MINNESOTA GEOLOGICAL SURVEY

PAUL K. SIMS, *Director*

Information Circular 8

SUMMARY OF FIELDWORK 1970

UNIVERSITY OF MINNESOTA

MINNEAPOLIS

1970

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.

The Survey welcomes inquiries concerning any aspect of the geology of the State. Inquiries by mail should be addressed to:

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SUMMARY OF FIELDWORK

1970

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BEDROCK GEOLOGIC MAP, DULUTH SHEET

by

G. B. Morey

Geologic mapping in the 1:250,000 Duluth sheet was completed during the 1970 field season. Emphasis was placed on mapping the southwestern corner of the sheet where the Hillman Tonalite, Warman Quartz Monzonite, and Isle Quartz Monzonite are exposed.

The Hillman Tonalite is exposed in a large area south and west of Mille Lacs Lake in Mille Lacs, Crow Wing, and Morrison counties. The tonalite is a locally massive, but more commonly foliated rock containing 40 percent quartz, 45 percent andesine, 10 percent biotite, and 5 percent hornblende. Where foliated, the unit is typified by inclusions of biotite or hornblende schist, generally in layers, most of which have been drawn out into schlieren trending in a northeasterly direction. Locally the tonalite is cut by pegmatite veins containing quartz, feldspar, minor biotite, and large subhedral grains of garnet.

Large areas of garnetiferous biotitic metagraywacke -- tentatively assigned to the Thomson Formation -- occur within the boundaries of the Hillman Tonalite as defined by Woyski (1949). Generally these rocks are strongly foliated in a northeasterly direction, more or less parallel to the regional structure observed in the Thomson Formation. Secondary isoclinal folds with axes plunging 45°-50° N. 40°-60° E. are fairly common and minor cross-folds trending 50° N. 20° E. locally offset the major foliation direction. In these areas of metasedimentary rocks, which are inferred to be isolated remnants of country rock, the Hillman Tonalite occurs as small dikes and irregular pod-like masses; in places these bodies cross-cut the regional foliation, whereas elsewhere they are conformable. At some localities, both the igneous and metasedimentary rocks appear to have been deformed contemporaneously; locally metasedimentary layers have been boudined parallel to the igneous foliation. These relationships suggest that deformation and metamorphism of the Thomson Formation took place prior to, but was somewhat overlapped in time by, emplacement of the Hillman Tonalite, i.e., The Hillman Tonalite is syntectonic.

No contact relationships between the Hillman Tonalite and the Warman and Isle Quartz Monzonites were found. However, Grout (as cited in Woyski, 1949) described an outcrop, now buried, south of Onamia, where the Warman Quartz Monzonite cross-cuts the Hillman Tonalite.

The Warman Quartz Monzonite is a massive, light gray, medium-grained, equigranular rock containing 60 percent feldspar, 25-30 percent quartz, and 5-10 percent biotite. Inclusions of biotite schist and biotite-bearing metagraywacke are fairly numerous; and wispy concentrations of biotite, which may be the remnants of partially digested inclusions, are scattered throughout the unit.

The Isle Quartz Monzonite also is a medium-grained, biotite-quartz-plagioclase-bearing rock and Woyski (1949) considered it to be a phase of the Warman Quartz Monzonite. However, two distinct rock types can be seen at a quarry five miles south of the Village of Isle in Mille Lacs County. One phase is a medium-grained slightly porphyritic rock that texturally and mineralogically resembles the Warman Quartz Monzonite, whereas the other, although mineralogically similar, is coarse-grained and porphyritic. It is this phase that Goldich and others (1961) termed the "Isle Quartz Monzonite". The fine-grained phase appears to cross-cut the coarse-grained phase, although contacts appear to be gradational, suggesting little, if any, difference in age. The only other known exposures of the coarse-grained phase occur along Hay Creek, two miles west of Woodland. Thus cartographic relationships between the Warman and Isle are difficult to define. It appears necessary for mapping purposes to consider the Isle a subordinate phase of the more areally extensive Warman Quartz Monzonite.

BEDROCK GEOLOGIC MAP, STILLWATER SHEET

by

G. B. Morey

Mapping of the Precambrian bedrock geology in the northern third of the sheet was started during the 1970 field season, and approximately 95 percent of the entire sheet now has been completed.

The Warman Quartz Monzonite, the Isle Quartz Monzonite, and the Hillman Tonalite, typically exposed in the Duluth Sheet, have been traced southward into the Stillwater sheet, where they are intruded by the "St. Cloud Red Granite" phase of Woyski's (1949) "Stearns Magma Series". Characteristically the St. Cloud Red Granite is reddish gray to light pink, coarse-grained, and characterized in the field by large intergrown grains of quartz and K-spar. This rock contains an average of 50 percent perthitic orthoclase and microcline, 30 percent quartz, 10 percent oligoclase, and 10 percent biotite. Hornblende locally may also be an important mineral phase.

Throughout most of the area, the St. Cloud Red Granite is structureless, but in places is strongly sheared and epidotized. Most shear zones follow a general easterly trend. Swarms of inclusions are common, and include large angular blocks of gray granodiorite and biotite schist and small "knots" of biotitic or hornblendic material of unknown origin. A variety of basaltic dikes, described by Hanson (1968), trending from N. 50° E. to east, cut the granite.

Several small and isolated exposures of actinolitic gabbro crop out near Mora. The age relationships of this rock are as yet unknown, but a general lack of structure suggests that it is not equivalent to the strongly foliated metadiabases exposed in Carlton County, as was orginally suggested by Woyski (1949). This massive medium-grained rock has a diabasic texture and was orginally composed of plagioclase and pyroxene and/or olivine. However, it has been extensively altered and is now composed of 60 percent plagioclase (zoned labradorite), 25 percent actinolite, 10 percent chlorite, and 20 percent zoisite.

The granitic and associated rocks noted above are unconformably overlain by the Upper Keweenawan Fond du Lac and Hinckley Formations. To the east, these rocks are in fault contact with a thick pile of Middle Keweenawan lava flows. Southward, the Keweenawan rocks in turn are unconformably overlain by Upper Cambrian strata assigned to the Mt. Simon Sandstone. The stratigraphic relationships of these and other sedimentary rocks in the southern part of the sheet have been delineated by water well data collected in 1968 and 1969 by G. S. Austin and Darryl Tharalson.

BEDROCK GEOLOGIC MAP, TWO HARBORS SHEET

by

John C. Green

Reconnaissance mapping of the Two Harbors 1:250,000 sheet was virtually completed during the 1970 field season, with major contributions by Bill Bonnichsen, D. M. Davidson, Jr., and J. C. Green. Most mapping this season was concentrated in areas where there had been very little if any information available previously because of glacial cover and inaccessibility, such as central Lake County and central and western Cook County. Troctolitic, gabbroic, anorthositic, and granitic phases of the Duluth Complex have been outlined, and major groups of lavas have been traced inland for tens of miles from the Lake Superior shore.

The northwestern corner of the sheet is underlain by Lower Precambrian rocks of the Vermilion district, dominated by metavolcanic rocks and volcaniclastic strata. In this belt, the rocks nearly

everywhere dip very steeply and trend roughly east-west. They are broken into many slices and blocks by major faults of Algoman age, many of which show left-lateral displacement. These stratified rocks are intruded by the Algoman Giants Range and Vermilion batholithic complexes, which are also cut by the major faults. To the east along the Canadian border the Lower Precambrian rocks are overlain unconformably by the Middle Precambrian Gunflint Iron-formation and Rove Formation.

The majority of the map sheet is underlain by Upper Precambrian (Keweenawan) igneous rocks that constitute the Duluth Complex and the North Shore Volcanic Group. Both contain magnetically reversed (older) and normal-polarity sequences and, although precise age determinations are not yet available, the igneous rocks may have been emplaced over a much longer time interval than has been previously envisioned. The magnetically reversed lavas and intrusions are now considered to be Lower Keweenawan in age, and the normal-polarity units Middle Keweenawan. More magnetic-polarity and age determinations need to be obtained to establish the position and significance of the Lower/Middle Keweenawan boundary across the area.

BEDROCK GEOLOGIC MAP, EASTERN PART OF INTERNATIONAL FALLS SHEET

by

David L. Southwick

Approximately 10 man-weeks were spent in semi-reconnaissance geologic mapping of various parts of the International Falls Sheet. Southwick and his assistants finished mapping the shoreline of Namakan Lake between Junction Bay and Deep Slough, the shoreline of Loon Lake and Lac La Croix, and the shoreline of Pelican Lake. Extensive land traverses were made in the large area between Orr and Picket Lakes. Ojakangas finished mapping the western half of the sheet, an area where bedrock exposures are sparse.

