (Eden Prairie) at no cost.

(7) Literature research concerning best representation of hydrogeological data on maps, as well as on other media to facilitate computer processing and analysis.

All above activities are still in progress. A continued interest in the area and the problem is expected, as this project lends itself very well to an intensified study of the effects of urbanization on the physical and chemical characteristics of watersheds. Once the natural characteristics and behavior have been studied, continued observation will provide an evaluation of the effects of urbanization. The area is ideal for this kind of study because it presents at this moment a cross section from highly developed urban areas in the east to almost completely rural characteristics in the west. Hence the effects of suburban development can be studied in space. If a sufficient observation network can be established now in one of the rural western watersheds, effects of urbanization with time can be studied, because this region is one of the fastest growing metropolitan areas in the country, and it is expected to be completely urbanized in the next 10 years.

It will be possible to generalize findings and to apply them to other metropolitan centers showing similar geologic conditions. As a matter of fact, most of the heavily populated and growing urban areas in the upper Midwest and in New England show similar geologic characteristics.

GLACIAL AND ENGINEERING GEOLOGY OF THE MINNEAPOLIS - ST. PAUL AREA

by

J. E. Stone

Mapping of the glacial geology of the Centerville 7½-minute quadrangle, in the northeastern part of the metropolitan area, was completed during the summer, and the map is being prepared for publication. The western and central parts of the quadrangle are underlain mainly by sand and silty sand and contain broad areas of swamp deposits, mostly peat and muck. Windlaid deposits of fine silty sand are common west of the lowland occupied by the numerous lakes of the area. The eastern part of the quadrangle is dominated mainly by till deposited by ice of the Grantsburg Sublobe.

It is tentatively planned next summer to complete a detailed reconnaissance map of the glacial deposits of the Seven-County metropolitan area and prepare a report that summarizes the physical properties of the various units.

GEOLOGY AND MINERAL RESOURCES OF THE MINNEAPOLIS QUADRANGLE

by

R. K. Hogberg

Urban expansion in the seven-county Twin Cities metropolitan area has for the most part displaced or shortened the operating life of aggregate properties and has hindered the industry's exploration for new near-market reserves. Study of the Minneapolis 15-minute (1:62,500 scale) quadrangle, an area of rapid population growth, has been carried out during the past three summers to provide information on the sand, gravel, and crushed rock resources for both the aggregate and associated industries and the effected communities.

Surficial mapping was performed by making field observations in natural and man-made exposures to delineate and evaluate, within a stratigraphic framework, the near-surface gravel and rock resources.

Four types of restricted gravel depositional environments are recognized: (1) braided outwash fan; (2) ice-contact deposits, including crevasse fillings, and the less important esker and kame-like deposits; (3) valley train deposits; and (4) lagged deposits in the Minnesota River Valley. Important dolomite crushed rock resources occur within the middle part of the Upper Ordovician Prairie du Chien Group at near-surface positions in the Minnesota River valley.

A report on the Minneapolis quadrangle that will include colored 1:48,000 bedrock and surficial geologic maps will be published during the coming year.

STRATIGRAPHY OF THE PRECAMBRIAN RED CLASTIC SERIES, SOUTHEASTERN MINNESOTA

by

G. B. Morey

It has been known that a great thickness of upper Precambrian (Keweenawan) sedimentary rocks lie beneath Paleozoic strata in southeastern Minnesota since these rocks were first described in 1874 by Winchell and Peckham. Although many "deep wells" have penetrated the Paleozoic cover since that time, only a few good lithologic descriptions of the Keweenawan rocks are available. Most of the descriptions available in the literature and in the files of the Minnesota Geological Survey describe the Keweenawan rocks merely as consisting of hundreds of feet of red shale or sandstone. Fortunately during a search in southeastern Minnesota in 1965 and 1966 for reservoirs suitable for the underground storage of natural gas, 13 deep test wells penetrating pre-Paleozoic rocks were drilled in Dakota and Rice counties, Minnesota. As a result of this project, an aggregate total of 3,660 feet of Keweenawan rocks was obtained. The core recovery was approximately 99 percent. The longest core penetrated an interval of 1,929 feet whereas approximately 10 feet was the shortest interval recovered. The core material obtained during this project comprises the most complete record available from the subsurface Precambrian sedimentary rocks in southeastern Minnesota, and therefore presents a unique opportunity to examine these rocks over a large continuous stratigraphic interval, and to describe in detail lithologic characteristics, sedimentary structures, and other features not normally obtained in subsurface studies.

Four cores comprising a total interval of 2,923 feet have been described and studied in greatest detail. The cores were logged on a foot to foot basis with special emphasis placed on sedimentary structures. In addition, the mineralogy of these cores, using both x-ray and thin sections, was studied with a sample interval of approximately 10 to 20 feet. The other diamond drill cores were examined in detail sufficient to provide supplementary data that were incorporated into a detailed description.

Several reports are now in preparation which will present data concerning the origin and mode of deposition of these rocks. In addition the study has promoted a better understanding of the sedimentary and tectonic history of the Keweenawan System in the vicinity of the mid-continent gravity high, and has provided additional data pertaining to the recognition of the Precambrian-Cambrian boundary in southeastern Minnesota.

Of particular interest is the fact that the study has provided additional data regarding the nomenclature and correlation of these Keweenawan rocks. As previously stated, the first reference to these red-colored sedimentary rocks was that of Winchell and Peckham in 1874. It was generally assumed that these red-colored sedimentary rocks were correlative with similar-appearing rocks exposed at the surface near Duluth, Minnesota, and named the Fond du Lac Formation. However, Hall and others (1911) felt that there were many problems with the correlation and therefore introduced the name "Red Clastic Series" as an informal term to describe the subsurface occurrences. This dual system of nomenclature -- i.e., Fond du Lac for surface exposures and "Red Clastics" for subsurface occurrences -- has been used in Minnesota and elsewhere in the Middle West since that time. In general, the terms have been used interchangeably. For example, the term "subsurface Fond du Lac" has been used as far away as southern Illinois. However, Kerwin (1963) suggested that it was possible to subdivide the "Red Clastics" into five distinct intervals on the basis of variations in mineralogic composition. Data obtained in this study have confirmed and somewhat refined Kerwin's original classification and have shown that only one of these intervals is mineralogically like that found at the type locality of the Fond du Lac Formation (Morey, 1967).

