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Pre-Cambrian geology of the Norway Lake area, Dickinson County, Michigan

by

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Michigan Department of Conservation

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Pre-Cambrian geology of the Norway Lake area, Dickinson County, Michigan

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Abstract

The Norway Lake area straddles the south margin of the Sagola basin, an embayment of Huronian sedimentary rocks into the west side of a complex of crystalline and sedimentary rocks of pre-Huronian age. The north part of the Norway Lake area is underlain by the Randville dolomite, an unnamed succession of slates, Vulcan iron-formation, and interbedded slates and graywackes of the Sagola basin. The Sturgeon quartzite has not been definitely recognized in the Norway Lake area. The Randville dolomite is more than 800 feet thick and can be subdivided into upper and lower dolomite members separated by a slate member. The Vulcan iron-formation and the footwall slates are exposed only in the Deerhunt exploration. A thick section of red and gray slates with interbedded graywacke, of probable Upper Huronian age, underlies the northwest part of the mapped area. The south part of the Norway Lake area is underlain by granite gneiss, an arkose series, and schists, all of pre-Huronian age.

The principal structural elements of the Norway Lake area are high angle faults, and such faults form most of the boundary between Huronian and pre-Huronian rocks in the area. The structure of the Huronian rocks, particularly in the vicinity of the Deerhunt exploration, cannot be determined with certainty on the basis of information now available.

Magnetic anomalies were found to be associated with the slate member of the Randville dolomite, basalt interbedded with the arkose series, and a magnetite-bearing member in hornblende schist.

It is possible that economic deposits of iron ore occur within the mapped area. However, exploration will be tedious and costly because of the structural complexity of the area and the paucity of exposures. Furthermore, the absence of strong magnetic anomalies, such as typically are present in areas known to be unde~lain by Vulcan iron-formation, suggests that the iron-formation is not present in abundance; in fact, it may be limited to the immediate vicinity of the Deerhunt exploration.

Field mapping and petrographic examination do not provide data to determine whether the granite gneiss formed from a magma. Chemical analysis of one sample suggests that it was formed from rocks of the earth's crust rather than by fractional crystallization of a basaltic magma.

The original feldspars of the granite gneiss were probably anorthoclase and analbite. During uplift and denudation these were changed to microcline microperthite and albite. These feldspars were contributed to the arkose series. During regional metamorphism of the granite gneiss and arkose replacement type microperthite and secondary perthite were formed, probably by redistribution of feldspars already present rather than by metasomatism.

Introduction

The area covered by this report extends from 1 mile north of the north line of T. 42 N., to 3 miles south of this line, and from 1 mile west of the east line of R. 28 W., to the west line of R. 29 W., Dickinson County, Michigan (fig. 1). It is crossed in a north-south

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Figure 1. Index map showing location of Norway Lake area.

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direction by county road 581, and in an east-west direction by county road 422 and an unnumbered county road. Norway Lake is the best-known geographical feature of the area.

This report is based on field work done during the summers of 1947 and 1948. The work is part of a general re-study of eastern Iron County and western Dickinson County by the U. S. Geological Survey in cooperation with the Michigan Department of Conservation, Geological Survey Division.

Most exploratory work in the Norway Lake area has centered on the Deerhunt exploration, which consists of a group of test pits and trenches dug in approximately 1905 and a series of diamond drill holes drilled in 1930. No ore has been produced.

Geologic mapping was done on aerial photographs, and the base map was compiled from the photographs by standard photogrammetric methods. Land sections 1 mile square were assumed except in the vicinity of county road 581 where the road survey was used for control. An area of excellent exposures of arkose and associated rocks on the East Branch of the Sturgeon River near the northwest corner of sec. 17, T. 42 N., R. 28 W., was mapped by plane table. Magnetic survey stations were located by pace-compass traverses adjusted to the geologic base map.

Acknowledgments.--The generous cooperation of Jones and Laughlin Ore Co., Cleveland Cliffs Iron Co., and M. A. Hanna Co., in permitting access to their files for drilling data is gratefully acknowledged. Valuable advice on the problems of the area was given by F. J. Pettijohn, H. L. James, and C. E. Dutton of the U. S. Geological Survey. R. B. Hall ably assisted the field work for one month in 1947, and E. R. Jacobus operated a magnetometer during the summer of 1948.

Literature.--The Norway Lake area was first mapped by Bayley (1899) as part of his study of the Sturgeon River tongue. His report lists brief references to the area by earlier workers and contains petrographic descriptions of most of the rocks in the area. Bayley's description of the area is briefly reviewed by Van Hise and Leith (1911), and his map is used with slight modification by these authors in compilation of their map of the Crystal Falls district (1911, pl. 22). Later regional geologic maps (pl. 1 in Leith, Lund, and Leith, 1935; and Martin, 1936) show a similar interpretation of the geology in the vicinity of Norway Lake.

The Norway Lake area is included in an aeromagnetic survey of Dickinson County made by the Geological Survey in 1948 (Wier, Balsley, and Pratt,   ). Pettijohn (   ) has studied the geology of a township adjoining the Norway Lake area on the west. Some aspects of the stratigraphy of the Norway Lake area are discussed briefly by James, Clark and Lamey (1952).

General geology

The Norway Lake area lies on the south margin of an embayment of sedimentary rocks of Huronian age into the west side of a complex of crystalline and metamorphic rocks of pre-Huronian age. The name Sagola basin, suggested by Pettijohn ( ), is used to designate this embayment in the present report in preference to the earlier term "Sturgeon River tongue" used by Bayley (1899, p. 458).

The northern part of the mapped area is underlain by Huronian sediments that include the Randville dolomite, footwall slates, Vulcan iron-formation, and Upper(?) Huronian slates (see table 1). The southern part of the area is underlain by rocks of pre-Huronian age, including granite gneiss, an arkose series, and hornblende and biotite schists. The Huronian rocks comprise the south part of the Sagola basin. The pre-Huronian rocks in the mapped area form the northern part of a block of crystalline and metamorphic rocks separating the Sagola basin from the Felch trough of Huronian sediments. The pre-Huronian rocks are strongly sheared; and the beds of the arkose series, the only bedded unit in the group, are vertical. The structure of the Huronian rocks is complex, and dips are generally steep. However, the rocks are not sheared, and the metamorphic grade is lower than that of the older series.

The principal structural elements appear to be high-angle faults. Within the area underlain by pre-Huronian rocks, some of these faults can be mapped with a reasonable degree of certainty, but within the area of Huronian rocks, exposures are not numerous enough to indicate whether repetition of beds has been caused predominantly by folding or by faulting.

Table 1

Sequence and character of pre-Cambrian rocks in the Norway Lake area

Age	Formation	Thick-ness Feet	Lithology and remarks
Upper(?) Huronian	Slate and graywacke	500+	Sericitic red and light-gray slate with minor interbedded graywacke.
Upper(?) Huronian	Graphitic slate	(?)	Black graphitic slate associated with red to gray slates containing chert.
	Unconformity?		
Middle Huronian	Vulcan iron-formation, and footwall slates	(?)	Iron-formation consists of banded red chert and hematite with minor magnetite. Footwall slates are green, thin-bedded, and contain intermixed quartz sand.
	Unconformity?		
Lower Huronian	Randville dolomite	800+	Exposed part consists of upper and lower dolomite members with intermediate slate member. Dolomite members thin bedded to massive with local intraformational conglomerates. Stromatolites fairly common. Slate member weakly magnetic.
	Unconformity		
pre-Huronian(?)	Metadiabase dikes	1-600	Massive. Composed largely of hornblende, quartz, and untwinned feldspar. Cut rocks of pre-Huronian age and are apparently controlled by foliation and joint planes.
pre-Huronian(?)	Biotite and hornblende schists	(?)	Mostly biotite schist in north part and hornblende schist in south part of schist belt. Iron-formation interbedded with hornblende schist.
pre-Huronian	Arkose series	1000+	Cross-bedded arkose, arkosic conglomerate, and tuffaceous arkose with interbedded basic volcanics. Volcanics strongly magnetic.
	Unconformity		
Archean	Granite gneiss	(?)	Ranges widely in texture and composition. Most common variety is coarse-grained red porphyritic granite gneiss. Strongly sheared in most places.
Archean	Quartzite and chlorite schist	(?)	Present as inclusions in granite gneiss. Chlorite schist dense, dark green. Quartzite strongly sheared. Contains interbedded sericite schist.

Metadiabase dikes cut the pre-Huronian rocks, but none are exposed in the area underlain by Huronian rocks.

Flat-lying Cambrian sandstone caps some of the hills in the central part of the mapped area. The sandstone is permeable, and springs are common at the outcrop of the base of the formation.

Glacial deposits consist of tills and outwash sands and gravels, the thickness of which is unknown in most of the area. The last ice sheet covering the area was a westward-moving portion of the Green Bay lobe of the last Wisconsin glaciation.

The absence of strong, persistent, magnetic anomalies in the part of the Norway Lake area that is underlain by rocks of Huronian age suggests that the Vulcan iron-formation is generally absent. Exploration for any iron ore bodies that might occur is likely to prove tedious and expensive because of the difficulty of determining the structure and stratigraphy of the Huronian rocks on the basis of available magnetic and outcrop data.

Rocks of pre-Huronian age

Chlorite schist and quartzite

Chlorite schist and quartzite occur only as inclusions in the gneiss. Although it was not practical to map the inclusions separately, exposed portions of some are measurable in terms of tens of feet in width and length.

Chlorite schist.--Exposures of the chlorite schist almost invariably contain some granite gneiss, despite the size of some of the schist masses. This relation indicates that the schist is not sufficiently resistant to erosion to be exposed except where protected by stronger rock. It is probable, therefore, that the chlorite schist is much more abundant than the outcrop data indicate.

The chlorite schist is dark green to black, fine grained, and has well-developed schistose structure. Contacts of the schist with the enclosing gneiss are sharp or, in some places, interlaminated in a zone a few inches thick. The gneiss is commonly fine grained at the contact. In thin section the chlorite schist is seen to be composed chiefly of chlorite and quartz, with some cloudy, untwinned feldspar, calcite, leucoxene, and magnetite. Epidote, colorless garnet, and titanite are present in some specimens.

Quartzite.--A fine-grained, light-red quartzite is exposed about 200 feet north of the south quarter corner of sec. 1, T. 42 N., R. 29 W., and occurs as angular pebbles in the Cambrian sandstone in the NW¼SW¼ of the same section.

Two masses of interbedded quartzite and muscovite schist are included in the granitic rock in the SW¼SW¼ sec. 2, T. 42 N., R. 28 W. One is about 10 by 25 feet and composed of white, vitreous, granular quartz. Near one corner of this mass, thin layers of muscovite schist are interbedded with the quartz. The interbedded zone is drag-folded. Another inclusion about 2 feet thick is composed of muscovite schist containing layers of granular quartz 2 inches thick. The association with muscovite schist indicates that the quartz masses are quartzite.

Age.--Neither the chlorite schist nor the quartzite in sec. 2, T. 42 N., R. 28 W., can be definitely correlated with rocks outside of the mapped area. The only clues to their age are their lithology and the fact that they are older than the gneiss in which they form inclusions. If the quartzite actually is of pre-Huronian age, as it appears to be, it is the first pre-Huronian quartzite to be recognized in northern Michigan.

It has not been established whether the quartzite that forms the isolated outcrop in sec. 1, T. 42 N., R. 29 W., is of Sturgeon (Lower Huronian) age or the equivalent of the quartzite in sec. 2, T. 42 N., R. 28 W.

Granite gneiss

Granite gneiss underlies most of the western part of the mapped area (pl. 1) and forms a thin wedge that extends to its eastern boundary, separating the dolomite and slates to the north from the arkose and schist to the south. The gneiss is exposed as glacier-sculptured knolls, the highest of which project about 30 feet above the surrounding surficial deposits.