The principal discoveries of scientific interest were the following:

(1) Almost all the islands in the main east-west part of Lac La Croix consist of sparsely garnetiferous biotite schist similar to that on the Kabetogama Peninsula, not granite as indicated on the 1932 State Geologic Map. Biotite schist also forms part of the south shore of the lake. Schistose felsite and greenstone locally are interbedded with the schist, but in general these metavolcanic rocks comprise only a minor part of the section. Ultramafic rocks rich in secondary chlorite occur on Dome Island.

(2) The nose of a large westward-plunging antiform in migmatite and migmatized biotite schist passes through Pelican Lake. Eastward-plunging folds are the rule throughout most of the Vermilion granite-migmatite massif; this fold is the only one of regional scale that plunges westward. The Pelican Lake antiform appears to be truncated on the southwest by the Vermilion fault.

BEDROCK GEOLOGIC MAP, WESTERN HALF OF INTERNATIONAL FALLS SHEET

by

R. W. Ojakangas

Reconnaissance geologic mapping of the western half of the International Falls 1:250,000 sheet, west of U.S. Highway 53, was completed during this field season. Outcrops were plotted on county roadmaps,

and photo-quadrangles were used in locating outcrops. Most of the area is underlain by mixed biotite-quartz-feldspar schist (commonly containing garnet) and granite; migmatites and gneisses are common.

The structural trend is consistently east-west, with steeply dipping foliation, layering, and original bedding parallel to one another. Lineations indicate that the broad folds of the area plunge gently to the east or west. A major fold axis may be present in the vicinity of Big Falls. In some zones, granite predominates over biotite-quartz-feldspar schist and in other zones, schist is dominant. It appears that the rock units mapped by D. L. Southwick east of U.S. Highway 53 can be extended across the sheet.

Amphibole-bearing schists are common in an easterly-trending zone south of Ray, and minor amphibolite pods and beds are present at several places in the map area.

A greenstone belt is poorly exposed in the northwestern corner of the area near Indus and Manitou. Tuffaceous metasedimentary rocks (chlorite schists) of the Rainy Lake greenstone belt are exposed in the village of South International Falls, but rocks of this belt are not exposed further west.

Diabase dikes, the youngest rocks in the area, trend north-northwestward parallel to those in the Roseau sheet and in the Rainy Lake-Kabetogama Lake area.

SURFICIAL GEOLOGIC MAP, NEW ULM SHEET

by

Charles L. Matsch

Mapping, begun last year, of the Quaternary deposits in southwestern Minnesota was continued in April and May, and much of that time was given to careful stratigraphic work along the Minnesota River Valley between Montevideo and New Ulm. The discovery of multiple tills with intervening weathered zones provides the framework for defining and naming formal rock-stratigraphic units in the Quaternary sequence there.

The youngest drift sheet, a deposit ascribed to the depositional activity of the Des Moines lobe, was sampled over a wide area. Laboratory analyses of these till samples indicate that there is a regular decrease in the shale content of the coarse sand size from over 50 percent along the Minnesota River Valley to less than 20 percent near both margins. Because the Des Moines lobe axis was very nearly coincident with the present position of the Minnesota River, the distribution of shale in this till is apparently related to the geometry of the ice lobe.

The Quaternary sand and gravel deposits of southwestern Minnesota fall easily into two composition groups: very shaly (up to 80 percent) and relatively shale-free (0 percent-5 percent). The shale content of sand and gravel deposits associated with the surface drift sheet (Des Moines lobe) is directly related to the origin of the deposits. Crevasse-fillings are long (up to 0.5 mile) narrow hills of shale-rich gravel, sand, and till that resulted from the accumulation of material by running water and by mass movements in crevasses on stagnant disintegrating ice. The low-density shale was also concentrated by sheetwash in depressions on the wasting ice surface, resulting in thin patches of shale-rich pea gravel and sand that now are irregularly distributed along the axes of the regional topographic trough.

Gravel deposits comparatively free of shale underlie a regional network of meltwater channels that are inset into the till plain. Major rivers, such as the Yellow Medicine and Cottonwood, follow courses set by these earlier ice-melt streams that apparently flowed along the margins of the receding ice sheet. Some

branches of this channel network head into flat terrane underlain by silts that must have been glacial lake bottoms. Another occurrence of gravel and sand that has a generally low content of shale is in the form of lenticular bodies of outwash that lie stratigraphically below the shaly surface till. These deposits are exposed in deep cuts along the sides of the Minnesota River Valley and in deep tributary valleys. They originated as outwash from an earlier glacier that did not cross the broad belt of Cretaceous shale that lies in eastern North Dakota, eastern South Dakota, and extreme western Minnesota. Another important group of gravel bodies underlies a series of terrace surfaces within the broad valley of the Minnesota River. Generally, the highest terrace is composed of coarse to fine-grained braided stream deposits that mark the course of the master meltwater stream that developed along the axis of the Minnesota River lowland as the last glacier ice melted northward. The lower terraces are generally underlain with bouldery bedload deposits marking former positions of the successive channel bottoms of River Warren as that capacious outlet to Lake Agassiz intermittently cut downward through the Quaternary pile to the resistant Precambrian bedrock.

Future mapping should trace the surface distribution of the Quaternary formations beyond the margin of the Des Moines lobe in the highly controversial area of extreme southwestern Minnesota, northwestern Iowa, and eastern South Dakota.

GRAVITY INVESTIGATIONS IN MINNESOTA

by

P. K. Sims

During the past year, a gravity map of the State of Minnesota was published at a scale of 1:1,000,000. This map (M-10), entitled "A simple Bouguer gravity map of Minnesota and northwestern Wisconsin", was compiled by Campbell Craddock and others, and includes gravity data in the state available in 1966. It will serve as an interim map until the more detailed state-wide gravity surveying, now in progress, is completed, probably about 1975.

During the year, gravity surveying was carried out in northwestern Minnesota and east-central Minnesota. The program is now being carried out under the direct or general supervision of Dr. L. D. McGinnis, Northern Illinois University, DeKalb, Illinois. Gravity stations are being established at one-mile intervals where practical.

The status of gravity surveying in the state and the areas completed during the past field season are shown in Figure 1.

Plans for next field season include completing gravity coverage of the New Ulm sheet in southwestern Minnesota, and starting surveying in the Bemidji sheet. The remainder of the Roseau sheet will not be completed until 7-½ minute topographic mapping is completed in this area.

SUBSURFACE GEOLOGY OF MINNEAPOLIS–ST. PAUL METROPOLITAN AREA

by

John Mossler

Collection of cuttings from water wells drilled in the metropolitan area has been accelerated, through a cooperative project with the U.S. Geological Survey. Descriptions of these cuttings are prepared and put on