Because of this nomenclatural confusion, the Red Clastic Series of Hall and others will be redefined and renamed in terms of modern nomenclatural usage. The term Belle Plaine Group -- after the first discovery at Belle Plaine, Minnesota -- has been tentatively suggested. As such, both the Fond du Lac Formation and the overlying Hinckley Sandstone, as well as a number of lithologically distinct, but as yet unnamed intervals will be included within the Belle Plaine Group.

PALEONTOLOGICAL INVESTIGATIONS OF PALEOZOIC STRATA OF MINNESOTA

by

G. F. Webers

This project was initiated this past summer with two main objectives:

(1) An investigation of microfossils in the lower Paleozoic strata of Minnesota, to ascertain the possible distribution of conodonts, scolecodonts, and chitinozoa. Strata involved include the St. Peter Sandstone, the Prairie du Chien Group, and the Jordan, St. Lawrence, Franconia, Galesville, Eau Claire, and Ironton Formations. With the exception of the Prairie du Chien Group, microfossils have not been reported previously from these units although they are present in correlative formations in other areas.

(2) A conodont investigation of the Glenwood Formation. Preliminary investigation has indicated the presence of three different conodont faunas in this formation in different parts of Minnesota. An attempt will be made to determine faunal composition and geographic distribution relative to shoreline directions as determined by G. S. Austin and W. E. Parham.

This past summer's activity was primarily devoted to sampling the several units. Formations sampled include the Glenwood Shale (35 sections), the Prairie du Chien Group (5 partial sections), and small partial sections of the St. Peter, Jordan, Franconia and Eau Claire Formations. This sampling program will be continued through the fall and spring of the academic year.

One conodont-rich fauna has been found at the base of the Prairie du Chien Group, although laboratory processing of the samples is in a very preliminary stage. It is hoped that many of the samples collected during the summer can be processed during this academic year.

GEOLOGY AND GEOCHRONOLOGY OF PRECAMBRIAN ROCKS, MINNESOTA RIVER VALLEY

by

J. A. Grant

This project involves mapping the basement rocks of the Minnesota River Valley at a scale of 1:20,000 with special attention to rocks between Sacred Heart and Morton. (The Granite Falls-Montevideo area was investigated earlier by G. R. Himmelberg (MGS Spec. Pub. 5, 1968). The mapping is supplemented by petrography and geochronology, the latter being funded largely by the National Science Foundation.

Field mapping was completed this summer, and a report on the Sacred Heart- Morton area is in preparation.

In the Sacred Heart-Morton area one finds a migmatitic terrane, in which a tentative stratiformity can be delineated. From lowest to highest the units are (1) interlayered quartz-dioritic gneiss and amphibolite (2) quartz-dioritic gneiss with amphibolite blocks and lenses (3) quartz-dioritic gneiss with rare amphibolite and (4) biotite-rich gneiss and amphibolite layers and lenses. In the uppermost unit (4) the gneisses may contain sillimanite, cordierite, garnet or anthophyllite, and quartz-rich gneisses and rare quartzite are found. A metasedimentary origin is suggested.

The structure is dominated by broad folding on a shallow eastward-plunging axis, locally complicated by crossfolding.

Quartz monzonite, generally gneissic, is widespread as concordant and discordant bodies ranging from intimate permeation of the gneisses to large subconcordant plutons or discordant dikes.

Preliminary Rb-Sr analyses of the biotite-rich gneisses indicate that these are more than 3 b.y. in age, and among the oldest metasedimentary rocks known.

The lithologies found here are broadly similar to those elsewhere in the valley, but correlation of units is still dubious. The structure is similar from Ortonville downstream at least to Morton, but the metamorphic grade at Granite Falls is granulite facies in contrast to upper amphibolite facies in the Sacred Heart-Morton area.

GEOLOGY OF CENTRAL PART OF DULUTH COMPLEX

by

W. C. Phinney

This investigation is part of a large scale project intended to gain a better understanding of the overall structural and petrologic relations of the Duluth Complex.

During four weeks in the summer of 1969 field work was done in the 15-minute Forest Center quadrangle, about 85 percent of which is underlain by the Duluth Complex. Between two-thirds and three-fourths of the mapping has been completed, but this includes the more easily accessible areas. To aid the mapping, air support has been obtained from U. S. Forest Service float planes. Remaining field work must be done by overland traverses from campsites in the B.W.C.A. A set of 1967 aerial photographs has been of great value for locating positions in the field.

Results to date have further emphasized the multiple intrusive nature of the complex. Several contacts between intrusive units have been found and partially traced in the Forest Center quadrangle, but further work is necessary to determine the shapes and sizes of units.

Most of the quadrangle, including the entire southern third, is underlain by gabbroic or troctolitic anorthosite. This rock type includes several separate intrusions as evidenced by dikes and inclusions of one type of anorthosite in another. Structural relations within the anorthosites are complex and appear to represent flowage of melts heavily laden with plagioclase crystals. Many basaltic and granitic dikes as well as an extensive hornblende-biotite-plagioclase dike containing basalt inclusions, which crosses Isabella Lake, occur in the anorthosites.