General character.--Although the composition and texture of the gneiss range widely, a coarse brick-red to very light red porphyritic granite is most common. The largest phenocrysts are 1½ inches long and are microcline. Other light-colored constituents of the granite are quartz, plagioclase, and muscovite. Dark minerals are generally present in minor amounts, but chlorite is locally abundant.

A marked cataclastic texture with strong secondary foliation is characteristic of the red porphyritic granite (see pl. 1A). Many of the microcline phenocrysts are fractured and rounded. They are separated by laminae of micaceous or chloritic minerals in which are embedded microcline fragments and thin, tabular quartz grains. Foliation in the laminae conforms to the boundaries of the larger mineral grains. The foliation of the rock as a whole results from the parallel arrangement of microcline, quartz, and mica grains.

The granite of secs. 15 and 16, T. 42 N., R. 29 W., is similar in appearance to that described above. However, biotite rather than muscovite is the dominant micaceous mineral and the effects of shearing are less pronounced. The rocks are light gray to light red.

A fine-grained, non-porphyritic granite is exposed near the center of the SE¼ sec. 2, T. 42 N., R. 28 W. This granite is of light-orange color and composed largely of potash feldspar and tabular quartz. The quartz grains are about 2 mm long. Parallel arrangement of the quartz grains in an apparently massive groundmass of feldspar gives the rock a distinct planar structure. A similar rock is exposed north of the road in the NE¼NE¼ sec. 7, T. 42 N., R. 28 W.

An abnormal granite unusually rich in quartz is exposed in the SW¼SW¼ sec. 2, T. 42 N., R. 28 W. Although the fresh feldspar is red, the rock weathers to a much lighter color than the other gneiss of the area. In addition to feldspar and quartz, the only other common mineral is muscovite. The original texture was medium grained and massive, but the rock is now sheared to the extent that this texture has been destroyed except in rounded, cobble-like fragments, which are enclosed in a granulated matrix. This material resembles the sheared arkosic conglomerate except that bedding and foreign pebbles are absent. Quartz veins and ill-defined masses of pegmatite are abundant. Quartzite and muscovite schist inclusions in this exposure were described previously. Similar granitic rocks are exposed 1,100 feet north of the south quarter corner of sec. 2, T. 42 N., R. 28 W., in the southeast corner of the NW¼NE¼ sec. 7, T. 42 N., R. 28 W., and in the SE¼NE¼ sec. 10, T. 42 N., R. 28 W.

A rock composed largely of microcline and calcite with minor chlorite forms an exposure 200 feet east of the west quarter corner of sec. 12, T. 42 N., R. 29 W., immediately north of an arkose outcrop. The microcline grains are brick red and identical in appearance to those of the red porphyritic gneiss. The calcite occurs interstitially and as fracture filling in the microcline grains. Quartz is absent. A similar rock is associated with red porphyritic granite 1,100 feet east of the center of sec. 3, T. 42 N., R. 29 W. In this exposure the relation between the two rock types is not clear, but the calcite-bearing rock is probably a phase of the red porphyritic granite.

Structural relations.--The gneiss is in fault contact with the dolomite and slates to the north and is overlain unconformably by the arkose series to the south. Contacts of the gneiss with the sedimentary rocks are exposed in but two places, and both of these contacts are with the arkose series.

In the SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 7, T. 42 N., R. 28 W., typical arkosic conglomerate with quartzite and gneiss pebbles is in contact with chlorite schist that is bordered on the north by gneiss and is undoubtedly an inclusion in the gneiss. The contact is not diagnostic, but there is no evidence that the gneiss has intruded the arkose; nor is there evidence of a greater amount of shearing at the contact than elsewhere in the vicinity.

The north contact of the block of gneiss near the center of the NE$\frac{1}{4}$ sec. 10, T. 42 N., R. 28 W., is not exposed, but field relations indicate that it is a fault. A short portion of the south contact is visible near the east end of the gneiss block. The south contact is apparently depositional, for the lithologic change at the contact is sharp, and there is evidence of faulting or intrusion of the arkose by the gneiss.

Age.--No evidence is available to show whether the gneisses of different composition are of one age or different ages. They are assumed in this report to be of the same age. Bayley (1899) considered the gneiss to be Archean in age, and in the absence of evidence to the contrary his assignment is accepted here.

Arkose series

The arkose series forms a nearly east-west belt, which is in places more than a mile wide. Like the gneiss, the arkose series is exposed in glacier-sculptured knolls. In general, however, the arkose knolls have lower relief than those of the gneiss, and few project more than 10 feet above the surrounding surficial material.

General character.--The arkose series includes arkose, arkosic conglomerate, and interbedded basalt flows and basic tuffs. The sedimentary rocks are characterized by coarseness of grain, poor sorting, cross-bedding, and recurrent beds of conglomerate throughout most of its belt of exposure. Conglomerate beds are absent only in the southern part of sec. 2, T. 42 N., R. 28 W., and in the most southerly 500 feet of the exposed section of the arkose series where basic tuffs are interbedded with the arkose. Beds more than a few inches thick in which argillaceous material was the predominant constituent are rarely exposed, either as a result of absence from the section or of slight resistance to erosion. One such originally argillaceous bed, a muscovite schist about 100 feet thick with abundant coarse grains of quartz and feldspar, is exposed in the northeast corner of sec. 10, T. 42 N., R. 28 W.

Most clastic fragments in the conglomerate (see pl. 5) are less than 4 inches in length, but some boulders are more than a foot long. Except in the northern part of sec. 10, T. 42 N., R. 28 W., where boulders of gneiss are relatively abundant, about 75 percent of the clastic fragments more than an inch long are quartzite. Gneiss is next in order of abundance, followed by sericite slate. Pebbles of milky-white, opalescent quartz containing small lenses of white mica are common. Rare pebbles of hematitic chert or quartzite are present. No fragments of dolomite, hematite, jasper, or jaspilite occur in the arkose series. Fragments of feldspar crystals form an important portion of the pebbles less than an inch long.

Most of the quartzite pebbles are of light-orange color and contain small amounts of feldspar. Many of the quartzite pebbles are thin-bedded, and some show cross-bedding.

The gneiss pebbles range widely in composition and texture as does the gneiss of the mass north of the arkose series. Pebbles of fine-grained felsitelike rocks, coarse pegmatitic or porphyritic granite, medium-grained quartz-rich granitic rock, and rare graphic granite are included.

The non-tuffaceous, coarse sand phase and the matrix of the conglomerate phase of the arkose are composed largely of grains of quartz and quartzite. Feldspar comprises 15 to 35 percent of the sand phase and is divided about equally between microcline and orthoclase. Plagioclase is rare. Muscovite forms about 10 percent of the rock.

In the upper part of the exposed section of the arkose series, thin-bedded basic tuffs are interbedded with thick-bedded arkose. The tuffs are dark gray in general color and are composed of feldspar, quartz, epidote, and pyrite. Small tabular masses of microcline-hornblende pegmatite occur in this phase of the series. The feldspars form a higher proportion of this rock than of the arkose, commonly comprising more than 50 percent of the rock. The arkose interbedded with the tuff is better sorted than that lower in the section, resulting in a coarse-grained rock of fairly uniform grain size. Recrystallization of these beds has produced a rock closely resembling granite gneiss in texture and composition. The assemblage of recrystallized arkose, dark micaceous tuff beds, and pegmatites about 1,100 feet south of the northwest corner of sec. 17, T. 42 N., R. 28 W. (pl. 2), can easily be mistaken for a granite gneiss. However, well-preserved cross-bedding in several of the arkose beds proves the dominantly sedimentary origin of these rocks.

Metamorphosed basalt flows are interbedded with the arkose. The best exposures showing the character of the metabasalt and its relations to the arkose are in the northwest corner of sec. 17, T. 42 N., R . 28 W. (pl. 2). This rock is a flow, as shown by its conformity to the bedding of the arkose and by a zone of calcite and quartz amygdules near the top of the flow. The metabasalt is composed of hornblende, biotite, feldspar, epidote, quartz, and magnetite. In the upper 6 feet of the flow, apparently in the originally scoriaceous zone, a very coarse-grained skarn-like rock consisting of microcline, hornblende, epidote, calcite, quartz, and pyrite is present.

In the southern part of the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 8, T. 42 N., R. 28 W., north of the basalt flow described above and separated from it by an arkosic conglomerate bed, is a group of rocks that has the general appearance of the basalt in outcrops. In places, however, the rocks appear to be bedded; and in the northeast corner of the area shown on plate 7 there is a suggestion of agglomerate texture. This group is believed to be a series of basic flows and pyroclastics whose original texture has been largely destroyed by recrystallization.

Interbedded with these rocks in the southwest corner of sec. 8, T. 42 N., R. 28 W. (pl. 2), is a conglomerate with quartzite pebbles in a nearly black matrix of quartz, feldspar, biotite, chlorite, and epidote.

Adjacent to the flows, and in places to the dikes, the arkose has been altered to a dark-gray to black vitreous rock, resembling quartzite in appearance. This rock is composed largely of quartz, with subordinate feldspar, green biotite, and epidote.

Arkose beds in the group of exposures in the SE$\frac{1}{4}$ sec. 16, T. 42 N., R. 29 W., contain pebbles of vein quartz, feldspar, and granitic rock as much as three-fourths of an inch in diameter. Interbedded with the arkose are tuff beds and layers of biotite schist and hornblende schist. The hornblende schist is identical in appearance with the hornblende schist in the belt south of the arkose series.

The arkose exposed in the $NW\frac{1}{4}SW\frac{1}{4}$ sec. 3, T. 42 N., R. 29 W., contains pebbles of quartz, red granitic rock, sericite slate, and red feldspar. The pebbles average one-half inch in diameter. Gradational bedding and poor cross-bedding suggest that the tops of the beds face south. Other outcrops in this arkose belt are less easily identifiable. They consist of muscovite schist with coarse feldspar grains and recrystallized quartz-feldspar rocks with a texture resembling that of the sand phases of the arkose series.

Thickness.--Because of drag-folding and repetition of beds by faulting, it is impossible to measure the thickness of the arkose series. However, a thickness in excess of 1,000 feet seems probable.

Structural and stratigraphic relations.--Most of the granitic pebbles in the conglomerate are composed of the quartz-rich, nonporphyritic granitic rocks most common in the eastern part of the mapped area. However, some pebbles in the conglomerate are either coarse porphyritic granite or pegmatite, and the abundant small pebbles of microcline in the arkose were probably derived from the coarse porphyritic red granite. The quartzite pebbles in the conglomerate were probably derived from the quartzite beds that form inclusions in the granite. It can be stated that the arkose series is younger than some of the gneiss of the belt to the north and therefore can reasonably be considered younger than all of these gneissic rocks unless it is shown that they comprise gneisses of more than one age.

The contact between the arkose series and the schists to the south is not exposed and could be conformable, unconformable, or a fault. The fact that some interbedded schists in the upper part of the arkose series resemble in lithology some of the schists in the belt south of the arkose series suggests that these rocks may conformably overlie the arkose series.

Age.—The arkose series was mapped as Sturgeon Quartzite by earlier investigators (Bayley, 1899, p. 471; Van Hise and Leith, 1911, p. 301), but the present studies indicate that it is of pre-Huronian age.

The primary lithologic features of the arkose series suggest the following conclusions:

(1) Active diastrophism with rapid uplift prevailed during its deposition.

(2) The sediments were derived from a terrain underlain by granitic gneiss, quartzite, and slate.

(3) Jaspilite was absent, and dolomite was probably absent from the source area.