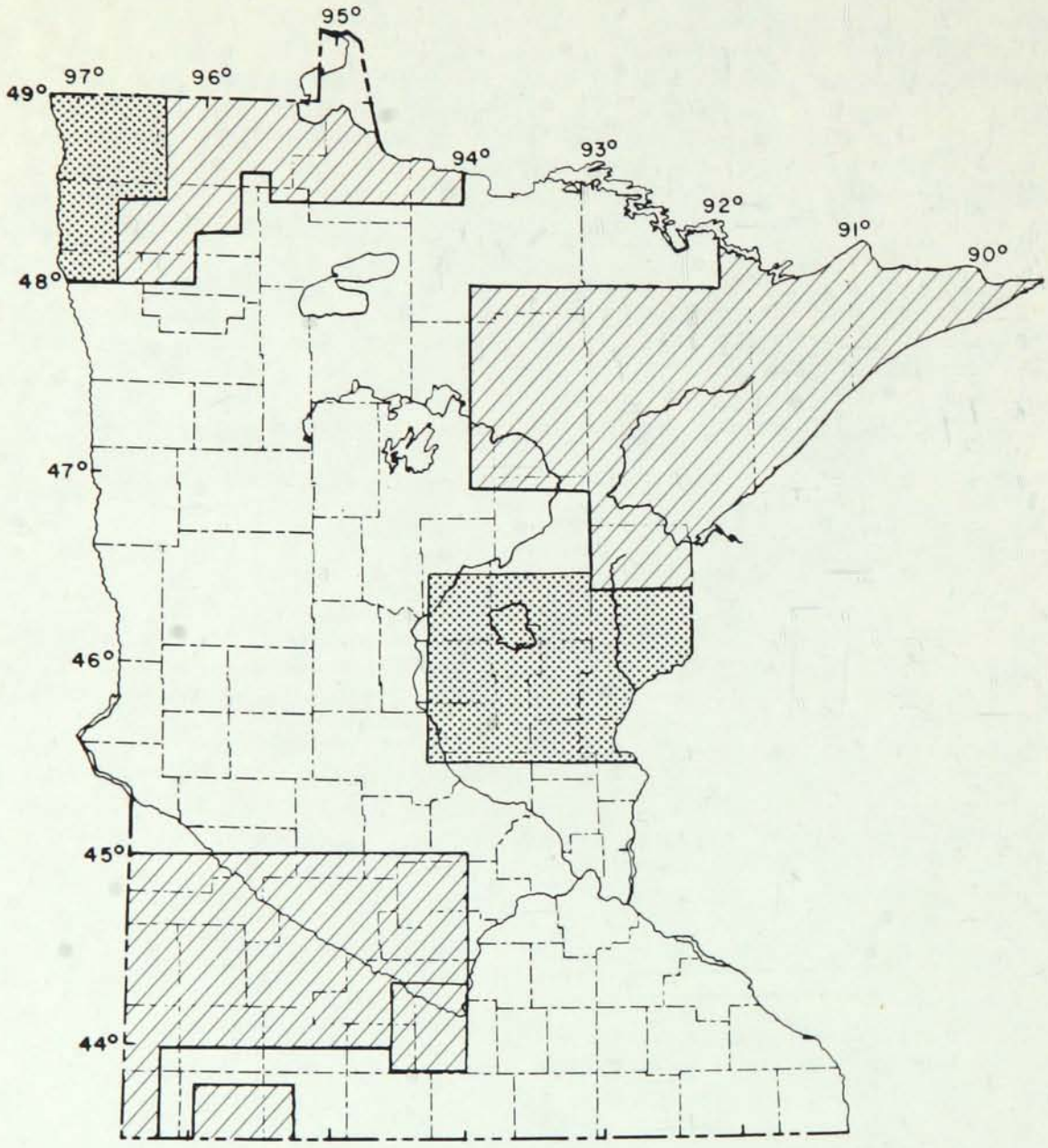

Figure 1 – Status of gravity surveying in Minnesota. (Lined area surveyed previously, stippled area surveyed in 1970.)

file at the Minnesota Geological Survey. In addition, copies of sample analyses are sent to the U.S. Geological Survey for use in its study of the geohydrology of the Twin Cities area.

Sample analyses of cuttings from water wells and other drill holes are useful in determining the areal extent and variation in lithology, altitude, and thickness of the various geologic formations underlying the metropolitan area. Accurate mapping of changes in the preceding parameters will enable hydrologists to assess more accurately ground water resources of the Twin Cities area.

In addition, the Minnesota Geological Survey and the U.S. Geological Survey are transferring lithologic and stratigraphic data in their files onto computer data cards as part of a larger program to incorporate Minnesota geologic data needed in hydrologic studies into a rapid data retrieval system.

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

by

H. O. Pfannkuch

Fieldwork conducted during the summer of 1970 was in part an extension of investigations initiated in 1969 to study hydrogeological aspects of small watersheds in the southwestern metropolitan area. In addition, a joint program with the U.S. Geological Survey St. Paul Office has been started with the specific purpose of establishing hydrologic relationships between buried pre-glacial valleys and the bedrock aquifers north of the Twin Cities (Anoka Co.).

In the continuation of the 1969 project, morphometric analysis of the three watersheds was carried out. From aerial photographs taken in 1968 a land use determination was made to obtain background information about open water, vegetation-cover, and urbanized areas. This information is to be used in more refined evapo-transpiration estimates and water budget calculations and as basic information to quantify the degree of urbanization. To establish further quality data as basic information, several surface water samples were taken and analyzed for the most common parameter. This work will be continued in a more systematic way and will include ground water sampling programs, now that portable field analysis equipment is available.

Work on the surficial geology includes mapping, sampling of surficial material (180 samples) and laboratory analyses (85 sieve analyses, 10 sedimentation analyses, 10 mineral analyses, 6 permeability tests) with special emphasis on hydrologic parameters. These data will be used in the construction of an infiltration map, and in the preparation of a detailed map and feather diagram of the drift. For the same purpose six shallow observation wells have been drilled in cooperation with the U.S. Geological Survey and the Riley-Purgatory Creek Watershed District, and four seismic and three geolectric traverses have been run with the aid of Bison instruments.

About 1,300 well logs have been utilized in preparing surficial and bedrock topographic maps. Further analyses of samples and preparation of data will proceed throughout the year. A continuous program of basic data collection through local high schools and the watershed district has been initiated.

Information gathered so far will be used for the mapping of surficial geology, delineation of drift material from different provenances, construction of infiltration maps and mapping of hydrologic characteristics of the drift material, establishing the bedrock topology, especially that of buried valleys, and determining the hydrologic significance of these features. In addition, the results of this year's work have pointed to the importance of impermeable till sheets which seem to give rise to multiple aquifer or perched watertable conditions. This particular aspect will be investigated further.

The second activity deals with a detailed investigation of the hydrologic properties of the fill material of preglacial bedrock valleys, the morphology of the valleys, the hydrological interaction between valley fill and bedrock aquifers, and the groundwater flow situation in the valley itself.

The plan is to drill several observation wells into the central part of the valley and into the sides. Pumping tests will give some indication of hydraulic interconnection and long term observation of static levels will indicate horizontal groundwater flow directions and infiltration patterns.

Of the four wells that are planned, one has been completed in the bottom of the valley and one into the Jordan at the valley side. The well logs seem to indicate a clay-till sheet that prevents significant downward flow of water, at least near the valley cross-section as delineated by the drilling. Fill material at the bottom of the valley is a gravel of very high transmissivity. This indication seems to be verified by eleven electrical resistivity depth probes, some of which were conducted in close proximity to wells with fairly reliable driller's logs to obtain geologic control; the other depth probes were carried out by traversing the bedrock valley and filling in gaps of information between the two present drill sites.

The second project is being carried out in cooperation with the U.S. Geological Survey Water Resources Division, who will include the completed wells in its permanent observation network. A second important aspect of the investigation is to study the role of buried bedrock valleys as recharge areas for bedrock aquifers, as preferential channels of water transmission through their permeable parts, and, if possible, to establish how critical these features and parameters are in establishing land-use criteria.

GLACIAL GEOLOGY OF CENTRAL MINNESOTA

by

Paul J. Conlon

During the late summer and early fall, preliminary reconnaissance was made of an area in northern Stearns, southern Todd, and Morrison counties. A detailed examination of the surficial deposits and geomorphology of this area is planned for next summer. The information obtained can be incorporated into maps of the surficial deposits of the state presently being prepared by the Minnesota Geological Survey, and will be used in a doctoral dissertation to be presented to the University of Minnesota.

Earlier work by others, particularly H.E. Wright, Jr. and Bjørn Andersen, suggested a complex glacial history for this area because all major intrusions of ice into the state during the late Wisconsin glaciation influenced it. Deposits from four different episodes of ice advance have been identified on its surface. At least one other glaciation is indicated by a preliminary examination of samples taken from a well near Staples. This well also yielded wood fragments from a depth of 140 feet. These will be dated using carbon^{14} techniques, and should aid in determining the chronology of the various glaciations.

The St. Croix moraine is one of the more prominent topographic features in the area. However, much of the rough topography, which previously was considered part of the moraine complex, is in fact composed of material quite distinct from that of the moraine. Other noteworthy landforms are three sets of drumlins, trending north-south, east-west and northeast-southwest, and a large, intricate system of meltwater–drainage channels.

The lithologies of the various glacial drifts are sufficiently distinct to postulate a source area for each. The lithologies, the landform morphology, and the observed stratigraphy suggest the following preliminary reconstruction for the late Wisconsin glaciation of this area. Ice from the northwest moved into the region from almost due north; as it retreated, ice from Lake Superior advanced. Apparently this episode was short-lived since deposits of this lobe have been found only as thin beds in younger drift. Northwestern ice,

which again intruded from the north, apparently completely eroded the thin deposits of the Superior ice. Retreat of the northwestern ice was followed by an advance from the east of a lobe originating in northeastern Minnesota. The final episode is a third advance of northwestern ice, which entered the area this time from a generally westerly direction.

STUDIES OF RADIOACTIVITY IN VERMILION AND GIANTS RANGE GRANITES

by

R. F. Roy

Variations in the abundances of uranium, thorium, and potassium have proved to be useful indices of differentiation in a number of magmatic complexes. In addition, lateral and vertical variations of radioactive heat sources have an important bearing on thermal models of the crust and upper mantle and the origin of magma.

Approximately 70 samples, 5 to 20 kg each, have been collected from granitic outcrops between Ely, Idington, and Crane Lake, in northern Minnesota. The concentrations of K, U, and Th will be measured by gamma-ray spectrometry. The samples will be available to other investigators for additional petrographic, chemical, and isotopic studies.