In the east-central part of the quadrangle, a major intrusion into the anorthosite has a rather wide fine-grained basaltic margin, which has been traced along a N. 70°W. direction for more than five miles. This margin grades into a well flow-banded gabbro, then to pegmatitic gabbro containing Fe-Ti oxides, then to troctolite which in some areas is rather well mixed with troctolitic anorthosite. This intrusive unit generally dips about 35° N. Probably it is the same unit that lies farther to the north around Lakes Insula and Kiana, where it is nearly horizontal or has southerly dips. If so, this may be a large basin-like structure.

Within one and one-half to two miles of the north contact, the complex is primarily troctolite, with local layers having a high olivine concentration (40-50 percent). Dips measured on plagioclase laths and mineralogic layers are generally between 20° and 40° S. Rather wide dikes rich in olivine, mentioned above, occur in the anorthosite west of Lake Three and on the southern part of Lake Insula. A few inclusions of anorthosite occur in the troctolite units, but large blocks of fine- to medium-grained material are common. Some of the fine-grained inclusions are more than two miles long and lie along strike with other zones of similar material, suggesting that they may represent an earlier sill or the margin of an intrusive body. Within the troctolitic rocks there is evidence for more than one stage of troctolite intrusion. This is best illustrated at Benezie Lake where a troctolite unit is definitely intrusive into a much coarser-grained troctolite.

GEOLOGIC INVESTIGATIONS IN THE SOUTHERN PART OF THE DULUTH COMPLEX

by

Bill Bonnichsen

The purpose of this investigation is to:

(1) determine the distribution of rock types within the Duluth Complex and adjacent areas of Keweenawan-age rocks within the area bounded approximately by Duluth, Babbitt, and Lake Superior; (2) determine which rock types, geographic areas, and other aspects of the geology are worthy of more detailed examination; and (3) assist in the compilation of the Two Harbors and adjacent 1:250,000 sheets for the revised state geologic map.

Reconnaissance geologic mapping of the region is one-half to two-thirds completed. Most known outcrop areas within the southern part of the Duluth Complex have been examined and some localities in the area east of the complex have been visited.

Three specialized aspects of this regional study are in various stages of investigation:

(1) Quadrangle geologic mapping of the Hoyt Lakes-Babbitt area is nearly completed. Outcrops are fairly abundant within a few miles of the footwall contact in the Allen, Babbitt, Babbitt NE, Babbitt SE, and Babbitt SW 7½-minute quadrangles. The majority of these outcrops have been examined and sampled. A preliminary geologic map currently is being drafted and will be placed in open files. Detailed examination of samples from the area and rechecking of some of the field localities will be necessary prior to publication of the maps.

(2) A chemical and petrologic investigation of the origin, metamorphism, and possible metasomatism and partial melting of various types of inclusions within the complex is in the initial stages. Samples that were collected from a number of localities and a variety of geologic situations are undergoing preliminary petrologic investigation in order to pick the ones necessary for chemical analysis and detailed petrologic investigation.

(3) An examination of available long drill cores from the footwall area of the Duluth Complex is in a very preliminary stage. Parts of a few cores were examined during the summer of 1969 in order to plan how to handle the data that will be generated by this aspect of the investigation.

Several geologic points of interest are worth noting:

(1) The intrusive rocks along the western side of the southern part of the Duluth Complex are troctolitic at almost all localities. These rocks are younger than the anorthositic, gabbroic, and volcanic rocks that lie to the east. Very similar troctolitic rocks have been encountered as far southeast as the southern part of the Two Harbors 15-minute quadrangle.

(2) Anorthositic rocks are present in many areas in the southern part of the complex, but are not as abundant as in parts of the northern segment of the complex.

(3) Areas of hornfels, some having dimensions of hundreds or thousands of feet, are present at many localities within the Duluth Complex and in the area to the east of the complex. The nature of these hornfelses is variable; it is suspected that some are metasediments (Virginia Formation?) whereas many others appear to be volcanic in origin.

(4) The area between Lake Superior and the eastern side of the Duluth Complex, shown on the 1932 geologic map of Minnesota as Keweenawan lava flows, actually consists dominantly of intrusive rocks, mainly gabbros. Volcanic rocks are abundant only within a few miles north and east of Duluth, within a mile or two of Lake Superior, and locally in the northern part of the Whyte 15-minute quadrangle.

(5) The gross structural relationships within the Duluth Complex and between the complex and the rocks lying to the east are not as yet clear. It is apparent, however, that the "lopolith" concept for the structural form of the Duluth Complex is very misleading, in part because the complex is made up of a great number of separate intrusions.

GEOLOGY OF THE FELSIC ROCKS IN THE DULUTH COMPLEX

by

Donald M. Davidson, Jr.

The purpose of this project is to delineate the variety, extent, and structure of felsic rocks associated with the Duluth Complex. During the past summer, special emphasis was placed on comparing granophyric and other felsic rocks throughout the complex as a basis for a summary paper. Also, field mapping was carried out east of Sawbill Lake in the Beth Lake, Kelso Mountain, and adjacent quadrangles, an area shown on the 1932 State Geologic Map as containing two major granophyre units.

The following conclusions were made from the past summer's efforts:

(1) The felsic rocks of the Duluth Complex consist of a variety of rock types that nevertheless are remarkably uniform in having similar associations, structures, and apparent modes of emplacement.

(2) The so-called "red rock" or granophyre is not persistent along the southeastern margin of the complex as shown on the 1932 State map, but instead is sporadically distributed in "zones" on the order of 3 miles by 1 mile in size.

(3) Major granophyre units do not connect east of Sawbill Lake; rather, an augite troctolite, similar to rocks noted along the base of the complex,occurs.

(4) The occurrence of a basalt unit in the Sawbill area possibly explains the high gravity gradient observed by R. J. Ikola in the area.

(5) The intersection of major structural trends, that is, easterly versus northeasterly in the Sawbill area -- an observation made earlier by H. L. Nathan -- suggests the presence of a significant structural boundary within the complex separating older rocks to the east from younger rocks to the west.