Active diastrophism causing rapid erosion and deposition is indicated by the recurrent beds of conglomerate, abundance of feldspar, and thickness of the formation. Such conditions probably would not be limited to a small local area but should be reflected in any other Huronian formation in Dickinson or adjacent Counties with which the arkose series could be correlated.

The composition of the terrain that supplied the sediments is indicated by the rock types that occur as pebbles in the conglomerate. Thus granitic rock, quartzite, and slate were exposed at the erosion surface, but jaspilite was absent. Dolomite was probably absent, as it can reasonably be expected that at least a few pebbles would survive such rapid erosion and transportation . That dolomite pebbles once present in the conglomerate were later removed by alteration or reaction is unlikely, because clusters of epidote grains that would mark its former presence do not occur. Too, the calcite in the vesicles of the basalt flows has been preserved. The quartzite and slate pebbles cannot be taken as evidence that the arkose series is of post-Lower Huronian age, because these pebbles could have been derived from the quartzite and schist of probable Archean age that form inclusions in the gneiss.

The absence of dolomite and jaspilite pebbles suggests that Lower and Middle Huronian formations, particularly the Randville dolomite and the Vulcan iron-formation, were not present in the source area during deposition of the arkose series.

The Sturgeon quartzite, Mesnard quartzite, and Sunday Lake quartzite form the basal part of the Huronian series throughout much of northern Michigan. These quartzites are of very uniform character and are composed almost entirely of quartz. They are typical of deposits formed under stable conditions. Although the Sturgeon quartzite has not been recognized in the mapped area, it occurs in the Felch trough about 5 miles south of the belt underlain by the arkose series. Correlation of the arkose series with the Sturgeon quartzite would require that active uplift prevailed in a small area while the rest of the region was essentially quiescent.

Other Huronian formations with which the arkose series might conceivably be correlated on the basis of primary features of the lithology are the Ajibik quartzite (lower Middle Huronian), and the Goodrich quartzite (lower Upper Huronian). Both of these formations contain conglomerates and rest unconformably on underlying rocks. Assignment of the arkose series to the Keweenawan is not considered, because rocks of Keweenawan age south of Lake Superior show only moderate folding, in marked contrast to the strong deformation that has affected the arkose series.

The Ajibik quartzite has local conglomerate members, but it is composed largely of quartz sand and is lithologically similar to the Sturgeon and Mesnard quartzites rather than to the arkose series. Conglomeratic beds in the Ajibik quartzite are thin, and the pebbles are of local origin. These beds are basal conglomerates and intraformational conglomerates, unlike the hundreds of feet of mixed pebble conglomerate in the arkose series. Further, the angular discordance between the Ajibik quartzite and underlying beds is small, indicating little folding or uplift during the time interval represented by the unconformity.

The Goodrich quartzite (lower Upper Huronian) of the Marquette range and Republic trough resembles the arkose series more closely than do other Huronian formations. The Goodrich contains important conglomerate beds and overlies older rocks with an angular discordance, which in some places is large. Abundant granitic detritus occurs locally, indicating that Huronian rocks have been stripped away in some areas, although the Goodrich in most places rests on Middle Huronian strata.

The difference in intensity of deformation and of metamorphic grade between the arkose series and the Randville dolomite indicate that the arkose series is of pre-Huronian age. Comparison of two primary sedimentary features--the stretched pebbles in the arkosic conglomerate (pls. 1B and 5A) and the undeformed stromatolites in the dolomite (pls. 3A and 4)--shows that the arkose series has undergone much greater deformation than has the dolomite. The significantly higher metamorphic grade of the arkose series in contrast to that of the dolomite is indicated by the presence of such metamorphic minerals as epidote, hornblende, biotite, muscovite, and microcline in the arkosic conglomerate and interbedded volcanics. The low metamorphic grade of the dolomite is indicated by its fine-grained character as well as by the absence of metamorphic minerals.

Correlation of the arkose series with other pre-Huronian conglomerates of the Lake Superior region is not attempted at this time.

Biotite and hornblende schists

Biotite and hornblende schists occur in the southern part of the mapped area. Although only the north contact of the schist has been mapped, these rocks apparently form a nearly east-west belt parallel to the arkose series. The area underlain by the schists is covered largely by dense black spruce swamps. Schist is exposed in low knolls and ridges rising above the swampy ground.

General character.--The mapped part of the schist belt is predominantly biotite schist to the north and hornblende and hornblende-biotite schist to the south. The biotite schist is fine grained and is composed largely of biotite, quartz, and feldspar. Light colored minerals comprise more than 50 percent of the rock. In many places the schist shows a banding, parallel to the schistosity, caused by variations in the proportions of light and dark minerals, but it is not clear whether this banding represents a primary feature such as bedding or is caused by metamorphism. The hornblende schist is coarser grained than the biotite schist and is not as well banded. It is composed largely of hornblende with minor quartz and feldspar.

A coarse-grained schist composed of greenish-brown biotite, fibrous amphibole, quartz, and zoisite or clinozoisite is exposed in the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 17, T. 42 N., R. 28 W., and in the roadside exposures in the NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 16, T. 42 N., R. 28 W. The fibrous amphibole occurs in felt-like masses replacing large crystals that may have been pyroxene.

In the exposure about 300 feet northeast of the south quarter corner of sec. 18, T. 42 N., R. 28 W., a band of rock resembling a fine-grained, sheared augen gneiss is present in the hornblende schist. This rock contains grains of feldspar about 2 mm in diameter and tabular quartz aggregates in a groundmass of biotite and fine-grained quartz and untwinned feldspar. The large feldspar grains are seen in thin section to be microcline, oligoclase, and untwinned feldspar. They are irregular in outline, fractured, and cut by irregular masses and veins of calcite. Several contain grains of biotite, zoisite or clinozoisite, and quartz. The feldspar grains have obviously been fractured and altered, but it is not clear whether they represent clastic grains in an arkosic sediment, phenocrysts in an igneous rock, or early formed porphyroblasts. Most quartz grains, both in the tabular aggregates and in the groundmass mosaic show undulatory extinction. A similar rock is well exposed a quarter of a mile south of the center of sec. 16, T. 42 N., R. 28 W.

In the easternmost exposure in the SE¼ sec. 16, T. 42 N., R. 28 W., a zone in the biotite-hornblende schist contains sub-spherical grains of a dark-gray vitreous mineral, probably garnet. These grains are 2 to 12 mm in diameter and are embedded in coarse biotite or, in one place, in radiating fibrous aggregates of a light-colored mineral tentatively identified as grunerite. The rock has a high density and may be a thin iron-bearing formation, perhaps an outlier of the member that causes the strong magnetic anomaly in the south part of this section.

Coarse-grained pegmatites such as those cutting the hornblende schist west and south of the mapped area are not common in this area. One very coarse pegmatite 30 inches thick, cutting the biotite-hornblende schist, is exposed in the outcrop a quarter of a mile north of the southwest corner of sec. 16, T. 42 N., R. 28 W.

A quarter of a mile south of the center of sec. 16, T. 42 N., R. 28 W., lenticular masses 2 to 4 feet long and about 6 inches thick composed of quartz and red feldspar are associated with the rock that resembles augen gneiss. The rock of the lenses has a pegmatitic texture, although the quartz-feldspar ratio is approximately 4 to 1. The quartz is granular, probably as a result of shearing.

Age.--The schists have been considered to be of Archean age by previous investigators (Bayley, 1899, p. 463; Van Hise and Leith, 1911, p. 301), and their assignment is accepted here. Within the mapped area the only evidence of the age of the schists is the lithologic similarity between some of the schists and some of the rocks interbedded with the highest exposed portions of the arkose series. In view of the evidence for strong faulting elsewhere in the Sturgeon River tongue, the present geographic relations between the arkose series and the schist are of dubious value in determining the age relations of the two units until the nature of their contact can be determined.

Rocks of Huronian age

Sturgeon quartzite

The Sturgeon quartzite (see stratigraphic table, table 1) is widespread elsewhere in Dickinson County but has not been identified in the mapped area. The small outcrop of quartzite in the SW¼SW¼ sec. 3, T. 42 N., R. 28 W., and discussed elsewhere in this report, is tentatively included with the Randville dolomite but may be Sturgeon quartzite. It is possible also that the quartzite in sec. 1, T. 42 N., R. 29 W., is Sturgeon. Because of the resistant character of the Sturgeon quartzite, it would probably be well exposed if present.

Randville dolomite

The Randville dolomite is exposed in several widely separated groups of outcrops in the northern part of the mapped area. This rock forms hills as much as 40 feet high on the present land surface and apparently had the same topographic expression on the pre-Cambrian surface, for several low pinnacles of dolomite project more than 20 feet into the Cambrian sandstone.

General character.—The exposed portion of the Randville dolomite is apparently divisible into three members: an upper and a lower dolomite member with minor interbedded slate, separated by a slate member with minor interbedded dolomite. This division is apparent in the west central part of sec. 1 and the east central part of sec. 2, T. 42 N., R. 29 W. (pl. 1). The division is suggested in places where two dolomite outcrops, 300 to 500 feet apart across the strike, are separated by swamps or low ground, as in the SW¼SW¼ sec. 3, T. 42 N., R. 28 W., near the northwest corner of sec. 4, T. 42 N., R. 28 W., and in the NE¼ sec. 4, T. 42 N., R. 29 W. The total thickness is in excess of 800 feet. Neither the top nor the bottom of the formation are exposed, and there is no evidence of the character of the rocks that immediately underlie and overlie the Randville dolomite.

The most nearly complete Randville section is exposed in the west central part of sec. 1 and the east central part of sec. 2, T. 42 N., R. 29 W., where the structure is a syncline that plunges southeast at an angle of about 45 degrees (pl. 8). This area also provides the best exposures of the slate member.

The slates are dark gray to green-gray and are composed largely of sericite, with some quartz, chlorite, and microcline. Euhedral magnetite grains are locally abundant and cause a weak magnetic anomaly. The northernmost slate outcrop, in the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 1, T. 42 N., R. 29 W. (pl. 1), shows interbedded gray sandstone and black slate in beds as much as 4 inches thick. Gradational bedding shows tops of beds to the south in this exposure. A few conglomerate beds, each less than 2 inches thick and separated by sandstone and slate beds, contain well-rounded pebbles of quartz, feldspar, and granitic rock as much as an inch in diameter. In other exposures in this vicinity, dolomite beds from a few inches to approximately 5 feet thick are interbedded with the slate. Slate with interbedded dolomite is also exposed in the SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 4, T. 42 N., R. 28 W. The slate here is laminated quartzite and sericitic slate and contains octahedral magnetite grains.

Most of the dolomite is massive to thin-bedded, but algal and conglomerate phases are common. The dolomite is light gray to red on fresh surfaces and weathers white to light brown. It has a fine, sugary texture. Grains of quartz sand, most of which show undulatory extinction, are abundant in some beds and in some places comprise more than 50 percent of the rock. No oolites were found.