A HYDRODYNAMIC AND MORPHOLOGIC STUDY OF POTHOLES

by

Terrill Burch

A natural pothole thirty feet above the Kettle River near Sandstone, Minnesota was used to study currents and sediment movement in potholes. A pump-powered water jet was set at an angle of 30°. Currents and suspended sediments were measured at two different discharge velocities using a Price current meter and a USDH-48 suspended sediment sampler at predetermined points. Both instruments were loaned by the U.S. Geological Survey Water Resources Division in St. Paul. Preliminary evaluation of the data obtained indicates stronger currents and correspondingly higher sediment movement than model experiments would predict.

The second phase of this investigation is concerned with the characteristic morphology of potholes in various rock types. By measuring a statistically significant number of potholes in each different type of rock, a morphologic pattern might emerge which could be correlated with some parameter of the rock type. Potholes near the Minnesota and Temperance Rivers in Minnesota, the Harmony River in Ontario, and Devils Lake, Wisconsin were examined, but there were too few measurable ones to allow an analysis of their shape.

Measurement of potholes on the Kettle River and the St. Croix River at Taylors Falls indicates a definite shape difference between potholes in basalts and those in sandstone. Correlations between the rock parameters and the pothole shapes have not yet been completed.

PETROGRAPHY OF ST. PETER SANDSTONE

by

Walter E. Parham

A fundamental mineralogic investigation of the composition of the St. Peter Sandstone was initiated this summer as a cooperative study with the Mineral Resources Research Center of the University of Minnesota. Samples of the sandstone were taken vertically at five-foot intervals at each of 16 outcrops throughout southeastern Minnesota; the southernmost outcrop sampled is in Fillmore County and the northernmost is in Hennepin County. Grain-size analyses and the composition of the clay mineral assemblage of each sample are being determined. In addition, channel samples were taken at each locality for chemical analysis and for beneficiation tests by the Mineral Resources Research Center in order to help evaluate the sandstone's potential use as raw material for glass manufacture.

Preliminary data show that the clay mineral assemblage of the St. Peter Sandstone in Minnesota is kaolinite, illite, montmorillonite, and mixed-layer clay, with possible minor amounts of vermiculite. Some samples contain all these clay minerals whereas others contain only one. The clay mineral assemblage in the sandstone varies both vertically and laterally.

STRATIGRAPHY AND PETROLOGY OF PLATTEVILLE FORMATION, SOUTHEASTERN MINNESOTA

by

John Mossler

The purpose of this study is to describe the distribution, thickness, lithologic character, and chemical composition of the Platteville Formation where it crops out in southeastern Minnesota, and to evaluate its usefulness as an industrial rock.

Outcrops of the limestone have been described and collected. Some samples will be examined with a petrographic microscope to enable interpretation of origin and subsequent modification of the rock unit. In addition, selected samples will be chemically and mineralogically analyzed and physically tested to ascertain usefulness of the Platteville Formation for various industrial applications. Some descriptive material and analytic data on the Platteville limestone from unpublished theses at the University of Minnesota will also be incorporated into this report.

GEOLOGY AND PETROLOGY OF ORDOVICIAN SHAKOPEE FORMATION

by

George S. Austin

The Lower Ordovician Shakopee Formation, where exposed in southeastern Minnesota, is composed of dolomite with lesser amounts of quartz sandstone and is overlain by the Middle Ordovician St. Peter

Sandstone and underlain by the Lower Ordovician Oneota Dolomite. Detailed examination of the Shakopee Formation during the summer of 1970 consisted of measuring and sampling 27 outcrops and one core in southeastern Minnesota. Approximately 270 carbonate, 50 sandstone, and 25 shale samples were collected. Grain-size determinations have been made for all the friable sandstones. Thin sections of the carbonates and some of the sandstones are being prepared and clay mineralogy will be determined for the shales and some of the sandstones.

A cursory examination of thin sections of the Shakopee Formation indicates that the carbonate beds are entirely replaced dolomite and that the only calcite present is late secondary calcite which fills voids. Many of the original detailed sedimentary structures have been destroyed; however, where silica replaced the original limy sediment before dolomitization occurred, the detail remains.

During the summer field season the field relationships between the Shakopee Formation and the overlying and underlying formations and also between the members of the formation have become clearer. The Shakopee Formation exposed in the southeastern part of Minnesota is composed of two members, the underlying New Richmond Member and the overlying Willow River Member. The New Richmond Member, originally thought to contain only orthoquartzite below the dolomites and thin orthoquartzites of the overlying Willow River Member of the Shakopee Formation, is now considered locally to include sandy dolomite which lies below the orthoquartzite but above the nearly non-sandy Oneota Dolomite. In southwestern Wisconsin and northeastern Iowa an angular unconformity exists between the overlying New Richmond and the underlying Oneota. In the extreme southeastern part of the area studied in Minnesota, the New Richmond Member, composed of orthoquartzite, rests uncomformably on thick-bedded, clean, dolomitized algal mat biolithites of the Oneota Formation. From extreme southeastern Minnesota toward the Minneapolis-St. Paul area the thick orthoquartzite unit in the New Richmond Member thins and sandy dolomite occurs between the orthoquartzite and the lower contact of the Shakopee Formation. The rock just above the lower contact of the formation at several localities is a dolomite breccia and the matrix between dolomite clasts is composed of green sandy clay. In other areas near the Minneapolis-St. Paul area a foot-thick oolitic or oomoldic bed overlies the truncated Oneota.

In general, the upper Oneota Dolomite can be described as a non-sandy, thick-bedded dolostone composed of interbedded dolarenites and algal mat biolithites. The New Richmond Member of the Shakopee Formation may be characterized as being composed of orthoquartzites to the southeast and overlying orthoquartzite with underlying sandy dolomites and some thin orthoquartzites to the northeast and west. The most distinctive rock types within the New Richmond are the oolitic dolomite, dololutite, sandy intraclastic dolomite, sandy dolarenite, and dolomite breccia. These rock types apparently do not exist in the upper part of the Oneota. The upper contact of the New Richmond Member is placed just above the first thick orthoquartzite in the Shakopee Formation. However, this contact becomes more difficult to distinguish toward the northeast and west where the orthoquartzite thins. The lower part of the Willow River Dolomite Member contains orthoquartzites but also non-sandy dolarenites and thin-to medium-bedded algal mat biolithites. In addition, a one- to three- foot thick bed of algal mound biolithites is present one to four feet above the New Richmond-Willow River contact in almost all localities studied. To the north a dolomitized gastropod coquina is present just above the algal biolithite or two to four feet above the New Richmond orthoquartzite.

The contact between the overlying St. Peter Sandstone and the underlying Shakopee Formation was exposed at three localities and was present in the core examined. In general, the orthoquartzite of the St. Peter rests on a thin bed of green shale which in turn rests on dolomite of the Willow River Member of the Shakopee Formation. The contact is flat-lying in the area observed and truncation of the underlying rocks is not obvious.

PETROLOGY AND SEDIMENTATION OF LOWER KEWEENAWAN PUCKWUNGE FORMATION OF MINNESOTA

by

Allen F. Mattis

A study of the petrology and sedimentation of the Lower Keweenawan Puckwunge Formation was begun during the past year. This study consists of a detailed examination of the quartzites in Cook County and at Nopeming, west of Duluth. In Cook County, the Puckwunge Formation is intermittently exposed along a twenty-five mile stretch from Stump Lake in T. 64 N., R. 2 E., east to Lucille Island south of Pigeon Point in Lake Superior. At Nopeming, the formation crops out beneath the basal Keweenawan lava flows in several places along a half-mile distance.

Heavy mineral analyses will be included in the petrologic study. Paleocurrent indicators (cross-bedding and ripple marks) are being measured and, where conglomerates occur, pebble counts are being taken. This information will be useful for determining probable source areas for the formation.

Brief comparative studies of other Lower Keweenawan sedimentary rocks in the Lake Superior region are also being conducted. The Sibley Formation of Ontario, the Barron Quartzite of Wisconsin, and the Lower Keweenawan sedimentary rocks of the Penokee-Gogebic range are included in the study.

GEOLOGY AND PETROLOGY OF SELECTED UNITS WITHIN ORDOVICIAN ONEOTA DOLOMITE

by

W. L. Stubblefield

The summer's work, involving a petrologic study of selected units of the Oneota Dolomite in southeastern Minnesota, dealt primarily with field reconnaissance, measuring and collecting representative stratigraphic sections, preparing 130 thin sections, and conducting geochemical analyses. Emphasis was on the units of the Oneota Dolomite having commercial importance as building stones, though the complete formation will be studied. In the Mankato-Kasota area, five sections and a core supplied by the Mankato Stone Company were measured and samples collected. Two stratigraphic sections were measured in the Winona vicinity, including one from the Biesanz Stone Company's quarry. To assist in the correlation of these two areas, a core from Waseca, drilled by the Minnesota Gas Company, was described and samples were collected.