GEOLOGY OF LONG ISLAND LAKE QUADRANGLE

by

P. W. Weiblen

Field checking of the Long Island Lake quadrangle open-file map was completed this past summer. Mapping of the Duluth Complex in this quadrangle has outlined a layered sequence which ranges from troctolite at the base to granophyre at the top. This intrusive unit has been designated the Tuscarora Intrusion in the open-file map. Extensive masses of hornfels have been mapped at the base and the top of the intrusion. The series of interlayered intrusions mapped by H. L. Nathan in quadrangles to the east are intruded by the Tuscarora Intrusion near the western edge of the Gunflint Lake quadrangle. Reconnaissance mapping in the Gillis Lake quadrangle, to the west, indicates that the Tuscarora Intrusion continues westward for some distance.

The Tuscarora Intrusion consists of a contact zone of mixed hornfels and fine-grained gabbroic rocks, a medium- to coarse-grained layered troctolite unit, a transitional zone of interlayered troctolite and anorthositic gabbro, an anorthositic gabbro unit which grades into a ferrogabbro at the top, a ferrogabbro unit with amphibole and potassium feldspar, and finally local masses of granophyre. Isolated gossan zones also are found about two to three miles from the contact near the top of the transition from troctolite to anorthositic gabbro.

During the coming year, petrographic studies will be completed to determine the nature of the differentiation within the intrusion and the genetic relations of the layered units. Petrographic and compositional data on the different varieties of hornfels will be obtained as part of the study of the contact aureole of the complex. Detailed work on the contact effect of the Tuscarora Intrusion on the Gunflint Iron-Formation is in progress with the cooperation of G. B. Morey and J. J. Papike.

GEOLOGY OF NORTH SHORE VOLCANIC GROUP

by

J. C. Green

Detailed mapping and sampling of the lavas of the North Shore Volcanic Group was carried out for four weeks in the area between Grand Portage and Grand Marais and also between Lutsen and Schroeder. Strip maps showing individual flows and brief descriptive reports will be prepared for several areas during this academic year, and study will continue on the chemical relationships and differentiation trends of the lavas. Other specific projects under investigation are the compositions of pyroxenes from the lavas (with Prof. T. Konda of Yamagata University) and the zoning and paragenesis of vein and amygdule minerals in the North Shore Volcanic Group. The work in the Grand Portage area, at the base of the Middle Keweenawan succession, has shown a strong similarity between flows and underlying sandstones there and those at Duluth and in northern Wisconsin.

During the late summer, I attended the Symposium on Volcanoes and Their Roots at Oxford, England, and participated in a field trip to the Tertiary igneous rocks of northeast Ireland; the Tertiary igneous rocks of northeast Ireland are similar to some of the North Shore Volcanic Group.

GEOLOGY OF THE LOGAN SILLS AND ASSOCIATED ROVE FORMATION, HUNGRY JACK LAKE QUADRANGLE

by

G. B. Morey

Geologic mapping in the northern half of the Hungry Jack Lake 7½-minute quadrangle in Cook County, Minnesota, was started and completed during the 1969 field season by Edmund Mathéz of Arizona State University. This study is part of a continuing mapping program started in 1962 to delineate the geographic distribution and to evaluate the economic potential of the igneous and sedimentary rocks in this area.

In general, the stratigraphy and structure of the pre-Keweenawan rocks in the quadrangle are much like that previously mapped in the adjoining South Lake quadrangle and described by Morey and H. L. Nathan (in prep.).

The Hungry Jack Lake quadrangle is located on the north limb of the Lake Superior Syncline. This syncline, the major tectonic feature of northeastern Minnesota, is an elongate structural depression trending northeast-southwest. The Rove Formation and associated rocks define the north limb of this structural basin and dip gently southward 10 to 15 degrees, except near faults and igneous intrusives where the attitude is distorted or disturbed (e.g., near the Duluth Complex, there is a fairly regular increase in dip to a maximum of 60 degrees).

The geologic relationships in this area are further complicated by many tabular, concordant igneous bodies assigned to the Logan Intrusives. Commonly smaller dikes and sills merge along strike into a single large body, which may again be split into several smaller dikes or sills. Because such branching results in isolated, elongate "islands" of Rove between igneous masses, it is difficult to trace any stratigraphic horizon or marker in the Rove Formation over any great distance. A few faults with small throw have been noted at several Minnesota localities. Where these faults cut both the Rove Formation and the sills, it is possible to determine the amount of throw, but it is difficult to recognize their presence at all where they displace only the Rove Formation or the Logan Sills.

Minor folds exist in narrow zones near intrusives, where it is likely that the sedimentary rocks were folded under stresses associated with intrusion of the Logan rocks.

Although all the sills are diabasic gabbro, many have textural and compositional differences that imply fractionation in place. In addition, multiple intrusion is indicated in several sills by the presence of irregular contacts between two diabases, each exhibiting different grain sizes. The top and bottom of each sill are fine-grained basalt, which indicates chilling. Inclusions of Rove Formation near the margins are commonplace, and both the inclusions and wall-rock have been altered to hornfels. The upper part of the thickest sills is cut by dikes of porphyritic basalt, which contain plagioclase laths up to one inch long and are aligned roughly parallel to their contacts. The vertical extent of the dikes is unknown.

Major emphasis in this study will be placed on providing a comprehensive description of the sills and on outlining the history of their development. This work will be done by Mr. Mathéz as part of a Master of Science thesis to be submitted to Arizona State University.

GEOLOGY AND METAMORPHISM OF THE GUNFLINT IRON-FORMATION

by

G. B. Morey

The Gunflint range provides a unique opportunity to evaluate in detail many of the textural, crystallographic, compositional and phase changes that occur in an iron-rich rock within a thermal gradient developed during emplacement of the Duluth Complex. Consequently a cooperative study of the Gunflint range with J. J. Papike of the U. S. Geological Survey and with P. W. Weiblen of the Department of Geology and Geophysics, University of Minnesota, was started in 1967. Field mapping of the iron-formation and associated rocks was completed in 1968 and several reports summarizing some of the geologic aspects are now in preparation.

