ON AN OCCURRENCE OF "QUARTZITE" IN THE SOUTHERN COMPLEX NEAR PALMER, MARQUETTE COUNTY, MICHIGAN

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Robert A. Vehrs

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ON AN OCCURRENCE OF "QUARTZITE" IN THE SOUTHERN COMPLEX NEAR PALMER, MARQUETTE COUNTY, MICHIGAN

by

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ILLUSTRATIONS

ABSTRACT

An occurrence of "quartzite" and its associated rocks in the Southern Complex near Palmer, Marquette County, Michigan is described. The origin and age of the "quartzite" are discussed in light of field and laboratory observations.

It is concluded that the "quartzite" is a metamorphosed novaculite of probable pre-Huronian age.

ACKNOWLEDGMENTS

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What merits this thesis may possess are due in the greater part to these men.

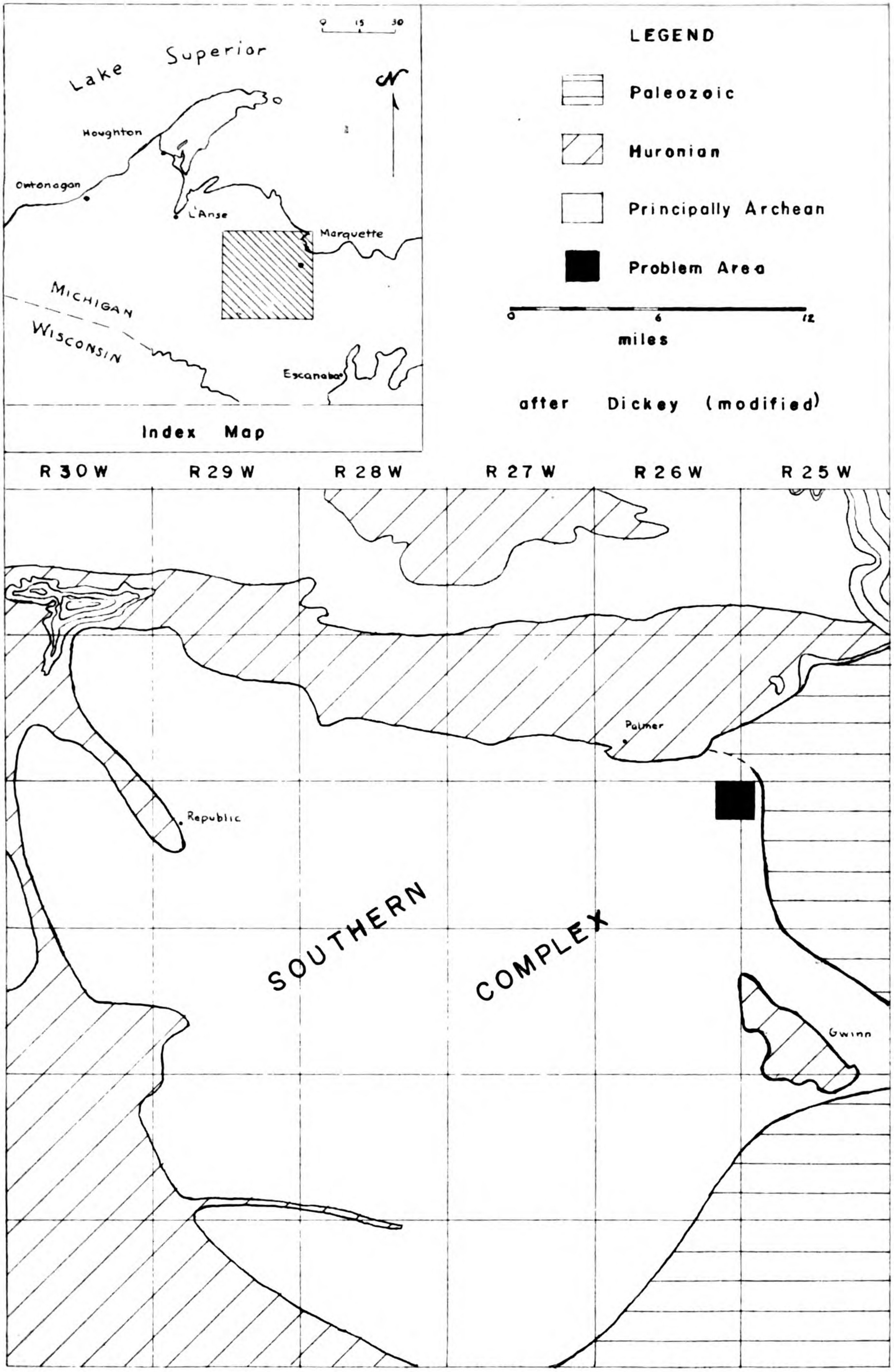


Figure I. Location of Problem Area in Northern Michigan

INTRODUCTION

The Southern Complex of the Upper Peninsula of Michigan is composed of Precambrian igneous and metamorphic rocks, predominately granites, gneisses, schists, and basic intrusives. It embraces an area of approximately 1400 square miles south of the Marquette synclinorium, bounded by folded Huronian (Animikie)1/ rocks to the west and south, and covered by flat-lying Paleozoic sediments to the east.