The stromatolites (algal structures) in the Sturgeon River tongue have been described by Richardson (1949). In sections normal to bedding planes they are concentrically banded structures with domal or columnar form, and in sections parallel to bedding planes concentrically banded elliptical forms. Most are 1 to 3 inches in diameter and 2 to 6 inches high. The banding of the stromatolites is convex upward, providing a reliable criterion for tops of beds. In some places partial replacement by chert has caused the structure of the forms to be accentuated on weathered surfaces. Stromatolites are shown best in the NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 4, T. 42 N., R. 28 W. (see pl. 7), where two algal biostromes are interbedded with massive dolomite, dolomitic slate, and dolomite conglomerate. A section across the biostromes is as follows:

		Estimated thickness (inches)
11.	Thin-bedded slate and dolomite	20
10.	Thin-bedded dolomite	4
9.	Biostrome	24
8.	Red slate	27
7.	Biostrome	50
6.	Cherty red to gray slate	10
5.	Dolomite conglomerate. Well-rounded pebbles of massive dolomite in sandy dolomite matrix	12
4.	Massive dolomite	4
3.	Dolomite conglomerate, like bed 5	16
2.	Thin-bedded dolomite	13
1.	Cherty, red to gray slate	1$\frac{1}{2}$

The biostromes are composed almost entirely of stromatolites partly replaced by chert. The thicker biostrome is exposed for about 150 feet along the strike, and the thinner one for about 25 feet. Stromatolites are also present in the northeast and southwest corners of the SW¼SW¼ sec. 3, T. 42 N., R. 28 W., and in the NW¼SE¼ sec. 35, T. 43 N., R. 29 W. Structures that may be stromatolites are found in dolomitic slate beds interbedded with dolomite and dolomite conglomerate in the outcrop on the north edge of the swamp in the NE¼NW¼ sec. 6, T. 42 N., R. 28 W. These structures are irregular, concentrically laminated, flat domes, convex to the northwest. They are about a foot thick and 2 to 4 feet in diameter.

Intraformational conglomerates (see pl. 3 B) are present in the NW¼SE¼ sec. 35, T. 43 N., R. 29 W., and in the NE¼NE¼ sec. 2, T. 42 N., R. 29 W., in addition to the stromatolite localities mentioned previously. Most of the pebbles are of dolomite, but a few pebbles of dolomitic slate occur. The pebbles are 1 to 4 inches in diameter and are well rounded. No strong dimensional orientation is evident. The matrix is dolomite with intermixed coarse quartz sand.

Outcrops of the dolomite are too scattered to show whether or not the conglomerate and stromatolite phases of the dolomite are restricted to certain horizons.

In general, silicification of the dolomite has been confined to partial replacement of organic structures and the formation of small nodular masses of chert in the dolomite and dolomitic shale. However, silicification has been complete in the exposures on the north line of sec. 6, T. 42 N., R. 28 W., a quarter of a mile east of the northwest corner of the section. These exposures consist of several small outcrops and a large number of residual boulders of chert and two test pits in slate. The chert shows textural features commonly found in limestone and dolomites, such as intraformational breccia and interbedded sandy and non-sandy material. The intraformational breccia now consists of angular fragments of chert in a matrix of chert with scattered grains of quartz. Other phases of these exposures show a complete gradation from a quartz sandstone cemented by chert, through massive chert containing abundant quartz grains, to completely non-sandy massive chert. Many of the quartz grains show secondary overgrowths.

A small exposure of vitreous quartzite and fine quartz conglomerate is present at the west end of the dolomite outcrop in the northeast corner of the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 3, T. 42 N., R. 28 W. It is here included with the Randville dolomite and may be part of the basal bed of this formation.

The dolomite near the north quarter corner of sec. 9, T. 42 N., R. 29 W., is poorly exposed. It consists of typical fine-grained, thin-bedded dolomite and strongly sheared dolomite. The sheared dolomite contains much secondary quartz and microcline, and weathering produces a dense spongework of these minerals.

Vulcan iron-formation, and footwall slates

The Vulcan iron-formation is exposed only in test pits and trenches of the Deerhunt exploration in the SW¼NW¼ sec. 35, T. 43 N., R. 29 W. The iron-formation here is composed of interbanded blue specular hematite and reddish jasper, with some associated soft, hematitic slate. Some of the jasper contains well-defined concentrically banded structures about 1 mm in diameter that resemble oolites. In thin section the structures are concentrically banded, with subcircular to elliptical outline. A few are irregular and consist of two or three smaller structures enclosed within a larger one. The structure is shown by concentric films of hematite in the chert and not by the texture of the chert itself.

Of several pieces of iron-formation picked at random from the test pits and tested with field instruments, some proved to have a high and others a low magnetic permeability.

A green thin-bedded sandy slate appears on the dump of the southernmost test pit of the Deerhunt group. It has not been recognized elsewhere in the mapped area. This slate may be equivalent to the footwall slate of the Menominee district, which it strongly resembles.

Rocks of probable Huronian age

Graphitic and associated slates

In the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 32, T. 43 N., R. 28 W., is a group of poor exposures of red to gray slates and black, graphitic slates. Some of the non-graphitic slates are cherty. The stratigraphic position of the rocks in these exposures is uncertain, but like the slate and graywacke described below, they closely resemble some of the Upper Huronian rocks of Iron County.

Red slates and graywackes

General character.--Scattered exposures of red and gray sericitic slate with subordinate interbedded graywacke are present in the northwest part of the mapped area. A section of these slates and graywackes more than 500 feet thick is exposed in the banks of the East Branch of the Sturgeon River in the northern part of the SW$\frac{1}{4}$ sec. 34, T. 43 N., R. 29 W. In most places the slates are red, with thin zones along joint and bedding planes leached to a light yellow-green. The slate in the test pits in the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 34, T. 43 N., R. 29 W., is light gray. Slaty cleavage is well developed in the fine-grained members of this series. The graywackes are fine to medium grained and are generally somewhat friable. They are deep red in general color and liberally dotted with white fragments, probably altered feldspars. In thin section the sand grains are seen to be angular and are mostly quartz showing strong undulatory extinction. Grains composed of radiating aggregates of a clay mineral, probably altered feldspars, are abundant. Fragments of chert and sericitic slate are common. The groundmass is a fine-grained mosaic of quartz, clay minerals, and white mica. These red slates and graywackes also occur as abundant float fragments in the southern part of sec. 31, T. 43 N., R. 28 W., north of the exposure of silicified dolomite, and in the upturned roots of a tree in the northeast corner of sec. 6, T. 42 N., R. 28 W.

As these relatively non-resistant slates and graywackes are the only rocks exposed in the northwest part of the mapped area, it seems highly probable that they are the only rocks present at the surface in this area.

Age.--Bayley (1899, p. 481) included the red slates and graywacke with the dolomite formation, and Van Hise and Leith (1911, p. 301) considered them to be Keweenawan. Although exposures are poor and dip readings not reliable, most of the slates appear to dip at angles of 45 degrees and less, in contrast to dips near 70 degrees common in the dolomites, suggesting that the slates unconformably overlie the Lower Huronian beds. However, the degree of folding and the presence of slaty cleavage appear incompatible with a Keweenawan age for these rocks. Too, the lithology of the slates and graywackes resembles that of the slates and graywackes of Upper Huronian age in Iron County, Michigan, more closely than that of the nearest known rocks of Keweenawan age, near Marquette, Michigan. Accordingly, these red slates and graywackes are here tentatively considered to be of Upper Huronian age.

Metadiabase dikes and related rocks

Metadiabase dikes intrude the gneiss, arkose series, and schists. They are not exposed in the part of the mapped area underlain by Huronian rocks and presumably do not intrude these rocks. Metadiabase is the most resistant rock in the mapped area, forming the backbone of ridges on which other rocks are also exposed. Parts of the large dike in the southern part of the mapped area form prominent hills. The metadiabase is fresh appearing, coarse grained, massive, and composed largely of well-formed hornblende crystals in a matrix of feldspar. Locally, the dikes are fine grained and schistose, but in general the massive character of the dikes is in contrast with the schistosity of the intruded rocks.

Dikes cutting the gneiss were not mapped separately except in secs. 3 and 4, T. 42 N., R. 29 W., and have not been studied in thin section.

In the southeast corner of the mapped area is a stock-like mass of rock similar in composition and perhaps genetically related to the metadiabase dikes. This rock differs in composition from the dike rocks in containing minor amounts of magnetite and phlogopite. It also contains phases that are much coarser grained than the dike rocks.

Structural relations.--The largest metadiabase dike, about 500 feet thick and more than 5 miles long, intrudes the schist in the south part of the mapped area. It is nearly straight and of fairly constant thickness though locally embayed by schist, as in the NE¼ sec. 16, T. 42 N., R. 28 W. A smaller dike closely parallels the larger one for 2½ miles in the southeastern part of the mapped area, and both dikes are parallel to the foliation in the schist. These dikes apparently extend outward from the stock-like mass of similar rock.

Dikes intruding the arkose series are smaller and more lenticular than those that intrude the schists. They are apparently associated with a nearly vertical joint system and with strike faults.

The contact of the stock-like mass with the surrounding schists is apparently not regular or well defined. Within the mapped area the approximate contact is exposed only in the group of outcrops in the SW$\frac{1}{4}$ sec. 11, T. 42 N., R. 28 W., where biotite schist is interbanded with hornblende-feldspar rock closely resembling the metadiabase of the dikes. The contacts of the interbanded rocks are not sharp, but gradational. Because of the mixture of schist and metadiabase, the contact of the stock-like mass can be located only approximately through these exposures. Also occurring at this locality is coarse-grained hornblende-feldspar pegmatite similar to that in the upper part of the arkose series.

Age.—Minor differences in composition between the metadiabase dikes that intrude the arkose series and those that intrude the schists may well be due to metamorphism and do not give adequate reason to assume more than one period of diabase intrusion. The structural relations of the dikes, together with the fact that the dike rocks are of the same metamorphic grade as the intruded rocks, indicate that the dikes were emplaced during or subsequent to the major period of deformation of the pre-Huronian rocks.

Elsewhere in Dickinson County diabase dikes are known to cut rocks of Huronian age. However, the available evidence indicates that the dikes in the Norway Lake area are of pre-Huronian age, although conclusive proof is lacking.

Structural geology

The trend of most structural features in the Sturgeon River tongue is nearly east-west. In the rocks of Archean and probable Archean age this trend is followed by strong secondary foliation, contacts between lithologic units, bedding in the arkose series, and major faults. In the part of the area underlain by rocks of Huronian age, strikes of the Randville dolomite suggest a general east-west trend.

Foliation and lineation.--In most places foliation in the gneiss, arkose series, and schist is within 10 degrees of vertical. In the gneiss the foliation is due to parallel arrangement of tabular feldspar and quartz grains and thin layers of micaceous minerals. The texture of the gneiss is in most places clearly cataclastic. Foliation in the arkose series is due to parallelism of micaceous laminae and stretched ellipsoidal pebbles and smaller clastic fragments.

Lineation is well developed in the arkose series and hornblende schist. In the arkose series the lineation consists of striations that resemble slickensides on the sides of quartzite and gneiss pebbles. Most of the lineation plunges about 80° NW. in the planes of foliation and is probably parallel to the direction of relative movement during deformation of the arkose series. This orientation is suggested by the appearance of the lineations and by the deeply dentate ends of some of the pebbles, which indicate that the pebbles were deformed by shearing rather than rolling. A nearly vertical stress is also suggested by the rare minor folds that can be seen in the arkose series. Most of these folds plunge at low angles, to either east or west.

Lineation in the hornblende schist was not mapped, but it lies in the planes of foliation and is caused by parallel hornblende crystals.

Faults.—The principal structural features of the mapped area are high-angle faults. Relative movement on the faults has brought a block of highly deformed pre-Huronian rocks on the south into juxtaposition with less-deformed Huronian rocks on the north. The probable steep dip of the faults is indicated by the foliation planes in the sheared rocks in the southern part of the area and by the regularity of the traces of the faults. The direction of movement on faults was probably parallel to the lineation in the arkose series and was accordingly almost vertical.

The presence of the fault extending from the south part of sec. 11, T. 42 N., R. 29 W., to the north part of sec. 11, T. 42 N., R. 28 W., is indicated by the offset in the gneiss-arkose contact at the west end of the fault (secs. 11, 12, 13, and 14, T. 42 N., R. 29 W.) and by the occurrence of a small block of gneiss in the center of the arkose belt in the SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 10, T. 42 N., R. 28 W. That the occurrence of gneiss in this position is not due to folding is indicated by excellent cross-bedding, which invariably shows that the tops of beds in the arkose series face south. Cross-bedding is abundant all the way across the belt underlain by the arkose series in sec. 10, T. 42 N., R. 28 W., except in the southernmost exposure of the arkose series in that section. It is also common in the area shown on plate 7 and in the eastern part of sec. 12, T. 42 N., R. 29 W.