The Gunflint Iron-formation crops out in the northwestern part of Cook County, in T. 65 N., R. 4 and 5 W., and extends from there northeastward to Thunder Bay, on Lake Superior. In Minnesota, the iron-formation crops out from Gunflint Lake on the east to a point 10 miles to the west, where it is truncated by the Duluth Comples. Immediately west of Gunflint Lake, the iron formation dips gently southward, and accordingly the outcrop of the formation is relatively wide. Throughout the remainder of its length, that is to the west of the Gunflint Trail, the iron formation forms a narrow outcrop belt, and dips 20°-60° S. The relatively steep dips at the outcrop led Broderick (1920) and later workers to conclude that the iron-formation is conformable to and dips relatively steeply beneath the Duluth Complex; however, mapping indicates that the dip on the base of the complex probably is less than 20° S., and dips more gently than the underlying Gunflint and Rove Formations. The structural picture is remarkably similar to that at Dunka River, at the east end of the Mesabi range, where metamorphosed Biwabik Iron-formation is in contact with the Duluth Complex (Bonnichsen, 1968).

The Gunflint Iron-formation is approximately 300 feet thick in Minnesota and is comparable lithologically to the Biwabik Iron-formation; consequently it is subdivided into the same four members recognized on the Mesabi range, from oldest to youngest: Lower Cherty, Lower Slaty, Upper Cherty, and Upper Slaty. The stratigraphy and character of these members has been described in many places and will not be repeated here.

East of the Gunflint Trail, the structure of the iron-formation is complex. Several relatively small faults cut and offset the iron-formation. Most of the apparent irregularities in the contacts shown on various maps result from the superposition of a rugged topography on the gently-dipping strata. The Upper Slaty Member is highly contorted adjacent to the Logan sills, but presumably the contortions are local and caused by forceful emplacement of the sills. In addition, a conspicuous anticlinal fold interrupts the southward-dipping rocks immediately east of the Gunflint Trail.

West of the Gunflint Trail, a major fault, the Lookout fault, which trends west- northwest, duplicates the iron-formation in the vicinity of the Gunflint Trail.

The iron-formation was metamorphosed by the Duluth Complex, and three metamorphic zones have been distinguished by changes in the mineralogy along the strike of the formation toward the complex contact.

Zone 1, *unaltered taconite,* occurs only adjacent to Gunflint Lake, in the extreme northeastern part of the map area. The taconite is composed of quartz, magnetite, hematite, siderite, and greenalite.

Zone 2, *moderately metamorphosed taconite*, is about 1.2 miles wide and extends to within 0.3 miles of the gabbro contact. The taconite is characterized by grunerite-cummingtonite, hornblende, and actinolite. Small-scale pre-metamorphic features such as granule structures are partly destroyed, but larger-scale primary structures and bedding features are little affected.

Zone 3, *highly metamorphosed taconite*, is adjacent to the gabbro, and is characterized by a wholly metamorphic fabric. The taconite is composed chiefly of quartz, magnetite, iron amphiboles, iron pyroxenes, and fayalite. The mineral assemblages in this zone are very similar to those from the Dunka River area, described by Bonnichsen (1968).

The petrologic, crystal chemical, and petrogenetic significance of the various metamorphic mineral assemblages are now being investigated using power and single crystal x-ray diffraction, and the electron microprobe. It is expected that this phase of the study will be completed by mid-1970.

OXYGEN ISOTOPE FRACTIONATION STUDIES

by

E. C. Perry, Jr.

Measurement of variations in the O^{18}/O^{16} ratio of rocks and of their constituent minerals can provide useful information about the history of these rocks. In particular, chemically deposited sediments such as cherts and carbonates reflect the isotopic composition of the water from which they form.

Under a travel grant from the Petroleum Research Fund (PRF) of the American Chemical Society and a research grant from the National Science Foundation, I spent May-August collecting Proterozoic iron-formations and carbonates in South Africa, Rhodesia, India, and Australia and Early Precambrian cherts, iron-formations, and carbonates from such rocks as the 3.4×10^9 year-old Onverwacht and Fig Tree Formations in South Africa and Swaziland. By studying the oxygen isotope composition of these samples as well as that of samples from North American localities such as the Biwabik, Gunflint, and Soudan Formations it will, hopefully, be possible to evaluate the O^{18}/O^{16} ratio of ocean water through geologic time. Preliminary studies have shown that this ratio may be one of the few distinctive and interpretable traces left by the Precambrian ocean-atmosphere system, and that this study may ultimately lead to a better understanding of igneous and sedimentary processes on the primitive earth.

GEOLOGY OF ELY QUADRANGLE

by

J. C. Green

Three weeks were spent in the Ely area, nearly completing work on this map. Of particular interest were the confirmation of several isoclinal folds within the northern greenstone belt, the discovery of volcaniclastic zones within this sequence, and the finding of several additional metaperidotite-serpentine lenses. Mapping will be completed during next field season.

GEOLOGY OF TOWER QUADRANGLE

by

R. W. Ojakangas and P. K. Sims

Geologic mapping of the Tower quadrangle, carried out mainly during the field seasons of 1965,1966, and 1967 by Ojakangas, was continued during 1969. The work during the past season was primarily a detailed structural study by Peter Hooper (University College of Swansea, Wales).