In the summer of 1951, Robert C. Reed, geologist for L. P. Barrett, U. S. Atomic Energy Commission contractor, noted several outcrops of a white, quartzose rock occurring in the granitic terrane of the Southern Complex near Palmer, Marquette County (Reed, 1958).

The presence of this rock posed many interesting questions regarding its origin, age, and relation to surrounding rocks. This thesis presents a record of the author's field and laboratory study of these questions.

1/ The U.S.G.S. has recently discarded the term "Huronian", used to describe the Middle Precambrian sequence of Michigan, and has replaced it with "Animikie" (James, 1958, p.33). Although most workers agree that Huronian is no longer acceptable in Michigan, they are far from unanimous in their acceptance of Animikie. The present writer, therefore, has retained the term Huronian.

Location and Extent

The area studied lies approximately 10 miles southwest of Marquette and 5 miles east-southeast of Palmer. The author examined Sections 1 and 12, T 46 N, R 26 W and Sections 6 and 7, T 46 N, R 25 W; portions of the surrounding sections were also visited in the course of the investigation. Mapping was completed in Section 1 and adjacent portions of Sections 6, 7, and 12.

A bold linear ridge of quartzose rock[2/] trends in an easterly direction across Section 1; and scattered, less prominent outcrops of this rock occur elsewhere in the mapped area. Numerous outcrops of granite, gneiss, and basic intrusives occur in the mapped area and surrounding sections.

Culture

Ready access to the area is provided by county road 553 from the east and state highway 35 from the west. Numerous sand roads traverse the interior; they are easily travelled by automobile. Tracks of the Chicago &

2/ This rock will be called "quartzite" throughout most of this report. "Quartzite", as used here, is strictly a convenient field term; it implies a granular, metamorphosed, quartzose rock, not necessarily derived from sandstone.

Northwestern R.R., connecting the Marquette range with Escanaba, pass to the east.

Fire lanes, generally along section lines, were plowed out in the early 1930's; and, although overgrown to some extent, they are still readily discernible. Some section corners are marked by pins.

Groves of pine and balsam and large expanses of open grassland cover most of the level, sandy portions. Mixed hardwoods grow in the more rugged, rockier areas. With the exception of a few hunting cabins and small-scale logging operations there is little evidence of human activity.

Previous Investigations

Development of the Marquette synclinorium into a major mining district, following discovery of iron ore in 1844, required intensive geological investigation. By the turn of the century, limits of the Huronian strata had been defined, and a large amount of detailed and reconnaissance mapping had been done in the district. Subsequent work has been devoted almost entirely to the study of the Huronian and to the search for iron ore. The complex igneous and metamorphic areas bordering the synclinorium on the north and south are unimportant economically, and have been largely neglected.

Van Hise and Bayley (1897, p.190), in their classic Monograph 28, describe the Southern Complex as:

> "...occupied by granites, gneisses, hornblendic and micaceous schists, and greenstone schists, together with the various acid and basic eruptives that intrude them."

Van Hise and Leith (1909, p.108-178) give a comprehensive summary of literature on the Michigan Precambrian to 1907. Regarding the Precambrian basement complex both north and south of the Marquette synclinorium, they state, (p.332) that:

> "these granites and gneisses show a variety of characters and are certainly not all of the same age, although with minor exceptions they antedate the Algonkian rocks."

Van Hise and Leith (1011) again give an excellant summary of previous work in the Lake Superior region. Their discussion of the Southern Complex (p.255) is brief and is devoted mainly to a description of the schists which occur infrequently in the Complex. They also describe the Palmer gneiss and suggest that parts of it may be metamorphosed sedimentary rocks.

Leith, Lund, and Leith (1936) give a compilation of work done in the Lake Superior region since 1911, but do not add to the description of the Southern Complex.

Lamey (1931, 1933, 1934, 1935, 1937) has done considerable work in the Southern Complex, particularly in the northern portion near Republic and Palmer. He considers the larger part of the complex to be post-Huronian granite, which he calls Republic granite. He also has studied the Palmer gneiss, and concludes that it is predominantly highly metamorphosed Lower and Middle Huronian rocks.

Dickey (1936) disputes Lamey's conclusions regarding the granite of the Southern Complex and states (p.317):

> "Granites representing three distinct periods of pre-Cambrian intrusions are recognized in the Southern Complex...Two of these are believed to be Archean, and one post-Huronian. The Southern Complex is made up dominantly of Archean rocks, and is not...composed for the most part of post-Huronian granite."