The fault extending from the south part of sec. 3, T. 42 N., R. 29 W., to the south part of sec. 2, T. 42 N., R. 28 W., forms a portion of the contact between Archean and Huronian rocks. Its existence is indicated by the fact that the top of the dolomite beds in the SW¼SW¼ sec. 3, T. 42 N., R. 28 W., face south, toward the Archean rocks, as indicated by stromatolites. The fault is also indicated by truncation of the Randville dolomite in sec. 3, T. 42 N., R. 28 W., and sec. 1, T. 42 N., R. 29 W.

The fault extending from the west boundary of the map (pl. 6) into sec. 35, T. 43 N., R. 29 W., is a straight-line extension of a fault mapped by Pettijohn (   ) in T. 42 N., R. 30 W.

No evidence was found to indicate whether the narrow band of arkose in the SW¼ sec. 3, T. 42 N., R. 29 W., is folded into the granite or bordered on one or both sides by a fault.

<u>Stfucture of the arkose series</u>.--Beds in the arkose series are in most places nearly vertical. Cross-bedding (see pl. 2) invariably indicates tops of beds to the south, showing that the arkose series is not isoclinally folded although several small folds (pl. 5, A, B) have been found. Axes of the small folds are parallel to the general strike of the beds and plunge east or west at angles of less than 20 degrees.

Structure of rocks of Huronian age.--Little information is available to indicate the structure of the rocks of Huronian age. In the northeast part of the mapped area the Randville dolomite, the only formation in this group for which usable structural information is available, is exposed in several widely separated areas. Tops of beds in the northernmost and southernmost exposures are indicated by stromatolites to face south. The field evidence is not sufficient to show whether the repetition of the Randville dolomite is caused by folding, faulting, or a combination of the two. Structures that are probably stromatolites suggest that tops of beds in the NW¼ of sec. 6, T. 42 N., R. 28 W., are to the north. No evidence of the direction of tops of beds was found in the groups of exposures in the SE¼ sec. 35, T. 43 N., R. 29 W., and the NE¼NE¼ sec. 2, T. 42 N., R. 29 W.

In the vicinity of the west quarter corner of sec. 1, T. 42 N., R. 29 W., the Randville dolomite forms a syncline that is truncated on the south by a high-angle fault. The orientation of the syncline appears anomalous inasmuch as it plunges about S. 30° E. at an angle of about 45 degrees, in contrast with the more nearly east-west general trend of the dolomite.

Magnetic anomalies

The Norway Lake area is included in an aeromagnetic survey of Dickinson County made by the Geological Survey in 1948. Crests of anomalies shown on the north-south aeromagnetic profiles have been plotted on the geologic map (pl. 6) accompanying the present report. Wherever possible, crests on adjacent profiles have been joined to indicate trends of individual anomalies.

Within the area underlain by granite gneiss only small anomalies have been found, and these are rare. The anomaly in the south part of sec. 6 and the north parts of secs. 7 and 8, T. 42 N., R. 28 W., may be related to chlorite schist inclusions in the gneiss. Some of the chlorite schist has been found to contain magnetite.

Within the area underlain by the arkose series, magnetic anomalies that are locally strong are associated with interbedded metavolcanics. Anomalies in T. 42 N., R. 29 W., on the apparent extension of the arkose belt, may be related to interbedded metavolcanics (Wier, Balsley, and Pratt,) or possibly to dikes (Pettijohn,).

The strong magnetic anomaly in the south parts of secs. 14, 15, 16, and 17, T. 42 N., R. 28 W., is related to a magnetite-bearing iron-formation (Wier, Balsley, and Pratt,).

Within the part of the Norway Lake area underlain by rocks of Huronian age one strong anomaly and several weak anomalies were disclosed by the aeromagnetic survey. Of the strong anomaly extending westward from sec. 32, T. 42 N., R. 29 W., Wier, Balsley, and Pratt (195) say, "The anomaly is very broad, and therefore the rock causing it is probably deeply buried." The cause of the small anomalies in the northwest corner of the area shown on the geologic map (pl. 6) is not known. Other small anomalies are in the vicinity of dolomite exposures and are tentatively assigned by the above writers to the magnetite-bearing slate member of the Randville dolomite.

Lack of agreement is evident in some places between aeromagnetic data and positions of geologic contacts and magnetic crests as determined by ground surveys. This may be due in part to errors in position of aeromagnetic determinations (Wier, Balsley, and Pratt, 195) and to the lack of adequate base maps.

The results of a magnetic survey of a limited part of the Norway Lake area, made before results of the aeromagnetic survey were available, are shown on plate 8. The survey was made with a Wolfson vertical intensity magnetometer with a sensitivity of about 35 gammas per scale division. In this survey only the anomaly associated with the magnetite-bearing slate member of the Randville dolomite in the western part of sec. 1, T. 42 N., R. 29 W., is definitely correlated with a stratigraphic unit. The anomaly in the SE¼ sec. 34, T. 43 N., R. 29 W., and the NE¼ sec. 4, T. 42 N., R. 29 W., is assumed to be associated with the same beds, but it is not definitely correlated.

Anomalies found at the Deerhunt exploration, where the iron-formation is present at the surface, are of such small extent that they can be missed with magnetometer stations located at 100-foot intervals. It is not known whether the very local character of the anomalies is due to a range in magnetic permeability of different parts of the iron-formation or to different thicknesses of iron-formation under the various stations.

Possibilities for exploration

There is no positive evidence that the iron-formation occurs at or near the bedrock surface anywhere in the area except at the Deerhunt exploration. Rare boulders of hard blue hematite ore have been found in glacial deposits east of the Deerhunt exploration; and inasmuch as the ice moved westward in this area, a source east of the Deerhunt exploration is indicated. It is not known, however, whether the source was within the mapped area. Pebbles of jaspilite, obviously derived from exposures at the Deerhunt exploration, are abundant in the glacial drift for some distance west of the exploration.

Elsewhere in Dickinson County the Vulcan iron-formation is characterized by strong persistent magnetic anomalies. Accordingly, the absence of such anomalies in the part of the Norway Lake area underlain by rocks of Huronian age suggests the absence of the iron-formation in most of the area. Evidence from outside the Norway Lake area suggests that the iron-formation may have been removed in the southern part of the Sagola basin area by pre-Upper Huronian erosion. If so, targets for exploration will be small. This, coupled with the difficulty of determining the geologic structure on the basis of magnetic and outcrop data, will make an exploration program tedious and expensive and the results doubtful.

Exploration to determine the source of the strong anomaly in secs. 14, 15, 16, and 17, T. 42 N., R. 28 W., might be warranted.

Petrography and petrology of the granite gneiss and arkose series

The discussion of the petrography and petrology of the granite gneiss and arkose series is concerned primarily with the metamorphism of these rocks as reflected by the feldspars. The same assemblage of feldspars characterizes both lithologic units. Microcline is present in the gneiss as fractured microperthitic porphyroblasts and in the arkose as clastic grains which are also fractured and microperthitic. Microcline also forms small unfractured grains, of secondary origin, in both units. Albite is present in the two units as exsolution and replacement type perthites, inclusions in the microcline, and as individual grains in the groundmass. In some places, albite has entirely replaced the microcline of the gneiss to form albite granite, and similar replacement by albite has occurred locally in the arkose. The similarity of the feldspars in the granite gneiss and arkose shows that (1) the feldspars in the arkose have been derived from the granite, and (2) that the two adjacent units have been recrystallized, presumably simultaneously, under similar conditions of regional metamorphism.

The mineralogical features of these rocks provide the material necessary to investigate their thermal history with some degree of precision and to check one method of geologic thermometry against another. Data available from the feldspars could be supplemented by that derived from determinations of the compositions of the adjacent albite and epidote grains in the altered basalt and tuffs interbedded with the arkose series, and by determination of the confining pressure of the liquid and gas inclusions present in the quartz and microcline grains of both units.

However, a laboratory investigation of such extent is beyond the scope of the present study and the ensuing discussion must be of a qualitative nature.

Granite gneiss

Petrography.--Most of the granite gneiss is composed chiefly of microcline, albite, and quartz, with subordinate amounts of white mica, green biotite partly altered to chlorite, and calcite. Minor minerals include specular hematite, zoisite, titanite, and monazite. Myrmekite and micrographic intergrowths of quartz and albite are found in some specimens. Effects of cataclasis are marked (see Plate 11) and are shown by the fractured and granulated feldspar grains, tabular aggregates of quartz showing strong undulatory extinction, and bent mica grains, as well as by the foliated character of the rock as a whole.

Much of the microcline is present as fractured and granulated porphyroblasts. It is generally clear, but a slight cloudiness is produced in some grains by minute liquid inclusions. Locally as in the SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 2, T. 42 N., R. 28 W., unfractured grains of microcline, about one quarter of the average size of the porphyroblasts, are present. The clarity, lack of fracturing, absence of replacement perthite, and the very irregular shape of these grains suggest that they were formed after the deformation.

Albite is present in the following forms:

(1) Subhedral, randomly-oriented inclusions in the microcline, and separate grains in the groundmass.

(2) String and stringlet type perthite of Alling (1938).

(3) Veinlet and patch type perthite of Alling (1938).

(4) Elongate anhedral grains related to fractures and to veinlet and patch perthite.

(5) Chessboard albite.

(6) Granoblastic mosaic of anhedral grains between microcline and quartz grains.

The first 3 types of albite are widespread in the granite and the last 3 are present locally. The composition of all types of albite seems to be very nearly the same. The extinction angle of twinned forms is 15°, measured normal to (010) and the indices are less than 1.54, indicating a composition of about Ab 95, a value in accord with the chemical analysis of the red porphyritic granite (table 2). Untwinned albite has the same relief as the twinned forms, where the two are in contact.

The randomly-oriented inclusions of albite (plate 12A) are probably of primary origin. Many of these grains are fractured as is the host microcline, but they show no evidence of being genetically related to the fractures in the microcline. Nearly all of the albite grains contain abundant inclusions of white mica, but have clear rims in which the inclusions are absent.

The string and stringlet type perthite is common and widespread. No particular relation to the boundaries of the microcline grains, inclusions, or fractures, was noted.

Albite forming the veinlet and patch type perthite is probably of replacement origin. It has formed preferentially in fractures and near the boundaries of microcline grains. The fact that all of the albite in the fractures in a single microcline grain extinguishes simultaneously indicates that the orientation of the albite was controlled by the host microcline. Albite of this type is clear, owing to the absence of inclusions and alteration. The elongate grains of albite found within the microcline grains and the clear rims on the randomly-oriented inclusions show the same features as the veinlet and patch type perthites and for that reason are believed also to be of secondary origin.

Chessboard albite has been found in only one thin section of the granite gneiss. This specimen is from the SW¼SW¼ sec. 15, T. 42 N., R. 29 W., and is megascopically typical of most of the granite in the north part of section 15. The chessboard albite contains randomly-oriented, rimmed inclusions of albite as does the microcline of the red porphyritic granite and also contains veinlets of albite (plate 12B). These features show that the chessboard albite was formed by the replacement of microcline. The less-sheared appearance of this rock in exposures may well be due to the healing of some of the fractures during the crystallization of the secondary albite.

Albite forms a granoblastic mosaic with microcline and quartz in a medium-grained granite exposed in the NE¼SE¼ sec. 2, T. 42 N., R. 28 W. Albite is the dominant mineral. Most of the albite grains do not show twinning and are extensively altered to white mica. These grains have the same relief as scattered, unaltered twinned grains. Albite is also present as veinlet type perthite in the microcline of this rock. Here again the effects of shearing are less pronounced than in rocks containing less albite, suggesting that the albite is of post-deformation origin.