The stratigraphy in the quadrangle is complex, as might be expected in an unstable volcanic environment. An older unit of mafic volcanic rocks (Ely Greenstone), mainly pillowed metabasalt, is overlain stratigraphically by several units, which in part intertongue. The Soudan Iron-formation, the major banded iron-formation in the area, overlies the Ely Greenstone on the north. Elsewhere, either quartzite or metagraywacke lie directly on the greenstone. The quartzite and metagraywacke are epiclastic deposits. The metagraywacke unit contains two small bodies of pillowed metabasalt, which are stratigraphically well above the Ely Greenstone. Above the Soudan Iron-formation is a complex unit of tuff-breccia of felsic-intermediate composition, which interfingers westward with chloritic metagraywacke and slate.

The quadrangle together with the adjacent Soudan quadrangle contains an excellent stratigraphic succession that shows the change with time from early mafic volcanism to later felsic-intermediate volcanism. The Soudan Iron-formation, which overlies the mafic extrusive rocks of the Ely Greenstone and represents an interval of quiescence in the volcanism, is directly overlain at places by coarse pyroclastic deposits of dacitic composition. Previously (Clements,1903), the coarser fragmental rocks were called conglomerates.

Studies by Hooper have demonstrated two major episodes of deformation in the quadrangle. Early, tight folds that probably had gentle plunges were refolded by folds that have nearly vertical axial planes that strike N.80°E. The movement pattern for the younger deformation can be regarded as a series of right-lateral tear faults with local drag folds. The nearly vertically-plunging folds, such as the Tower inverted anticline, can be explained by the multiple deformation.

GEOLOGY OF SHAGAWA LAKE QUADRANGLE

by

P. K. Sims

The Shagawa Lake quadrangle, in the central part of the Vermilion district, just west of Ely, is of interest because it contains parts of two separate bodies of mafic volcanic rocks separated by the Knife Lake Group as well as the Vermilion Granite and associated high-grade (amphibolite facies) metamorphic rocks. Approximately 50 percent of the quadrangle has been mapped. The amphibolite facies rocks are separated from the greenschist-facies rocks of the district proper by a major fault (Vermilion fault).

The older mafic volcanic unit, for which the formal name Ely Greenstone is retained, consists of pillowed metabasalt and meta-andesite, metadiabase, fragmental rocks of intermediate composition, thin lenses of banded iron-formation, a thin layer of pyrrhotite-bearing siliceous argillite, and thin layers of metatuff. Small bodies of porphyry of intermediate composition cut the unit. The other body of mafic volcanic rocks is younger than the meta-argillite of the Knife Lake Group and consists dominantly of metabasalt and meta-andesite lavas and metadiabase. A few small lenses of impure siliceous marble occur in the upper part of the unit, and two layers of banded iron-formation are known. Three small bodies of metaperidotite have been mapped to date.

The metamorphic rocks associated with the granitic rocks of the Vermilion batholith are amphibolites, which represent metamorphosed extrusive volcanic rocks, and biotite schists (metagraywacke). Along the southern edge of the batholith, an older foliated trondhjemite, the Burntside granite gneiss of Grout (1926), intrudes both amphibolite and biotite schist. In turn, the foliated trondhjemite is cut by pink or gray leucocratic biotite quartz monzonite, the major rock type of the batholith in this area. The granite intrudes the older metamorphic rocks in a lit-par-lit manner and irregularly replaces them. The field relations indicate that the granitic rocks were emplaced at relatively shallow depths, and according to the classification of Buddington(1959) are epizonal.

Analyses of randomly selected samples from the several ultramafic bodies in the Ely and Shagawa Lake quadrangles are given in the table below.

Table 1 -- Analyses, in parts per million, of selected samples of metaperidotite bodies from Ely area. (Analyses by U. S. Geological Survey, Denver Laboratory)

Sample Number	Chemical[2]							Semiquantitative Spectrographic[1]				
	Au[2]	Ag	Pb	Cu	Zn	Ni	Pd[3]	Mn	B	Ba	Co	Cr
AJP-125	N	0.2	N	N	N	N	N	1500	200	N	150	G5000
AJP-126	N	0.4	N	68	60	68	0.011	1500	50	N	150	G3000
AJP-127	N	0.4	N	180	N	34	N	2000	50	N	150	G3000
AJP-128	N	0.6	N	N	40	840	N	1500	L	L	150	G5000
AJP-129	N	0.2	N	330	25	60	0.009	1000	100	N	150	G5000
AJP-130	N	0.2	N	105	50	24	0.008	1500	20	L	150	G5000
AJP-131	N	0.6	N	88	56	900	N	1000	50	L	200	G5000
AJP-984	N	1.0	N	69	44	770	N	1500	100	L	100	G5000
AJP-988	0.04	1.0	N	16	L	870	N	1000	100	L	150	G5000

1 Spectrographic analyses by J. Motooka and D.J. Grimes. Spectrographic limit of semiquantitative analysis, in ppm; Mn, 10; B, 10; Ba, 20; Co, 5; and Cr, 5. N, not detected; L, detected, but below the limit of semiquantitative determination.

2 Analyses by atomic-absorption spectrometry by J.G. Frisken, Z.C. Stephenson, M.S. Rickard, L.W. Bailey, and J.G. Viets. Limit of detection for Au, 0.02 ppm; Pb, 25 ppm; Cu, 10 ppm; Zn, 25 ppm; and Ni, 5 ppm.

3 Analyses by L.B. Riley, W.D. Goss, and Joseph Haffty. Method used for Pt, Pd, and Rh (Talanta, 1968, v. 15, p. 111-117).

GEOLOGY OF VERMILION DISTRICT

by

P. K. Sims

Geologic studies in the Vermilion district, started in 1962, continued during the 1969 field season. The area west of longitude 91°30'W. has now been mapped by reconnaissance methods and seven quadrangles -- Gabbro Lake, Isaac Lake, Embarrass, Ely, Shagawa Lake, Tower, and Lost Lake -- have been or are being mapped in detail. (See index map and accompanying table for status). The purpose of the project is to determine the stratigraphy, structure, and geologic history of the district and adjacent areas, to aid exploration for massive sulfide deposits (copper,zinc, silver) and to provide a firm basis for extrapolation of the geology in covered areas to the west.