A geochemical approach was used in studying color variations within the Oneota Dolomite. This approach included: X-ray diffractometer analysis of thirty selected samples prior to dissolving in acid; X-ray and binocular examination of the insoluble residue after dissolving in acid; Titration of the soluble filtrate to determine the relative percentage of ferrous iron per sample; And utilization of atomic absorption to determine the percentage of total iron, manganese, and magnesium per sample. The dolostones were dissolved in formic acid with a small amount of 6N hydrochloric acid added to ensure complete dissolving. With the potential oxidation of the ferrous to ferric iron, dissolving of samples was conducted under a blanket of nitrogen. Except for examination of the insoluble residues and the atomic absorption test for magnesium, the geochemical work is completed.

Bowles, in 1918, reported that color variation in the Oneota was not due to either the total iron or the oxidation state of the iron. Preliminary results of this investigation dispute Bowles' hypothesis. The range

of total iron in the samples was from 0.14 to 1.54 percent, with a mean of 0.59 percent. This compares favorably with the published figure of 0.96 percent iron oxide in the Oneota within the Mankato-Kasota area. The ferrous content ranged from 0.15 to 1.11 percent with a mean of 0.30 percent. Random comparison of the geochemical data and the color of the samples suggests that samples with a deeper red hue have greater total iron concentration and a higher percentage of ferric iron than do samples with a lighter red hue. At this point in the study, the manganese, with a range from 0.02 to 0.06 percent and a mean of 0.04 percent, appears to have little effect on the observed color.

The project will be expanded to compare iron, magnesium, and manganese concentrations between samples from Mankato-Kasota and Winona. Using 27 samples from Mankato-Kasota and only 3 samples from Winona, iron content appears to be much greater in Mankato, with a concentration of 0.63 percent as compared to 0.26 percent in Winona. The oxidation state of the iron differs between localities, with 47 percent of the iron appearing as ferric iron in the vicinity of Winona.

The combining of petrologic and geochemical data has been a seldom-used tool in the study of sedimentary rocks. This project, at this stage, is producing most favorable results and suggests that the final data will yield a more comprehensive understanding of the deposition and diagenesis of the Oneota Dolomite in southeastern Minnesota.

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

by

S. Viswanathan

Eleven distinct granitic phases have been recognized in the western part of the 2.7 b.y. old lower Precambrian mesozonal Giants Range batholith (Mountain Iron-Grand Rapids sector) of northeastern Minnesota. From east to west, these are:

Britt phase (15 sq. miles): grayish pink, medium-grained, foliated biotite-hornblende-granodiorite, aplitic biotite-leucogranodiorite, granodioritic mylonite, and leucogranodioritic mylonite.

Mountain Iron-Chisholm phase or Zone 1 (15 sq. miles): pink, equigranular, massive, medium-grained, chloritized biotite leucogranite to leucosyenogranite with minor biotite (± amphibole) granodioritic and tonalitic rocks.

Spring Lake phase or Zone 2 (40 sq. miles): pink, porphyritic, moderately to strongly foliated, coarse-grained biotite-adamellite to biotite-granite.

Shannon Lake phase or Zone 3.1 (5 sq. miles): pinkish, equigranular, foliated, medium-grained biotite-adamellite to biotite-granite.

Shoepack Lake phase or Zone 3.2 (15 sq. miles): grayish white, gneissic, medium-grained, biotite-muscovite-granite, locally garnetiferous, cut by muscovite-leucogranite.

Leander phase or Zone 3.3 (30 sq. miles): pinkish gray, gneissic, medium to fine-grained muscovite-biotite-bearing rocks of tonalitic, granodioritic and granitic compositions, associated with biotite-leucogranite, aplite, pegmatite, and minor amphibole and biotite schists.

Luna Lake phase or Zone 4.1 (25 sq. miles): grayish, equigranular, weakly foliated, fine-grained, muscovite-biotite-granite, associated with biotite-leucogranite, aplite, pegmatite, and abundant biotite schist and amphibole schist.

Murray phase or Zone 4.2 (25 sq. miles): grayish, equigranular, massive to weakly foliated, fine-grained, muscovite-biotite-adamellite to granite, associated with abundant pegmatite and minor biotite schist.

Chisholm-Mahoning phase (10 sq. miles): gray, medium-grained, well-foliated sphene-biotite-hornblende-tonalite containing amphibolite inclusions.

Stingy Lake phase (20 sq. miles): pinkish, equigranular, occasionally porphyritic, foliated, medium-grained hornblende-granodiorite, clinopyroxene-hornblende-adamellite, biotite-hornblende-tonalite, and biotite-quartz tonalite, associated with schistose inclusions.

Mahoning-Nashwauk-Grand Rapids phase (30 sq. miles): whitish gray, medium-grained, weakly to well-foliated, biotite-quartz tonalite, containing inclusions of biotite-hornblende-schists, cut by biotite-granite and pegmatite.

A tentative geochronological sequence of these granitic phases is (from oldest to youngest): Mahoning-Nashwauk-Grand Rapids and Leander phases; Chisholm-Mahoning phase; Stingy Lake and Britt phases; Shannon Lake and Spring Lake phases; Shoepack Lake phase; Luna and Murray phases; Mountain Iron-Chisholm phase.

Field and laboratory studies suggest that these eleven granitic phases belong to four genetic groups: anatectic, metasomatic, treptomorphic, and magmatic.

Geology in the central region of the western part of the Giants Range batholith between Nashwauk and Chisholm is much more complex than hitherto believed: (1) North of Nashwauk, a heterogeneous migmatitic unit composed of biotite-hornblende-plagioclase-quartz gneisses, amphibolite layers, agmatite, and granitic and pegmatoid leucosomes, separates the granite from a sequence of pillowed basalt and metabasalt with schistose intercalations; (2) North of Keewatin, conspicuous units of striped amphibolite, and numerous prominent north-northwest- to northwest-trending gabbro dikes occur between the granite and the main mass of the mafic metavolcanics; and (3) North of the Hibbing-Buhl sector, a metasedimentary unit, eight miles long and one half to one mile wide, consisting of fine-grained gneisses containing quartz, microcline, plagioclase, biotite, hornblende, clinopyroxene, and epidote (in various combinations and amounts), intervenes between the granite and the metasedimentary country rocks.

Apatite with pleochroic cores in shades of blue, brown, and purple has been observed in some pre-granite metasedimentary rocks of the area. The implications of this discovery are interesting: Apatite with pleochroic cores is reported to occur only in granitic rocks that have assimilated foreign material (Baker, G. 1941, American Mineralogist, v. 26, pp. 382-390). If this is true, some of the pre-Giants Range Granite metasedimentary rocks, presently interpreted to be volcanigenic, appear to have been derived from an older granitic terrane. This opens the possibility that in the Early Precambrian history of northeastern Minnesota there had been a "granitic event" much before the formation of the 2.7 b.y. old Giants Range batholith.

Laboratory studies carried out during the past year include optical petrographic work on some 400 thin sections, point-count modal analyses of 71 thin sections, measurements of O^{18}/O^{16} ratios in 28 quartz concentrates, determination of 23 trace, minor, and major elements (Y, Ce, La, Ba, Zr, Rb, Sr, Pb, Zn, Cu, Ni, Co, Cr, Mn, Ti, V, Nb, Th, K, Ca, Fe, Si, Al) in each one of 100 samples (33 whole rocks, 36 mafic minerals, 31 felsic minerals) by X-ray emission spectroscopy, and analysis of plagioclase and potash feldspars using an electron microprobe.

A new classification of granitic rocks was devised (Abstract, Inst. on Lake Superior Geol., p. 40-41, 1970). Unlike the ones currently in use which mainly emphasize the modes of quartz, potash feldspar and plagioclase, the new classification recognizes the importance of additional parameters such as: (1) Amphibole/biotite ratios; and (2) Proportions of non-opaque calcic trace minerals (sphene, apatite, epidote, etc.).

STABLE ISOTOPE STUDIES

by

E. C. Perry, Jr.

Several stable isotope studies have been pursued during the past year. These were undertaken with support from the National Science Foundation, the Petroleum Research Fund of the American Chemical Society, and the Office of International Programs, University of Minnesota.

Carbon

A study of carbon isotope variations in the Biwabik Iron-formation conducted by Dr. Francis Tan and me strongly suggests that the carbon isotopic composition of siderite and ankerite in iron-formations can be used to detect certain diagenetic and metamorphic oxidation-reduction reactions. One of the most important of these is the reaction:

$$Fe_2O_3 + C_{(Organic)} \longrightarrow Fe_3O_4 + CO_2$$

This reaction permits exchange between an organic-carbon reservoir and a carbonate-carbon reservoir of very different isotopic composition. Our results, which provide an important new parameter for use in the study of iron-formations, were presented at the 1970 UNESCO conference on iron-formations and iron ores at Kiev, Ukraine, Russia.