Albite extensively altered to white mica is also present in the calcite-rich gneiss in the NW¼SE¼ sec. 3, T. 42 N., R. 29 W. This albite is untwinned, but has the same relief as that forming veinlets and inclusions in the microcline of this rock.

Origin of the granite gneiss

Only a small amount of the granite gneiss and associated rocks is exposed, and the field evidence is not sufficient to indicate whether the granite is of replacement or magmatic origin. Evidence provided by the chemical and mineralogical analyses shows only that the granite is derived from the earth's crust rather than by differentiation of a basaltic magma. The evidence does not show whether the granite passed through a magmatic phase.

Most of the ensuing discussion rests insecurely on a chemical and mineralogical analysis of a single sample of red porphyritic granite exposed in the NE¼NE¼ sec. 7, T. 42 N., R. 28 W. (table 2). This is the most widespread type of gneiss in the area, and the petrographic features of the other types, such as the albite granite, suggest that they were derived from a similar rock. The most notable variations in composition from the analyzed specimen as deduced from the mineralogy are in the amounts of silica and soda. Silica is abundant in all types, and the variations are probably not significant for purposes of the present discussion. Much of the soda in the more sodic rocks is almost certainly of secondary origin and therefore not of immediate concern.

Table 2

Chemical and mineralogical composition of porphyritic red granite

	Weight per cent
SiO_2	70.18
Al_2O_3	16.22
Fe_2O_3	1.15
FeO	1.79
MgO	0.71
CaO	0.28
Na_2O	3.30
K_2O	5.36
H_2O-	0.09
H_2O+	0.23
TiO_2	0.30
P_2O_5	0.20
CO_2	0.11
MnO	0.03
	99.95

Analysis by U. S. Geological Survey

Norm[1]

Salic		Femic	
Q	26.3	En	2.0
C	4.6	Fs	1.6
Or	32.0	Mt	1.2
Ab	30.0	Il	0.4
An	1.5	Ap	0.5
	94.4		5.7

Mode[2]

Microcline	36
Albite (An 3±%)	23
Quartz	23
White mica	4
Biotite + chlorite	11
	100

Chip sample weighing in excess of 5 pounds from NE¼NE¼ sec. 7, T. 42 N., R. 28 W.

[1]Calculated according to Barth (1952, pp. 79-81).

[2]Obtained by point counter technique described by Chayes (1949). Values only approximate owing to small size of sample (1 thin section), foliated character of rock, and great range in grain size.

The original minerals of the granite gneiss were apparently anorthoclase, analbite, quartz, and minor minerals. Biotite or muscovite or both may have been present. That the original alkali feldspar contained some albite is suggested by the presence of stringlet type perthite, generally believed to be the result of exsolution of albite from an alkali feldspar. The companion feldspar of anorthoclase would be analbite. The white mica in the albite grains may have formed from the potash originally present in the albite—on the assumption that the mica is muscovite rather than paragonite.

The equilibrium diagram of Bowen and Tuttle (fig. 2A) seems at first to provide evidence that the red porphyritic granite was formed by replacement. According to this diagram, a single alkali feldspar will crystallize from a melt of the composition shown, and albite will not appear until the temperature falls to the point where, in the solid state, the albite exsolves from the alkali feldspar. This would explain the secondary albite forming the veinlet type perthite, but does not explain the randomly-oriented albite inclusions. Rather, it would appear that the feldspars began to crystallize at low temperature with the simultaneous crystallization of two feldspars. With rising temperatures the two feldspars would approach each other in composition until a single alkali feldspar was formed. However, it should be noted that the diagram of Bowen and Tuttle represents conditions at a pressure of only 2000 kg per square cm. Pressures at least two or three times as great are to be expected within the earth's crust. Such pressure might lower the liquidus until two feldspars would crystallize directly from a melt.

When the chemical composition of the red porphyritic granite is plotted on the an-ab-or diagram (fig. 2 B) it is seen to lie within the _or_ field. The possibility that some of the soda in this rock is secondary is not of immediate concern because the effect of removing soda would be to move the composition to the right, but it would still fall within the _or_ field. Terzaghi (1935) shows that a magma of this composition cannot be derived from a magma approaching basalt in composition because the composition of the melt cannot cross the boundary curve. Higazy (1950) further discusses the origin of the potash- and soda-rich granitic rocks and emphasizes the difficulty of deriving rocks of these compositions from a basaltic magma. He believes that they were formed from magmas derived by partial remelting of the crust or by metasomatic alteration of other subalkalic rocks.

The petrographic data obtained in this study do not permit use of the an-ab-or diagram to determine whether the red porphyritic granite crystallized from a melt. According to Barth (1938) the course of reaction of the alkali feldspars is toward the left along a line nearly parallel to the _or-ab_ join. _Or_ solid solutions would crystallize first from a melt of this composition, but plagioclase crystals would begin to appear after about 17 percent of the feldspar liquid had crystallized. The petrographic data do not prove that the first albite formed before this amount of material had crystallized.

Arkose series

Petrography.--The most common lithologic type of the arkose series--poorly sorted arkosic conglomerate--has essentially the same mineralogy as the granite gneiss except that quartz is more abundant. Determinations in two slides of representative coarse arkose showed 57-65 percent quartz, 22-32 percent microcline, and 10-11 percent white mica. Albite is scattered and rarely forms as much as 1 percent of the rock. Biotite and magnetite are present in most specimens, and ilmenite, leucoxene, garnet, titanite, and epidote are present in some. Most of the arkosic conglomerate is strongly sheared.

In thin section, the quartz derived from quartzite cannot be distinguished with certainty from that derived from the granite. Both consist of elliptical aggregates of elongate grains showing strong undulatory extinction and sutured contacts. Secondary quartz, in the form of roughly equidimensional grains showing no undulatory extinction is common, but overgrowths on clastic quartz grains have not been found.

Most of the microcline grains are clear, but liquid inclusions are common. Thin perthite lamellae are present in most grains, and many show veinlets and borders of secondary albite, although these are less common than in the granite and in some other phases of the arkose. Some of the small grains show no evidence of deformation and may be of secondary origin.

In detail, the margins of the microcline grains are irregular, penetrated by white mica and interlocking with the quartz. Obviously, this interlocking character requires local overgrowth or local replacement by quartz, perhaps both, at the margins of the detrital microcline grains. Thus, the origin of the interlocking quartz-microcline contacts would be similar to the origin of the sutured contacts between two adjacent quartz grains. However, overgrowths on microcline grains have not been distinguished in the arkosic conglomerate.

The dominant textural features seen in thin section are those resulting from deformation. The general rounded outline of many of the microcline grains (pl. 14A) might be regarded as a result of abrasion during transportation, but comparison with some of the grains in the gneiss (pl. 11) indicates that the rounded character could be either primary or the result of cataclasis.

An interesting feature is the contrast in the reaction of quartz and microcline to stress. The quartz grains have been stretched and redistribution of the quartz from original clastic grains to secondary, unstrained grains has been extensive. The microcline, on the other hand, has been more rigid. Many microcline grains show undulatory extinction, much weaker than that of the quartz, but most grains have yielded by fracturing. In spite of the fracturing, however, the microcline grains are much more nearly equidimensional than the quartz grains. The presence of aggregates of secondary quartz, in the structural "lee" of the microcline grains, that is, on the sides of the grains that are normal to the schistosity, emphasizes the different reaction of the two minerals.

Only one thin section of a quartzite pebble from the arkosic conglomerate has been examined. This specimen contains about 10 percent microcline and 90 percent quartz. Liquid inclusions are abundant in the quartz, but less common in the microcline. The inclusions are distributed uniformly in both microcline and quartz. The quartz grains are elongate, like those of the smaller detrital fragments, and the contacts are strongly sutured. The microcline grains are also elongate parallel to the quartz and to the schistosity of the enclosing rock. The microcline grains do not show undulatory extinction. It is uncertain whether the microcline was present in the quartzite before deformation of the arkose, or whether it was deposited there during deformation of the arkose.

Tuffaceous arkose.--In general the arkose of the zone containing interbedded tuff and tuffaceous arkose is less foliated than the arkosic conglomerate. The feldspar and quartz grains of the tuffaceous zone are more nearly equidimensional and the rocks commonly have a granoblastic texture.

The mineralogy of the tuffaceous zone is similar to that of the conglomeratic arkose, but biotite and epidote are much more abundant and microcline is more abundant at least locally. Pyrite cubes are found in some of the biotite-rich layers and titanite is present locally.

Microcline in these rocks forms relatively large, probably clastic grains, veinlets, anhedral grains in the granoblastic mosaic of quartz and feldspar, and overgrowths on rounded, apparently clastic grains.

Most of the grains identified as clastic microcline contain abundant liquid inclusions, some of which contain gas bubbles. Liquid inclusions are present but far less abundant in the overgrowths on these grains, making the overgrowth much clearer.

The microcline in the veinlets is water-clear and contains few liquid inclusions. These grains are not fractured. The texture of the veinlets is granoblastic. Some very thin lamellae in the microcline in the veinlets apparently have a higher relief and birefringence than the enclosing microcline, but these lamellae have not been proven to be perthite. Many of the clear anhedral microcline grains in the groundmass of these rocks appear to be identical with the microcline in the veinlets and the overgrowths on the clastic grains and are probably of secondary origin.

The massive coarse-grained rock appearing in hand specimen to consist largely of pink microcline and hornblende and occurring as pods in the tuffaceous arkose consists largely of epidote, quartz, microcline, and hornblende. Pyrite is common. The microcline is of the clear, apparently secondary, type, and most of the quartz grains are unstrained. The hornblende crystals are skeletal. The extinction angle is about 24 degrees and the pleochroism is X, light green; Y, deep green; and Z, fairly deep blue-green. The microcline has inclusions or replacement masses of quartz and epidote.

Scattered grains of untwinned feldspar, showing the same birefringence as the replacement albite, is present as separate grains in some of the tuffaceous arkose.

Locally, in zones extending about 5 feet into the arkose from contacts with altered basalt or diabase, microcline is absent or deeply embayed by albite (pl. 13). Quartz with blebby inclusions of albite is also common in these rocks. Some of the feldspar grains consist entirely of albite and others contain irregular patches of microcline in a sea of albite. Grain boundaries are very irregular and interlocking. These relations indicate that the microcline has been extensively replaced by albite. That the replacement took place after the deposition of the microcline grains in the arkose series is indicated by:

1. The restricted distribution of microcline grains showing such extensive replacement by albite.

2. Widespread occurrence of albite rims on microcline grains in the arkose, showing that replacement of microcline by albite did occur in the arkose series.

3. The absence of fractures in the secondary albite, although fractures are common in the clastic feldspars.

4. Although microcline is by far the most abundant feldspar in the arkose it is absent or far less common in thin sections from this zone.

The most abundant minerals in the altered basalts interbedded with the arkose are albite, poikilitic hornblende, epidote, and biotite. The order of abundance differs from one specimen to the next. Quartz comprises as much as 25 percent of the rock and euhedral magnetite as much as 10 percent. Chlorite is present in all specimens. A mineral with a granular habit similar to some of the epidote but showing much higher relief and birefringence is present in most specimens and is tentatively identified as titanite. The structure of the rock ranges from schistose to massive. Complete recrystallization is shown by the absence of evidence of deformation of any of the mineral grains.

The albite in most specimens forms a fine-grained granoblastic groundmass. In places it is clear, and twinning is apparent only in rare grains. In other places it is dusty owing to alteration. Locally, elongate twinned grains are present. These grains contain abundant inclusions of other minerals in the rock, and their outline is very irregular, strongly suggesting secondary origin.