Some major conclusions resulting from the investigation that differ widely from earlier published views follow:

(1) The sequence in the district proper is a volcanic pile accumulation, deposited in a dominantly marine environment,

(2) Mafic volcanism was repeated in time, and accordingly pillowed basalt- andesite flows are not diagnostic of a unique time-stratigraphic unit (the Ely Greenstone of earlier reports),

(3) There is no evidence in the western part of the district for a major unconformity between mafic volcanics (Ely Greenstone) and younger strata, as proposed by Clements (USGS Monograph 45, 1903),

(4) The coarser fragmental rocks at Stuntz Bay and adjacent areas, north of Tower and Soudan, previously called conglomerate by Clements, are tuff-breccia deposits which mark initial felsic-intermediate volcanism that followed deposition of the Soudan Iron-formation,

(5) The widespread porphyries are shallow, intrusive (hypabyssal) equivalents of the extrusive rocks, and

(6) Metamorphism and deformation in the western part of the district followed deposition of the youngest clastic strata, and were virtually synchronous with emplacement of the Giants Range and Vermilion batholiths, both Algoman (ca. 2,600 m.y.) in age.

A paper that will revise the stratigraphic nomenclature for the western part of the district is being prepared for publication. In it, the Survey will retain the name Ely Greenstone for that body of mafic volcanic rocks that is continuous with the type area at Ely, and will restrict the name Knife Lake Group to the type area mapped by J. W. Gruner (1941) in the eastern part of the district. A mafic volcanic unit that overlies Knife Lake rocks near Ely will be renamed, as will the metagraywacke, quartzite, and felsic volcanic rocks in the Tower area.

PETROLOGY AND ORIGIN OF GRANITIC AND METAMORPHIC ROCKS IN AND ADJACENT TO WESTERN PART OF GIANTS RANGE BATHOLITH.

by

S. Viswanathan

Previous knowledge of the geology and petrology of the granitic complex in and adjacent to the western part of the Giants Range batholith in northern Minnesota has been limited to the work of I. S. Allison (1925). The present study was commenced during the summer of 1968 and continued during the past summer.

Detailed reconnaissance geologic mapping of some 500 square miles, at a scale of 1:24,000, has been completed in the Dewey Lake SE, Dewey Lake, Dewey Lake NW, Dark Lake, Stingy Lake, O'Leary Lake, Sherry Lake, and Side Lake quadrangles (St. Louis and Itasca Counties). In the mapping, a large scale zoning in the granitic rocks exposed in the Dewey Lake-Dark Lake area has been delineated. These rocks are mappable as four major northeast-trending conformable zones, which from south to north are: Zone I, a medium- to coarse-grained, massive biotite granite (13 miles long and 3 miles wide); Zone II, a coarse-grained, foliated, porphyritic biotite granite (13 miles long and 4 miles wide); Zone III, a medium-grained, muscovite- and biotite-bearing gneissic granite which is locally garnetiferous (13 miles long and 3 miles wide); and Zone IV, a fine-grained biotite-muscovite granite (12 miles long and 3 miles wide). A second contribution of the mapping has been the discovery of a migmatitic complex in the O'Leary Lake area, which has an areal extent of some 30 square miles.

During the mapping, the following possibilities were considered to account for the origin of the granitic rocks of the four zones: (1) The granites of zones I and II are magmatic; (2) The granites of zone III are products of replacement of pre-existing metasedimentary rocks (essentially quartz-plagioclase-biotite assemblages); and (3) The granites of zone IV are recrystallized bodies resulting from the partial melting of pre-existing metasedimentary formations similar to those from which the granites of zone III were produced. Preliminary oxygen isotopic analyses of quartz in the granites and the metasedimentary rocks support the above hypotheses. The migmatitic complex of the O'Leary area appears to represent a granitized graywacke-amphibolite sequence.

In addition to conventional petrographic studies, the techniques of electron probe microanalysis, oxygen isotope geochemistry, and major and minor element analysis by x-ray fluorescence are being used in the study.

MULTI-SPECTRAL ANALYSIS OF THE MESABI RANGE

by

Alta Walker

This joint Minnesota Geological Survey-USGS project in remote sensing is a study to determine the geologic information that can be obtained for the Mesabi Iron Range area from imagery and photographs taken with selected electromagnetic wavelengths. Three NASA flights over the range provided radar, black and white infrared (taken during both day and night), and ultraviolet imagery as well as near-infrared color photography. These data were compared with conventional high-altitude aerial photographs and with available geologic maps.

Infrared imagery measures thermal radiation. Faults, reflected by thermal changes in the ground, vegetation differences, and moisture absorption patterns in the soil and bedrock are among the geologic features detectable by infrared. Radar imageryrecords the reflected radar waves and provides information on structure and microtopography not readily identifiable on the ground. Roads, water, cities and ground patterns are detected by ultraviolet radiation. However, most of the energy in the ultraviolet wavelengths is absorbed by the atmosphere so the imagery is hazy and difficult to interpret.

Field work consisted of examining lineaments, ridges, and other structures noted on the imagery in an effort to determine the nature of the feature recorded. Special emphasis was placed on lineaments that did not appear on existing geologic maps of the area.

In addition, the orientation of numerous lineaments observable on the imagery is being measured and compared with White's rose diagram (MGS Bulletin 38, p. 56) in an effort to establish and explain the prominent directions.

Preliminary results indicate that though none of the imagery is helpful in determining bedrock lithology, topographic expressions of faults and lineaments due to glaciation (possibly joint-controlled) are visible on radar, aerial photography, and infrared imagery. Each of the major faults indicated on the most recent geologic map of the area (MGS Misc. Map 5) could be identified on the photographs and on each type of imagery. In addition, one fault, which was not mapped previously, was discovered through a study of the imagery, and a second fault has been extended past its previously mapped limits.