Oxygen

A study of the 3,000-m.y.-old carbonates and cherts of southern Africa that Dr. Tan and I are preparing for publication shows that the isotopic composition of these rocks is significantly different from that of modern carbonates and cherts. We think it probable that this difference is primary and that it results from a progressive change in the isotopic composition of the ocean through time.

Sulfur

A study of sulfur in 3,000-m.y.-old syngenetic barite deposits of South Africa shows that, unlike modern volcanigenic barite, there is practically no sulfur isotope fractionation between sulfate and contemporaneous sulfide. Strontium isotope data show that these barites predate any recognized metamorphic event in the area, and we postulate that these sulfates were precipitated in an ocean that was characterized by a lower oxidation-reduction potential and a much different sulfur cycle than the present ocean.

Sulfur isotope ratios in the mineralized Duluth Complex are much different from those of basalts and other basic igneous complexes. One interesting possibility is that much of the sulfur was contributed by sulfur-rich underlying sediments, and that as it streamed up into the magma it scavenged cations.

ISOTOPIC STUDIES OF LOWER PRECAMBRIAN ROCKS, NORTHEASTERN MINNESOTA

by

Bor-ming Jahn

A study of the Lower Precambrian basement in Minnesota and its transformation processes should provide some clues to an understanding of crust-mantle evolution in the early history of the Earth. Rocks in northeastern Minnesota exhibit features characteristic of Archean terranes. Detailed field studies by the Survey have revealed that the layer-cake concept of stratigraphy is not applicable to the associated rock formations—Ely Greenstone (mainly pillowed basalts and andesitic flows), Knife Lake Group (mainly feldspathic graywackes and conglomerates), Lake Vermilion Formation (quartzo-feldspathic, volcaniclastic and felsic conglomerate members), and Newton Lake Formation (mainly metavolcanic rocks)—rather, an intertonguing of units is characteristic of this sequence.

One of the important geologic problems in northern Minnesota is the mode of formation of the Giants Range and Vermilion batholiths. Usually the vast areal extent of granitic batholiths, with associated minor basic rocks, is quoted as a fundamental problem of differentiation of basaltic magma. However, granitization or anatexis which also possibly leads to the formation of batholiths seems less applicable here, because the associated Greenstone belt has not been subjected to high-grade metamorphism. Thus, the batholiths were more likely formed by direct extensive differentiation of the upper mantle.

The Sr isotopic tracer method is to be employed in this study. During the past summer a fairly complete spectrum of rocks other than granites was collected. These rocks belong to the intertonguing lithostratigraphic units and were subjected only to low-grade metamorphism. Granite samples will be obtained from Dr. R. F. Roy and additional rocks of the sedimentary-volcanic sequence will be obtained from Dr. E. C. Perry, Jr.

The purpose of this study is to shed some light on the following questions:

1) Whether the batholithic granites were derived from a primitive upper mantle by extensive differentiation or from partial melting of pre-existing clastic sediments and volcanics;

2) The genetic relationship between granites and the volcanics and clastic sediments with which they intertongue;

3) Provenance of quartzo-feldspathic components in clastic sediments – whether these components were derived from the volcanics or from any pre-existing (older than Ely Greenstone) granite cratons for which no outcrop evidence exists;

4) Intertonguing stratigraphy – radiometric dating may disclose whether the rock-stratigraphic terms could be used as time-stratigraphic units in certain areas;

5) Geologic evolution of Precambrian mobile belts.

Thin sections of all rocks collected are under careful examination and whole rock powder samples are being prepared. Hopefully, some preliminary report on the isotopic analysis will be presented at the coming American Geophysical Union meeting.

TRACE AND MINOR–ELEMENT DETERMINATIONS IN ROCKS OF VERMILION DISTRICT, MINNESOTA

by

E. C. Perry, Jr.

Lower Precambrian rocks of the Vermilion district, northern Minnesota contain anomalously high concentrations of heavy metals and are similar in age, type, and geologic setting to rock sequences that elsewhere are significant or potentially significant sources of nickel, copper, zinc, silver, gold, chromium, and platinum. To evaluate the resource potential of the Vermilion district, a study of trace and minor elements in the rocks of the area was conducted during the past field season in cooperation with the U.S. Geological Survey. The U.S. Geological Survey furnished a geologist and a fully manned portable laboratory including an emission spectrograph, an atomic absorption spectrophotometer, and some rock crushing equipment.

Semiquantitative spectrochemical analyses of good precision were performed for 30 elements on all samples, and atomic absorption or other colorimetric determinations for As, Au, Cu, Co, Ni, Pb, and Zn were performed on most samples. Not all collected material could be processed in the field during the time available, so that many routine determinations and all specialized determinations, such as Pt, will be done at permanent U.S. Geological Survey laboratories in Denver, Colorado.

Though evaluation of data is incomplete, the following conclusions are justified:

1) Soils in the direction of glacial movement from known Cu-Ni deposits in the Duluth Complex have anomalously high concentrations of Cu and Ni at considerable distances from the deposit. Soil analysis would thus seem to be a valuable adjunct to geologic mapping programs in this terrane.

2) Assuming that high concentrations of heavy metals can be detected by soil sampling, no evidence for extensive mineralization was found along the major faults mapped in the area.

3) Extensive low-grade copper mineralization occurs on Ely Island in Lake Vermilion.

4) In the greenstone belts, we find anomalously high, but not impressive, concentrations of Cu, Ni, and Cr but little Au.

The program may ultimately be useful in evaluating geochemical similarities and differences between Archean rocks and more recent rocks of the same type. As a practical matter, the program should be continued to aid in determining whether ore-concentrating processes have produced any economically significant deposits.

GEOLOGY OF EASTERN PART OF DULUTH COMPLEX

by

Donald M. Davidson, Jr.

To aid in completing the Two Harbors bedrock geologic map (1:250,000), twelve weeks of semi-detailed reconnaissance geologic mapping were undertaken in the eastern part of the Duluth Complex. More specifically, the area extended from the eastern edge of the Forest Center quadrangle (91° 15′ W.) to Mineral Center (89° 40′ W.) and from 47° 45′ to 48° 00′ N. This area encompassed fifteen 7½-minute quadrangle sheets as well as selected areas in the Cramer (15-min.) and Tait Lake (7½-min.) quadrangles. In addition, drill core from the Brule Lake Area, provided by the New Jersey Zinc Co., were logged.

Based on this past summer's work, the eastern part of the Duluth Complex can be characterized as consisting of two major units of gabbroic anorthosite separated by a zone of rocks composed of felsic intrusives, granofels, and augite troctolite. The anorthositic units are bounded on the south by Keweenawan volcanics and mafic intrusives and on the north by assemblages of troctolite, as described by Paul Weiblen in the Long Island Lake quadrangle, and magnetite-rich gabbroic rocks, as noted by Nathan.

The easternmost extent of the western gabbroic anorthosites is about longitude 91° 00′ W. The rocks are coarse-grained with inconsistent foliations, and have been intruded by troctolites, such as may be noted along the western edge of Alice Lake.

By comparison, the eastern gabbroic anorthosites are medium-grained, locally well-foliated, and contain zones rich in magnetite, particularly near the western contact (90° 50′ W., e.g., in the vicinity of Smoke, Jack, Kelly and Burnt Lakes). The eastern anorthositic rocks are separated into so-called eastward-westward-trending north and south limbs by a granophyric granite unit noted south of Winchell Lake and a group of interlayered volcanics and medium-grained poikilitic gabbros which extend eastward from Brule Lake.

The northern limb anorthosites grade gradually into older (?) troctolite rocks, for example on Little Saganaga Lake, but contact abruptly against the older magnetite-rich gabbro and troctolitic sequence described by Nathan.

The southern anorthosite limb extends from the eastern edge of Sawbill Lake to Mineral Center, thus including a large volume of rocks previously designated as the Reservation River Diabase. This unit contains inclusions of metasedimentary rocks (Virginia Formation?).

Fine-grained granophyric granite sills separate the anorthositic units near 91° W. Adjacent to these felsic intrusions and related to them in origin are large masses of dense, fine-grained granofels, noted in the Lake Polly and Kelso Mountain quadrangles. Moreover, a variety of felsic intrusive units are spatially proximal and probably true equivalents of the granophyric granites. These intrusions include the Smoke, Dent, and Wine Lake intrusive complexes noted by early workers. A large body of well-foliated, medium-grained augite troctolite, which is locally interlayered with a dense granofels, occurs at the northern end of Sawbill Lake. This unit is quite similar to troctolitic units mapped in the Long Island Lake quadrangle and may represent the southern margin of a troctolite basin.