The hornblende is apparently a sodic variety with pleochroism as follows: X, light yellow-green; Y, deep yellow-green; and Z, blue-green.

The rock that superficially resembles skarn and is associated with the vesicular zone of the flows contains small masses of clear undeformed and perthitic microcline in a groundmass whose mineralogy is similar to that of the rest of the basalt.

The minerals of the altered diabase are the same as those of the altered basalt, but the proportion of dark minerals is much greater in the altered diabase. Blue-green hornblende comprises about 45 percent of the rock, strongly zoned epidote 5 to 30 percent, green biotite 10-20 percent, and albite and quartz each about 5 percent. Titanite and magnetite are present in some specimens.

Parallel hornblende and biotite crystals impart a planar structure to the altered diabase but the quartz and albite in the groundmass show a granoblastic texture. Some of the quartz has undulatory extinction, but in general the evidence of mechanical shearing is weak.

Recrystallization of the feldspars

The history of the feldspars following their crystallization in the granite gneiss can be summarized as follows:

1. Limited exsolution of albite from alkali feldspar.
2. Erosion of part of the gneiss and deposition of the arkose series.
3. Burial of the gneiss and arkose series.
4. Further exsolution of albite from alkali feldspar.
5. Development of replacement perthite, albite granite, and albite-rich arkose.
6. Development of secondary microcline.

Some of these processes probably overlapped and the development of secondary albite and microcline are perhaps listed in the wrong order. To facilitate the following discussion, the various kinds of feldspar and their occurrences are listed in table 3.

The first change to effect the original feldspars of the granite was probably exsolution of albite from the alkali feldspar to form the string and stringlet types of perthite. Presumably, exsolution began during the uplift and denudation of the gneiss with attendant lowering of pressure and temperature. The extent of exsolution during this stage may not have been great. Although Spencer (1937) found that in some feldspars exsolution of albite was very rapid, other workers (e.g., Barth, 1938, Chayes, 1952) believe that stress facilitates exsolution.

Table 3

Feldspars in granite gneiss and in arkose series

Probable primary feldspars in granite:

Anorthoclase (porphyroblasts)

Analbite (inclusions in porphyroblasts, separate grains).

Probable primary feldspars of arkose series:

Microcline microperthite)
) clastic grains derived from granite.
Albite)

Secondary feldspars in granite and arkose series:

Microcline, microperthitic at least in part

(overgrowths on grains in arkose series, veinlets in arkose series, separate grains in both granite and arkose series.

Albite (replacement perthite, chessboard albite, granoblastic mosaic with quartz in ground mass locally in both arkose and granite.

Further exsolution of albite probably took place following burial with attendant increase in pressure and temperature and the imposition of regional strain and non-uniform stress in individual grains. It seems probable that at least some of the albite that forms veinlet and patch type perthite originated by exsolution. Presumably, the redistribution from the strings and stringlets to the veinlets and patches took place during this period.

The absence of fracturing of the secondary microcline grains show that they were formed after relaxation of the regional strain. However, the temperature was still elevated as shown by the presence of perthite lamellae in the microcline in the marginal zone at the south edge of the heavy basalt layer in NW¼NW¼ sec. 17, T. 42 N., R. 28 W. These secondary perthites were probably derived from an alkali feldspar formed above the exsolution curve (fig. 2 A).

The secondary microcline was probably derived from the original microcline abundant in both the arkose and the granite gneiss; Gilbert (1949), for example, has shown that solution and redeposition of both albite and potash feldspars has taken place even in such undeformed rocks as the California Tertiary reservoir sands. There seems to be no reason to assume that the secondary microcline is related to foreign solutions or magmatic processes.

The secondary albite in the albite granite and albitized arkose poses a more complex problem. The composition of this albite is apparently very close to that of the primary albite in these rocks. This suggests that it may have been derived from other parts of the granite mass and arkose and concentrated in favorable places. However, the possibility of foreign origin cannot be eliminated.

Reconstituted granite.--The term "reconstituted granite" is used here to avoid awkwardness in referring to recrystallized arkose that strongly resembles granite in appearance. It is recognized that the granite detritus has been contaminated by quartzite debris. Why does some of the arkose resemble granite although most of the arkose retains textural features that clearly denote its clastic origin? The answer is to be found in the good sorting of the arkose that formed reconstituted granite in contrast to the poor sorting of the arkose that did not.

The reconstituted granite is compared with representative coarse arkose in table 4. The reconstituted granite does not possess foliation and the arkose selected for comparison was one with minimum evidence of deformation.

The chief differences between the arkose and the reconstituted granite are in the range of grain size and the amount of secondary microcline. If it is true that the amount of cataclasis of the two rocks chosen for comparison is similar, as it appears to be (pl. 14, A, B), the range in grain size is largely a primary feature and shows that the reconstituted granite was a well-sorted sediment whereas the arkose was poorly sorted. Good sorting of the original arkose could facilitate the development of an equigranular reconstituted granite by providing (1) a raw material of fairly uniform grain size, and (2) maximum porosity (Pettijohn, 1949) and the largest pores.

Table 4

Comparison of arkose with reconstituted granite

Arkose	Reconstituted granite
Outcrop and hand specimen	
Bedded.	Massive. Poorly preserved crossbedding present locally.
Range in grain size 3 mm to less than 0.5 mm.	Majority of grains are 0.5 to 1.5 mm diameter.
Microcline grains equidimensional, grain boundaries smooth.	Microcline grains equidimensional to elongate, grain boundaries feathered.
Thin section	
Wide range in grain size, see plate 9A.	Restricted range in grain size, see plate 9B.
Microcline grains fractured but not granulated.	Microcline grains fractured but not granulated.
Secondary overgrowths on microcline absent or rare. Clear, probably secondary, microcline rare.	Secondary overgrowths on microcline common. Clear, probably secondary, microcline common.
Margins of feldspar grains shallowly cuspate.	Margins of feldspar grains deeply cuspate.

It is possible that the abundance of visible overgrowths on the microcline grains in the reconstituted granite in contrast to the absence of such overgrowths in the arkose gives a false notion of the relative amount of redistribution of microcline in the two rocks; in the well-sorted sediment more space and larger interstices would be available for the development of recognizable overgrowths than in the poorly sorted sediment. However, Gilbert (1949) has shown that solution and redeposition of quartz and feldspar in Tertiary reservoir sands in California oil fields has beengreater in the "clean", porous sands than in those with an argillaceous matrix and low porosity. He argues (p. 14):

> "The existence of clay between the sand grains would tend to prevent or make less effective the mechanism of differential solution and complementary deposition just outlined. Compact clay tends to transmit more uniformly the stress due to overburden and thus to reduce the heterogeneity of the stress and its concentration at points of solid contact between grains."

Although the matrix in all but the finest arkose beds was apparently silt and fine sand rather than clay, the same argument appears valid.

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Plate 4. Strongly sheared red porphyritic granite gneiss. Large grains are microcline phenocrysts. NW¼NE¼ sec. 7, T. 42 N., R. 28 W., Dickinson County, Michigan. Scale divisions are in centimeters.

Plate 6. Cross-bedded arkose. Horizontal surface. Tops of beds face south, toward top of photograph. NW¼NW¼ sec. 17, T. 42 N., R. 28 W., Dickinson County, Michigan.

Plate 7. Stromatolites in Randville dolomite. Globular forms developed on the flatter forms that compose biostromes. Surface normal to bedding plane. Tops of beds face south, toward top of photograph. NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 4, T. 42 N., R. 28 W., Dickinson County Michigan.

Plate 9. Small fold in arkose series plunging toward observer at low angle. Bedding plane marked by contact between conglomerate and finer-grained arkose. Note that long axes of pebbles parallel the foliation of the rock rather than the bedding planes. Rock surface slopes toward observer. NE¼NE¼ sec. 10, T. 42 N., R. 28 W., Dickinson County, Michigan

Plate 10. Small fold in argillaceous layer interbedded with arkose. Horizontal surface. Folds plunge west (left of photograph) about 45 degrees. Note thickening of beds in synclines. Near northeast corner sec. 10, T. 42 N., R. 28 W., Dickinson County, Michigan.

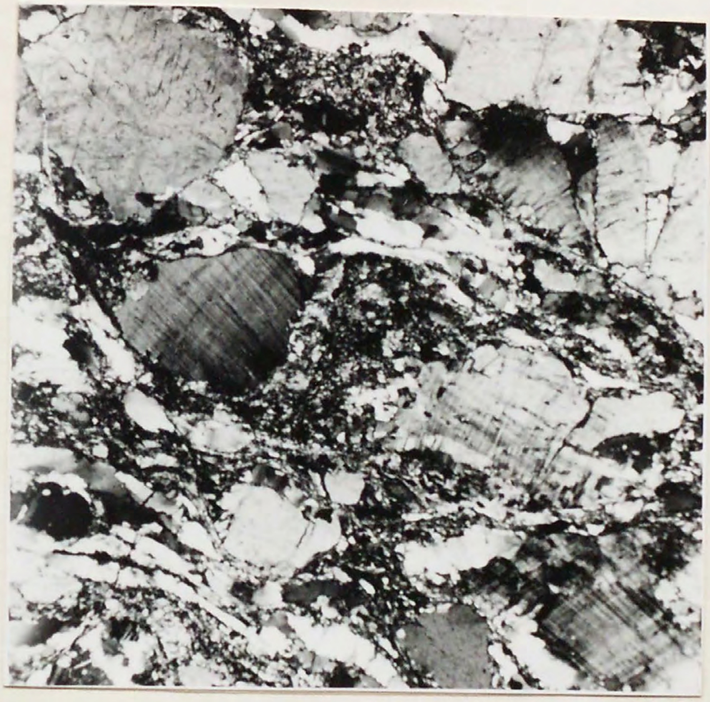

Plate 11. Photomicrograph of coarse red porphyritic granite gneiss showing fractured microcline grains (gray cloudy grains with twin lamellae) and elongate quartz grains with strong undulatory extinction. NE¼NE¼ sec. 7, T. 42 N., R. 28 W., Dickinson County, Michigan. x-nicols. 20X

Plate 12. A, Photomicrograph of microcline perthite with albite (twinned), quartz (white to gray) and biotite (black) inclusions. Diagonal white veinlets are albite. Note narrow clear rims on albite inclusions. Some specimen as plate 11. x-nicols. 30X

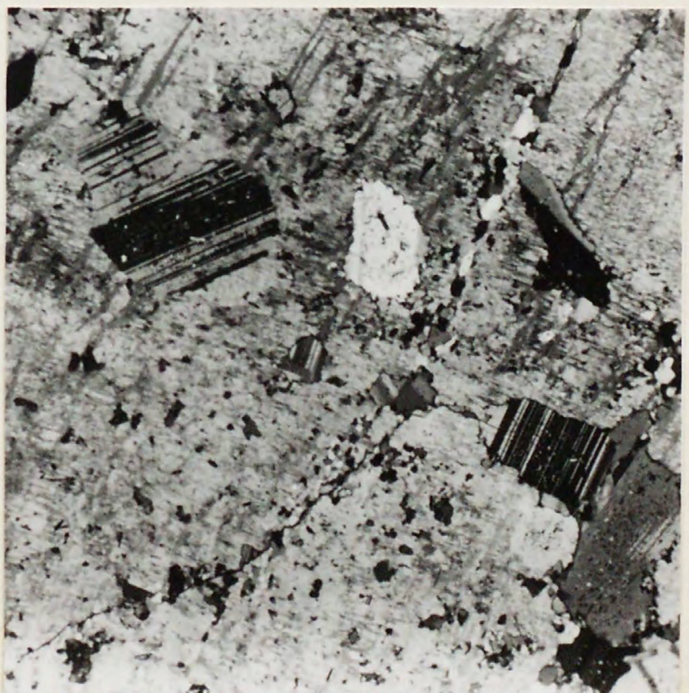

Plate 12. B, Photomicrograph of chessboard albite (mottled gray field) with albite inclusions. Diagonal white streaks are also albite. Granular secondary quartz along diagonal fracture. Note clear rims on albite inclusions whose cores are partly altered to white mica. NW$\frac{1}{4}$ sec. 15 T. 42 N., R. 29 W., Dickinson County, Michigan. x-nicols 30X