SEDIMENTOLOGY OF KNIFE LAKE GROUP

by

R. W. Ojakangas

An investigation of the metasedimentary rocks of the Knife Lake Group in the eastern Vermilion district was undertaken to gain a better understanding of the origin of these rocks and to make comparisons with similar sedimentary strata at Tower-Soudan, Rainy Lake, and Ontario.

Four weeks were spent in the area between Moose Lake and Saganaga Lake. J. W. Gruner's (1941) excellent map and descriptions make this type of survey possible. Not all parts of the area could be visited in the limited time available, but most of Gruner's 16 map units were sampled and about 300 samples were collected. Outcrops were studied to determine stratigraphic top indicators (grading, scouring, cross-bedding, and pillows) and to substantiate and expand upon Gruner's relative age determinations. Folding and longitudinal faulting severely complicate the picture.

Conglomerates, graywackes, and slates are common rock types. Volcanic detritus, much of it probably of direct pyroclastic origin, is very important in the sequence, forming massive quartz-feldspar tuffs (?) and agglomerates and undoubtedly contributing to detritus of the graywackes and slates as well.

This preliminary work, together with Gruner's descriptions, strongly suggests that the Knife Lake Group is another example of the mafic-felsic volcanic pile accumulation that appears to be so typical of the Archean in the southern part of the Precambrian Shield.

GEOCHRONOLOGY OF MAFIC DIKE ROCKS, NORTHEASTERN MINNESOTA

by

G. N. Hanson and R. Malhotra

A study of the geochronology and petrography of mafic dikes in northeastern Minnesota is nearly completed. About 20 dikes have been studied ,about half of which will be dated. Most of the dikes are andesitic to basaltic with tholeiitic affinities, and intrude Algoman granites and metamorphic rocks north of the Mesabi range; some lamprophyres also are being investigated. The dikes consist modally of plagioclase (about An_{50}), clinopyroxene, ± hornblende, ± microcline, and ± quartz. Almost every dike shows some degree of alteration of pyroxene to chlorite and of plagioclase to sericite and an as yet unidentified, very fine-grained, 3-10 micron, light-green mineral consisting of needle-like crystals. Whether the alteration is late-stage deuteric, related to much later hydrothermal activity, or related to low-grade metamorphism has not yet been resolved. Whole rock K-Ar ages suggest an age of 1600-1700 m.y. Whether this age is the time of intrusion or the time of alteration is not certain.

The study is being financed largely by a grant from the National Science Foundation.

GEOCHRONOLOGY OF THE GIANTS RANGE BATHOLITH

by

G. N. Hanson

The purpose of this study, which has just begun, is to define the time of and, if possible, the duration of the Algoman orogeny in the region of the Giants Range in northeastern Minnesota. Some samples have been collected and are now being processed for dating.

Lawson (1913), in defining Algoman granites, did not specify a type locality, but cited the Giants Range Granite as a good example. It is hoped that a detailed dating of the events in the Giants Range area may clarify possible correlations with the Algoman orogeny in other parts of the Canadian Shield as well as give a type locality for defining the Algoman orogeny.

The study is being financed largely by a grant from the National Science Foundation.

GEOCHRONOLOGY OF THE MINNESOTA-ONTARIO BORDER REGION

by

S. S. Goldich

Geochronological work along the Minnesota-Ontario boundary was started with NSF support in 1956 (Minn. Geol. Survey Bull. 41, 1961). Additional work was done (1966-68) under NSF Grant 575 to S. S. Goldich at New York State University at Stony Brook. Manuscripts are now being prepared on the Rainy Lake area with Dr. Zell Peterman, U. S. Geological Survey, who participated in the early investigations at the University of Minnesota, and on the Saganaga-Northern Light Lakes area with Dr. Gilbert Hanson, State University of New York at Stony Brook.

AGES OF ROCKS ASSIGNED TO THE PENOKEAN OROGENY IN MINNESOTA

by

S. S. Goldich

This project, supported by NSF Grant GA-12316 to S. S. Goldich, Northern Illinois University, will investigate the igneous and metasedimentary rocks of central Minnesota. The rocks in this part of the state were first dated by K-Ar and Rb-Sr age determinations on micas and whole-rock samples of slate and phyllite. The present investigation will emphasize whole-rock Rb-Sr determinations on igneous as well as metamorphic rocks. Isochrons of whole-rock samples and of whole-rock-mineral samples will be used to date the time of original formation and to probe the subsequent history. Some isotopic U-Pb age determinations will be obtained to supplement the Rb-Sr analyses. A number of lead-alpha ages are now available.

During August, Goldich and G. B. Morey of the Minnesota Geological Survey collected a large number of samples from the Thomson Formation, the McGrath Granite Gneiss, various granites, and the schist in the St. Cloud area. These samples are now being processed for isotopic investigation at Northern Illinois University.

The Penokean project is being closely coordinated with G. N. Hanson's Algoman project in northern Minnesota.

AGE OF THE PRECAMBRIAN ROCKS OF SOUTHWESTERN MINNESOTA

by

S. S. Goldich

This is a continuing project started at the University of Minnesota in 1956 (Minn. Geol. Survey Bull. 41, 1961). A manuscript "Age of the Morton and Montevideo gneisses and related rocks, southwestern Minnesota" by S. S. Goldich, C. E. Hedge, and T. W. Stern is in the stage of final review in the U. S. Geological Survey.

The Morton and Montevideo gneisses date back to 3500 m.y. ago. The subsequent history is a complicated one of metamorphic and igneous activity. Whole-rock Rb-Sr and U-Pb determinations date the Sacred Heart Granite at 2650 m.y. and the granite in section 28, just north of Granite Falls, at 1850 m.y. ago.

New studies under way at Northern Illinois University with support from the Graduate School are directed to the precise determination of the ages of specific granites in the Minnesota River Valley.

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