In addition to the completion of the Two Harbors project, this year's research will focus on the petrography of the various units and the investigation of definitive criteria for distinguishing age relationships between similar mafic rock units of the eastern part of the Duluth Complex.

GEOLOGIC INVESTIGATIONS IN SOUTHERN PART OF DULUTH COMPLEX

by

Bill Bonnichsen

Geologic investigations were concentrated in two areas during the summer of 1970.

About three weeks were spent examining outcrops in the Silver Bay and adjacent 15-minute quadrangles. Virtually no exposure is present along the western side of that quadrangle. Scattered outcrops of gabbro, and locally basalt, occur in the southern part of the quadrangle. An extensive area four to six miles across, underlain by granophyre, was encountered immediately west of Finland in the northeastern part of the quadrangle. The eastern part of the quadrangle is underlain by gabbro and associated rocks of the Beaver Bay Complex, which was previously mapped by Grout and Schwartz (1939, Minn. Geol. Surv. Bull. 28). Because of lack of outcrops in the northern and northwestern parts of the quadrangle, no direct lithologic information is available yet for the area occupied by the large positive gravity anomaly and associated magnetic anomalies. It is interesting to note, however, that this feature is flanked both to the east and the west by extensive areas of granophyre and felsic volcanics.

The remainder of the summer was spent examining drill core acquired by Newmont Mining Company during its Duluth Complex Cu-Ni exploration program in the Dunka River area. About 25,000 feet of a total of nearly 40,000 feet of core that is available was sampled, and some holes were logged in detail. This detailed investigation is aimed toward gaining a three-dimensional understanding of sulfide mineral

distribution within various lithologic units. Aidan O'Sullivan, a graduate student at the University of Minnesota, aided in this initial phase of the investigation. It is anticipated that O'Sullivan will study some aspects of the geology and sulfide mineralization in the Dunka River area as the topic of his Ph.D. dissertation. The Newmont drill core was moved from Ely to the U.S. Bureau of Mines in Minneapolis (Ft. Snelling) at the end of the summer.

ARCHEAN CONGLOMERATES OF VERMILION DISTRICT

by

Roger K. McLimans

An investigation of the conglomerates of the Knife Lake Group was undertaken this summer to gain information concerning the provenance and tectonic significance of these rocks. The area studied extends from Cache Bay, Ontario to Newton Lake near Ely.

Variations in pebble composition, pebble size, and sedimentary structures were recorded. Four distinct units were recognized: (1) At Cache Bay, the conglomerate consists of large, well-rounded Saganaga granite boulders in a coarse arkosic matrix; (2) At Ogishkemuncie Lake, the conglomerate consists of rounded pebbles of greenstone, other volcanics, Saganaga granite, and several miscellaneous lithologies. The conglomerate beds are interbedded with graded graywackes; (3) On Alpine, Ogishkemuncie, and Jenny Lakes, the conglomerate is similar to unit (2) but contains 4-6 percent jasper pebbles. (4) On Ensign, Chute and Moose Lakes, deformation has greatly elongated most pebbles, with the exception of the granitic ones.

All field work, petrography, and analysis of data will be completed before the 1971 field season.

GEOLOGY OF NORTH SHORE VOLCANIC GROUP

by

John C. Green

Approximately six weeks were spent mapping the North Shore Volcanic Group, partly as a reconnaissance for the Two Harbors 1:250,000 sheet, and partly as detailed mapping, especially along the Lake Superior shore and tributary streams. In addition, a one-week field trip of geologists currently working in the Keweenawan volcanics was held, starting in the Keweenaw Peninsula of Michigan and going through northern Wisconsin and up the North Shore of Lake Superior.

One significant result of the mapping was the tracing inland for considerable distances of some distinctive flows or groups of flows that are conspicuous along the Lake Superior shore. Near Good Harbor Bay, Cook County, the ridge-forming ophitic basalt, famous for its thomsonite, continues for a distance of at least 16 miles southwestward to the Poplar River. The porphyritic felsite flow complex of the Kimball Creek area, northeast of Grand Marais, was traced westward for about 16½ miles to the Cascade River. The group of porphyritic andesites that crops out on the Lake Superior shore just east of Good Harbor Bay continues west-southwestward for at least 21 miles past Onion River; and the thick rhyolite flow at Devil Track River, Grand Marais, was traced west-southwestward for about 23 miles to the Caribou Trail. This mapping has demonstrated that the ophitic flows at Tofte, which since 1959 (Minn. Geol. Survey Bull. 39) have been considered the topmost flows in Minnesota's sequence, are perhaps rivaled in stratigraphic height by coarser and thicker basalts a few miles east of Lutsen; an upwarp centered at the Onion River intervenes.

Near the base of the magnetically normal (Middle Keweenawan) sequence near Hovland are two distinctive porphyritic trachy-basalts with large, platy plagioclase phenocrysts. This summer's reconnaissance west of Hovland indicated the presence of a great thickness of similar flows. Lower Keweenawan (magnetically reversed) diabasic basalts with distinctive texture were also traced from the Grand Portage area westward for many miles.

Detailed maps of several sections of the Lake Superior shoreline are being constructed, and research is continuing on the petrology and mineralogy of the flows.

GEOLOGY OF NORTHERN PART OF GUNFLINT LAKE QUADRANGLE

by

James A. Grant

Six weeks were spent mapping the Rove Formation and Logan intrusions from the contact with the Duluth Complex to the Canadian border, with a view to defining the variations in these rocks, the nature of the metamorphism, and the actual contact relations with the complex.

The Rove Formation, described by Morey (SP-7, Minn. Geol. Survey, 1969), dips 8^{o} to 20^{o} south, except near the complex, where dips of about 40^{o} are common. It is intruded by several Logan sills, of which the largest forms the palisade between Gunflint and Loon Lakes. This sill is about 1,000 feet thick and is emplaced near the top of the lower argillite unit.

The metamorphism of the Rove, as seen in the field, is compatible with the description given by Morey, except that (a) chloritoid is widespread in certain laminae of the argillite below the main sill; (b) although the gneissic structure, as portrayed by Morey (p. 51), is common near the complex contact, it was not found elsewhere, even adjacent to the main sill; and (c) in this area there was no significant problem in distinguishing metamorphosed Rove Formation from either Logan or Duluth Complex rocks.

The Logan intrusions are differentiated, and in the thicker sills the sequence is from a chilled margin, to fine-, then medium-grained diabase at the top of a palisade, to a coarse gabbroic phase about two-thirds up the sill, a highly porphyritic (plagioclase) phase near the top, and an upper chilled margin. The age of the Logan intrusions relative to the Duluth Complex is still in question, but the following points suggest that a relatively young age is a strong possibility:

(a) Despite the gross truncation of the trend of the Logan sills by the complex no such truncation was actually seen in outcrop;

(b) Only chilled margins of Logan sills were recognized in contact with complex rocks;

(c) No definite evidence of metamorphism of Logan sills by the complex rocks was recognized in the field;

(d) The Logan sill on the Loon Lake peninsula is continuous with "Unit dy" of Nathan (1968, unpublished thesis, Univ. of Minnesota) which he considered, on petrologic grounds, to be a late phase of the Duluth Complex.

Because of the fine grain size of the Rove hornfelses, the chilled margins of the Logan sills, and the gross similarity between some parts of the sills and rocks possibly of the Duluth Complex, considerable petrography will be required as the next step in unravelling these relations.

GEOLOGY OF SHAGAWA LAKE QUADRANGLE

by

P. K. Sims

Geologic mapping was continued in the quadrangle during the past field season, and is about 75 percent completed. Michael Mudrey, Jr. is assisting in mapping the granite-migmatite of the Vermilion Granite in the northern part of the quadrangle. A brief summary of the general geology of the quadrangle was given in Summary of Fieldwork, 1969.

Mapping in the younger mafic volcanic unit, recently named the "Newton Lake Formation" (Morey and others, Rept. Inves. 14), disclosed two additional ultramafic bodies. The largest, exposed on the southeast flanks of the hills in secs. 19 and 24, T. 63 N., R. 12 and 13 W., is a differentiated intrusive mass 600-1,000 feet thick (estimated) that extends northeastward and underlies Little Long Lake. Field identification indicates that the intrusive body consists of about 150 feet of serpentinized peridotite that is overlain by a mafic pyroxene-rich rock that grades upward to diabasic gabbro. The uppermost part, on crests of the hills, consists of a coarse gabbro with radiating pyroxene crystals. The top of the body is truncated by the Vermilion fault. Another body, about 0.6 miles long and a maximum of 0.2 miles wide, is exposed in secs. 27, 28, and 29, T. 63 N., R. 13 W. It is closely associated spatially with diabasic gabbro, mafic tuff, and impure marble.