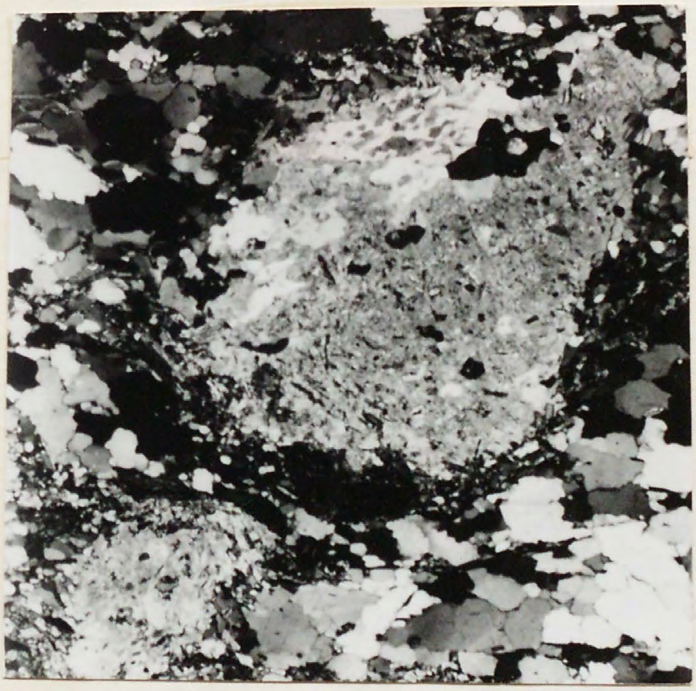

Plate 13. Photomicrograph of microcline in arkose largely replaced by albite (mottled gray grains with ill-defined boundaries) and blebby quartz. Quartz is white to black and clear. Elongate small black grains are mica, chiefly white mica within the feldspar grains and biotite in the groundmass. SW¼SW¼ sec. 8, T. 42 N., R. 28 W., Dickinson County, Michigan. x-nicols. 30X

Plate 14. A, Photomicrograph of coarse arkose. Cloudy and twinned gray grains are microcline; cleargrains are quartz. NW¼NW¼ sec. 17, T. 42 N., R. 28 W., Dickinson County, Michigan. x-nicols. 20X

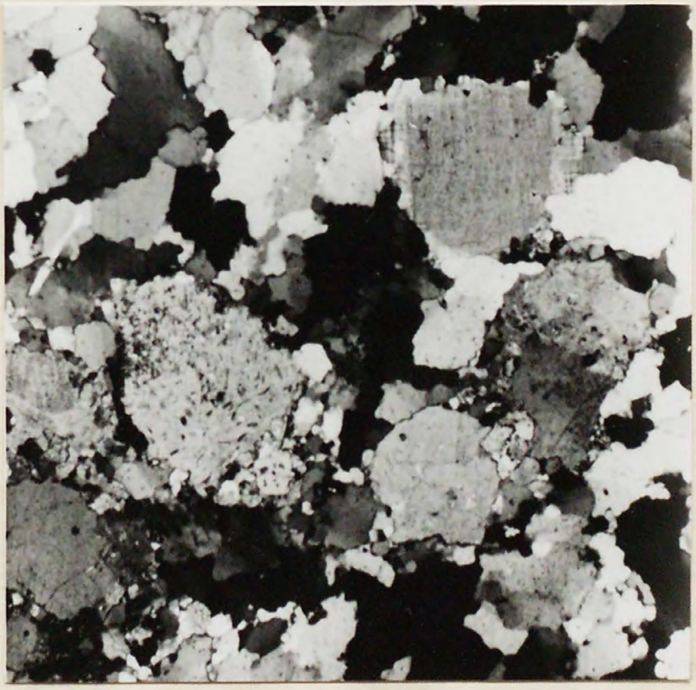

Plate 14. B, Photomicrograph of reconstituted granite (recrystallized arkose) showing clear overgrowth on cloudy microcline grain (cross-hatch twinning, upper right). Large gray grain (lower left) marked by elongate black grains is albite with white mica inclusions. Quartz is clear and contains liquid inclusions which show as dark gray dots. NW¼NW¼ sec. 17, T. 42 N., R. 28 W., Dickinson County, Michigan. x-nicols. 30X

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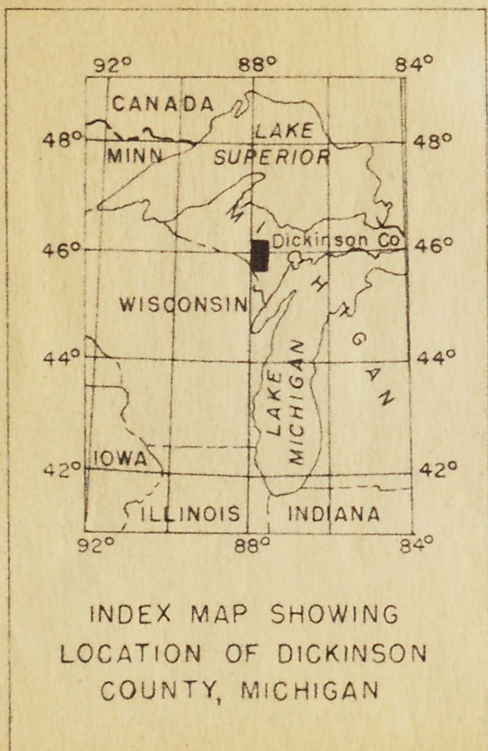

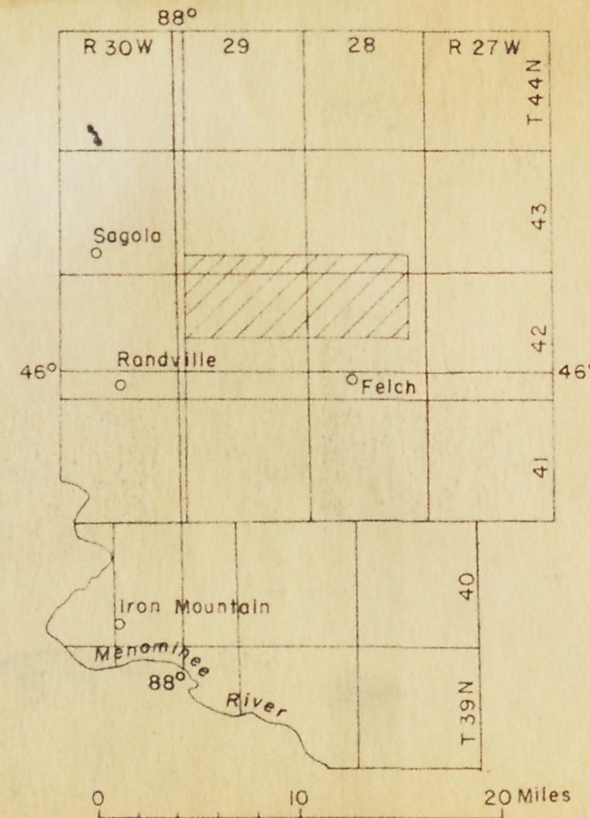

Figure 1. Index maps showing location of Norway Lake area.

This map is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

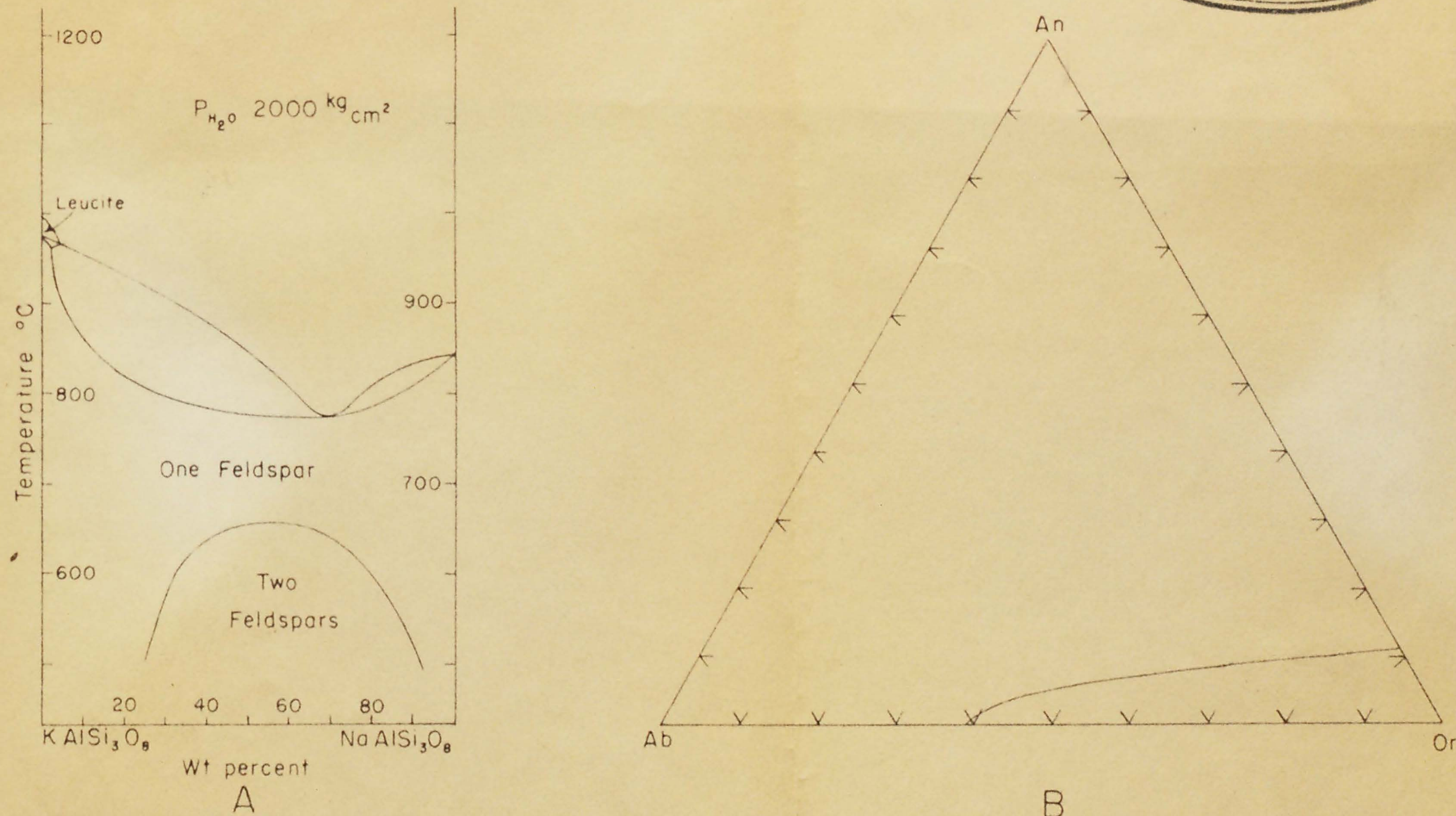

Figure 2. A, Isobaric equilibrium diagram for the alkali feldspars (after Bowen and Tuttle, 1950, fig. 3). B, phase diagram of the system orthoclase-albite-anorthite (after Barth, 1938).

Fig. 2

3 pieces in pocket.