Later (1938), he discusses a post-Lower, pre-Middle Huronian granite which he calls the Ford River granite.

Tyler, Marsden, Grout, and Thiel (1940) have studied the Lake Superior Precambrian rocks by accessory mineral methods. They recognize two pre-Huronian granites, a Huronian granite, and a post-Huronian granite in the Southern Complex. They conclude that the hyacinth variety of zircon indicates a pre-Huronian age, that malacon zircon indicates later pre-Huronian and Huronian ages, and that "normal" zircon indicates post-Huronian.

Ayres (1943) considers the Republic granite to be post-Huronian.

James (1955) delimits zones of regional metamorphism in the Precambrian rocks of northern Michigan. Later (1958) he establishes that Dickey's Ford River granite is probably pre-Huronian, not Huronian; he further recommends the abondonment of the term Republic granite because of the difficulty in determining relative ages of the granites present in the district.

Reed (1958) has examined much of the Marquette district in a search for radioactive deposits, but has not written extensively about the area.

Long (1959) describes the granite and metamorphic rocks occurring in an area south of the Palmer gneiss belt.

Sahakian (1959) discusses the injection gneiss and granite occurring in the northeastern portion of the Southern Complex.

GENERAL GEOLOGY AND STRATIGRAPHY

The most prominent geologic feature in Marquette County is a narrow, westward-plunging synclinorium about 40 miles long; it is composed of Huronian rocks, locally intruded by basic dikes, sills, and possibly by granite.

Flanking the synclinorium on the north and south are large masses of igneous and metamorphic rocks, called, respectively, the Northern Complex and the Southern Complex. The rocks in these areas are of widely varying ages, but are largely pre-Huronian.

A block of Huronian sedimentary rocks occurs on the southern rim of the synclinorium at Palmer. This locality has the aspect of a trough separate from the synclinorium. Bordering this area on the south is the Palmer gneiss belt. A narrow tongue of Huronian formations extends across the Southern Complex from the Marquette synclinorium to Republic; and an isolated basin of Huronian age occurs in the Gwinn district, about 13 miles south of Palmer.

Flat-lying Upper Cambrian sandstone rests unconformably on the Precambrian formations in the eastern portions of the Marquette district.

Following is a brief discussion of the rocks recognized in the Southern Complex and in adjacent Huronian areas. The reader should be aware that the problem of age relations in the Southern Complex is far from solved. Lacking absolute age determinations, the present writer must accept the sequence proposed by Dickey as that most applicable to the area discussed in this thesis. Dickey

(1936, p.339) proposes the following:

" 1. The oldest rocks visible in the area are Keewatin-type schists, which are classed as Archean.

2. These schists are intimately intruded...to produce injection gneisses...by...medium-grained gray to pink granite. This granite is believed to be Laurentian...

3. The second period of granitic intrusion is represented by a gray to pink granite of pronouncedly porphyritic character...this granite porphyry... is considered to be Algoman.

4. The youngest granitic intrusion...is a pink to red granite...fine-grained to pegmatitic...it is considered to be Killarnean."

Rock Sequence in the Marquette District according to Zinn (1939):

Pleistocene	--	Glacial sediments
Unconformity		
Upper Cambrian	--	Sandstone
Unconformity		
Keweenawan	--	Olivine diabase dikes
Erosian interval		
Post-Huronian folding and Killarney granite intrusion		
Upper Huronian	--	Upper Michigamme quartzite and slate Bijiki iron formation Lower Michigamme slates Clarksburgh volcanics and intrusives Greenwood iron formation Goodrich conglomerate and quartzite
Unconformity		
Middle Huronian	--	Negaunee iron formation Siamo slate Ajibik quartzite
Unconformity		
Lower Huronian	--	Wewe slate Kona dolomite Mesnard quartzite
Unconformity		Algoman granite and syenite
Temiskaming	--	Sediments and volcanics
Unconformity		Laurentian granite gneiss
Keewatin	--	Greenstone, lavas, and volcanic sediments

Lower Precambrian

The oldest rocks in the Southern Complex are mainly hornblendic and micaceous Keewatin-type schists. Many of these schists resemble metamorphosed volcanic rocks. Several different ages are probably represented.

Some Keewatin-type schists have been intruded by a granite (Laurentian?) to form migmatites.

A granite porphyry (Algoman?) cuts the migmatites. This pink to grey granite exhibits large phenocrysts of orthoclase, microcline, and microperthite, which often show parallel lineation. This granite is often deformed.

The Palmer gneiss is a belt of highly metamorphosed rocks immediately south of the Palmer area. The gneiss in places resembles metamorphosed sediments and elsewhere metamorphosed granite. The gneiss is generally placed in the pre-Huronian; however, Lamey (1935) believes it represents metamorphosed lower and middle Huronian rocks.