Mapping in the granite and metamorphic rocks north of the Vermilion fault has shown that the metamorphic rocks are complexly folded and faulted. A synform outlined by amphibolite in the vicinity of Shipman Bass Lake (secs. 10 and 11, T. 63 N., R. 13 W.) has a northeast-trending axial trace, is overturned to the southeast, and plunges northeast. A body of lamprophyre, 0.6 miles long and a maximum of 0.3 miles wide, lies in the axial region of the fold. Steeply-dipping faults strike north-northeast and northwest. The north-northeastward-trending faults have left-lateral displacements; the northwestward-trending faults in part at least have right-lateral displacements.

Sulphides occur sparsely in the metamorphic rocks within the quadrangle but locally are conspicuous, particularly in the intermediate-mafic tuffs and tuff-breccia units.

GEOLOGY OF ELY QUADRANGLE

by

John C. Green

Only about one week of field mapping was possible in this area during the 1970 season. Effort was concentrated on locating a major fault (the Waasa fault) in the southwestern corner of the map and on locating the Giants Range batholith/Ely Greenstone contact southeast of Ely.

The quadrangle is underlain by several east-northeast-trending belts of differing rock series, all of Early Precambrian age. From northwest to southeast they form a superficially symmetrical series of: Vermilion batholith and related high-grade biotite and hornblende schists and gneisses; thick metabasaltic and metadiabasic greenstone (Newton Lake Formation); slates and graywackes (Knife Lake Group); more thick greenstones (Ely Greenstone), including a major iron-formation in the Ely Trough; and Giants Range batholith. The symmetry is misleading because the three major stratified belts are not in a synclinal stratigraphic relationship; instead, they are progressively older from northwest to southeast.

The contact between the Vermilion batholith and the Newton Lake Formation in this quadrangle is a major fault (The Vermilion fault); a mylonite zone up to 1,000 feet thick lies along this fault, which is expressed as a distinct topographic trench. The southeastern contact of the Newton Lake Formation is also a fault in this area (Squaw Bay fault); isoclinal folds and other structures within the Newton Lake Formation are truncated at this contact against the older Knife Lake Group. The Knife Lake Group rests conformably on the Ely Greenstone in some places to the east, in the Gabbro Lake and Forest Center quadrangles, but the contact is a fault in the Ely quadrangle, truncating not only minor structures in each formation but the major isoclinal Ely Trough as well. In this trough, a thick iron-formation, which yielded the ores mined at Ely, filled the core; it represents the uppermost strata of the Ely Greenstone in this map area and any intervening deposits between it and the basal Knife Lake have been faulted or eroded away.

Continuing across the Ely Greenstone to the southeast, a higher proportion of andesitic to dacitic lavas are found than is present to the east in the Gabbro Lake quadrangle. The entire belt from the Ely Trough to the Giants Range batholith faces north, and the batholith clearly intrudes the lowest parts of the Ely. Major faults cut across this contact as well as across all the other formations in the quadrangle.

An open-file map is available in Minnesota Geological Survey offices.

GEOLOGY OF TOWER QUADRANGLE

by

R. W. Ojakangas and P. K. Sims

Additional mapping was carried out in the quadrangle during the past year to further refine knowledge of the structure of the rock strata. Geologic mapping was completed, and the quadrangle now is being prepared for publication.

The mapping confirmed the earlier interpretation of Peter Hooper (see Summary of Fieldwork, 1969) that the rocks were deformed by two major periods of deformation, followed by an episode of kink-banding and by faulting. Older northwest-trending, nearly isoclinal folds that had gentle(?) plunges were refolded by folds that trend nearly east-west and have nearly vertical axial planes. The older folds (F_1) can be mapped only where top-directions can be determined by means of graded beds (graywacke-slate units) or pillow structures (metabasalts). Interference patterns, locally visible, are a guide to the presence of an older set of folds. The younger folds (F_2), on both a large and a small scale, are mainly asymmetrical and Z-shaped. S-shaped folds are confined to the shorter, northeast-trending limbs of the major (F_2) folds. As a result of the younger deformation, most mappable folds and lineations plunge steeply ($>60^{o}$).

In exploring for mineral deposits in the region, cognizance should be given to the two fold sets. Concentrations of ore minerals could be related to fold axes of either set. If ore minerals were concentrated, for example, in the axial regions of F_1 folds, refolding could yield a variety of shapes, including corkscrew-shaped bodies.

GEOLOGY OF PIGEON POINT QUADRANGLE, COOK COUNTY

by

M. G. Mudrey, Jr. and P. W. Weiblen

Preliminary detailed geologic mapping of the Pigeon Point quadrangle and adjacent areas in the Grand Portage quadrangle was initiated this year. This area constitutes the most easterly bedrock exposures in

Minnesota and is adjacent to Canada. Previous work includes a detailed map and report by Bayley (1893), a discussion by Daly (1917) and a map and discussion by Grout and Schwartz (1933, p. 44).

On Pigeon Point the geology consists of gently-dipping Rove Formation (bedding N. 75° E. 15° S. E.), intruded by a 600-foot thick sill. Field relations disclose 300 feet of troctolitic gabbro, 40 feet of layered anorthosite, 200 feet of ferrogabbro, and 50 feet of contact zone, including granophyre, argillite inclusions, crystals of plagioclase, and blocks of anorthosite.

The Rove Formation is overlain by sedimentary rocks and volcanic flows of Keweenawan age. Small dikes (less than 20 feet thick) trend in an easterly direction in the Pigeon Point quadrangle. Calcite, barite, and iron and copper sulfide mineralization is found in shear zones, some of which were mined on Susie Island in the early part of this century.

Problems of the area that are being studied include the origin of "red rock" (granophyre), differentiation mechanisms within the sill itself, and tectonic changes accompanying the advent of Keweenawan volcanism.

One field season of mapping remains of which one-half is scheduled for next summer, and one-half for the succeeding summer.

AGE OF PRECAMBRIAN ROCKS OF SOUTHWESTERN MINNESOTA

by

S. S. Goldich

"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 press, Bulletin of the Geological Society of America.

The age of the granite in the vicinity of Fort Ridgely is now being determined by C. W. Keighin at Northern Illinois University.

GEOCHRONOLOGY OF THE GIANTS RANGE BATHOLITH

by

G. N. Hanson, L. Prince, and E. Catanzaro

K-Ar, Rb-Sr, and U-Pb ages have been determined on samples from the Giants Range batholith and it appears that the time of origin of the different units making up the batholith is about 2,700 m.y. Two U-Pb ages on sphene from the eastern end of the batholith are concordant and give about 2,700 m.y. A whole rock Rb-Sr isochron from the center of the batholith is 2,670 m.y. ($Rb^{87}\lambda_\beta = 1.39 \times 10^{-11}$ yr^{-1}) and seven K-Ar ages for hornblende from various parts of the batholith give ages of 2,600 - 2,700 m.y.

The main emphasis for the rest of this study will be to determine U-Pb ages for sphene in several other parts of the batholith and to try to determine the cause for the lowering of biotite ages to about 2,500 m.y. (Goldich and others, 1961).

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

GEOCHRONOLOGY OF MAFIC DIKE ROCKS, NORTHEASTERN MINNESOTA

by

G. N. Hanson and R. Malhotra

The main areas studied are in the Saganaga-Northern Light Lakes area and the Vermilion district. K-Ar mineral and whole rock ages have been determined on samples from fifteen mafic bodies. Times of intrusion are thought to be at about 2,600, 2,000, 1,300, and 900-1,100 m.y. Those samples which give K-Ar ages greater than 1,300 m.y. show extensive alteration that is characteristic of prehnite-pumpellyite-grade burial metamorphism and the whole rock ages for these samples have been lowered, suggesting burial metamorphism about 1,600 m.y. ago. The samples which give ages of 1,300 m.y. or younger do not have this style of alteration nor do the whole rock K-Ar ages appear to be lowered.

The study, the manuscript for which is now in preparation, is being financed largely by a grant from the National Science Foundation.

GEOCHRONOLOGY OF MINNESOTA–ONTARIO BORDER REGION

by

S. S. Goldich

Manuscripts presenting results of investigations in the Rainy Lake district and the Saganaga-Northern Light Lakes area are in preparation. The principal event in both areas is dated at 2,700 m.y. ago.

AGES OF ROCKS ASSIGNED TO PENOKEAN OROGENY IN MINNESOTA

by

S. S. Goldich

Sampling of rocks in central Minnesota, including some diamond-drill coring of the McGrath Gneiss and Thomson Formation, was carried out during July and August, 1970, with the assistance of G. B. Morey of the Minnesota Geological Survey.

Dr. C. W. Keighin and Dr. Andrew Turek of Northern Illinois University are collaborating in the Rb-Sr age measurements which are being made at Northern Illinois University in DeKalb, Illinois.

The Penokean project is supported by NSF Grant GA-12316 to Northern Illinois University.