Middle Precambrian

Lower Huronian

Mesnard quartzite is the basal Huronian formation; it lies with marked unconformity upon older rocks. Generally it grades upward from a basal conglomerate, through a quartzite, to a slate.

Kona dolomite overlies the Mesnard. Interstratified with the dolomite are slaty and siliceous layers. Possible algal structures are prominent in some sections of the formation.

Wewe slate overlies the Kona. It is derived from pelitic sediments and contains slate, graywacke, and chert.

Middle Huronian

Ajibik quartzite rests unconformably upon the lower Huronian formations. A basal conglomerate with interstratified slate and graywacke grades upward into a quartzite.

Siamo slate overlies the Ajibik. It varies from a quartzitic graywacke, though a massive graywacke, to a fine-grained slate.

Negaunee iron formation rests on the Siamo. It consists of jaspilite, ferruginous slates, iron-silicate schists, ferruginous cherts, and iron ore.

Upper Huronian

Goodrich quartzite unconformably overlies the Negaunee. It is conglomerate at the base, but dominantly a quartzite.

The remaining Upper Huronian formations are missing in the area discussed.

Huronian or Post-Huronian

Intruded into the Huronian formations are many <u>basic dikes and sills</u>. They are generally deformed and altered.

Post-Huronian

A <u>granite</u> (Killarney?) has intruded and in some places granitized Huronian rocks.

<u>Upper Precambrian</u>

Keweenawan

Brown-weathering, <u>olivine diabase dikes</u> cut all Precambrian formations in the district.

Aplites, pegmatites, quartz veins, and basic intrusives occur throughout the Southern Complex; they may be of many different ages and, for the most part, seem to be related to the various granite intrusions.

DEFINITION OF THE PROBLEM

The unusual occurrence of a large body of "quartzite" in the midst of the granites and gneisses of the Southern Complex presents many interesting problems. Prior to the present investigation, the only available information regarding this occurrence was the approximate location of the outcrops and a verbal description of the rock as highly quartzose.

The proximity of this occurrence to the controversial Palmer gneiss and to known Huronian formations immediately suggests the possibility that it is simply an outlier of Huronian quartzite. On the other hand, this location may be fortuitous. Relations between this rock and the neighboring granites and gneisses were not known. The very nature of the "quartzite" was an enigma; it might be a true quartzite, recrystallized chert, vein quartz, an igneous rock, or a silicified facies of the granite or gneiss.

Because of the unusual nature of the rock and the lack of previous descriptions of the area, it is the purpose of this study to present:

1. An outcrop map of the area
2. A petrographic description of the "quartzite" and associated rocks
3. A discussion of the origin and age of the "quartzite".

FIELD PROCEDURE

Field work was accomplished mainly during the weekends of late June and July, 1958. Several days in early September were spent rechecking field observations.

Prior to actual field work, a study was made of all available maps and aerial photographs of the area. A composite field map was made from the U.S.G.S. Sands and Palmer quadrangle topographic maps. The locations of all outcrops visible on aerial photographs were noted on the field map.

Several days were spent in a general reconnaissance of the area, prior to detailed mapping. This procedure provided a good picture of the regional geology and served to delimit the outcrop areas of the "quartzite." The level, open nature of the landscape and the numerous sand roads allowed a very rapid examination of almost all of the outcrops in over four sections. The general reconnaissance disclosed that outcrops of the "quartzite" were restricted essentially to Sec. 1, T 46 N, R 26 W and adjacent portions of Sec. 6 and 7, T 46 N, R 25 W.

The SE corner pin of Sec. 1 was located and was used as the origin of a north-south picket line, established along the eastern edge of Sec. 1. East-west traverses were made at eighth-mile intervals from the picket line. Pace and compass methods were used in mapping; this was considered sufficient because of the excellant control afforded by the topographic maps, aerial photographs, and well-marked section lines. No abnormal magnetic interference with the Brunton compass was noted.

A scale of 200 feet to the inch was used in mapping. Outcrops, topographic features, and specimen locations were plotted directly on large sheets of ¼ inch squared paper, which was carried in a clip-board. Detailed notes were entered in a field book. Representative samples were collected from all outcrops mapped. Oriented samples were taken in several places.

LABORATORY PROCEDURE

Thin sections of 25 representative samples were prepared; these included a thorough sampling of the "quartzite", several samples of the granite, and one of a cross-cutting dike. All thin sections were examined under a petrographic microscope, and a standard petrographic analysis was made of all rock types present. Mineral percentages were determined by use of a Leitz integrating stage. A petrofabric analysis was made of one of the oriented specimens; a Leitz four-axis universal stage was employed. An X-ray powder diffraction pattern was obtained from one specimen. Photomicrographs of selected specimens were taken. Igneous rocks were named according to the classification of Johannsen (1932).

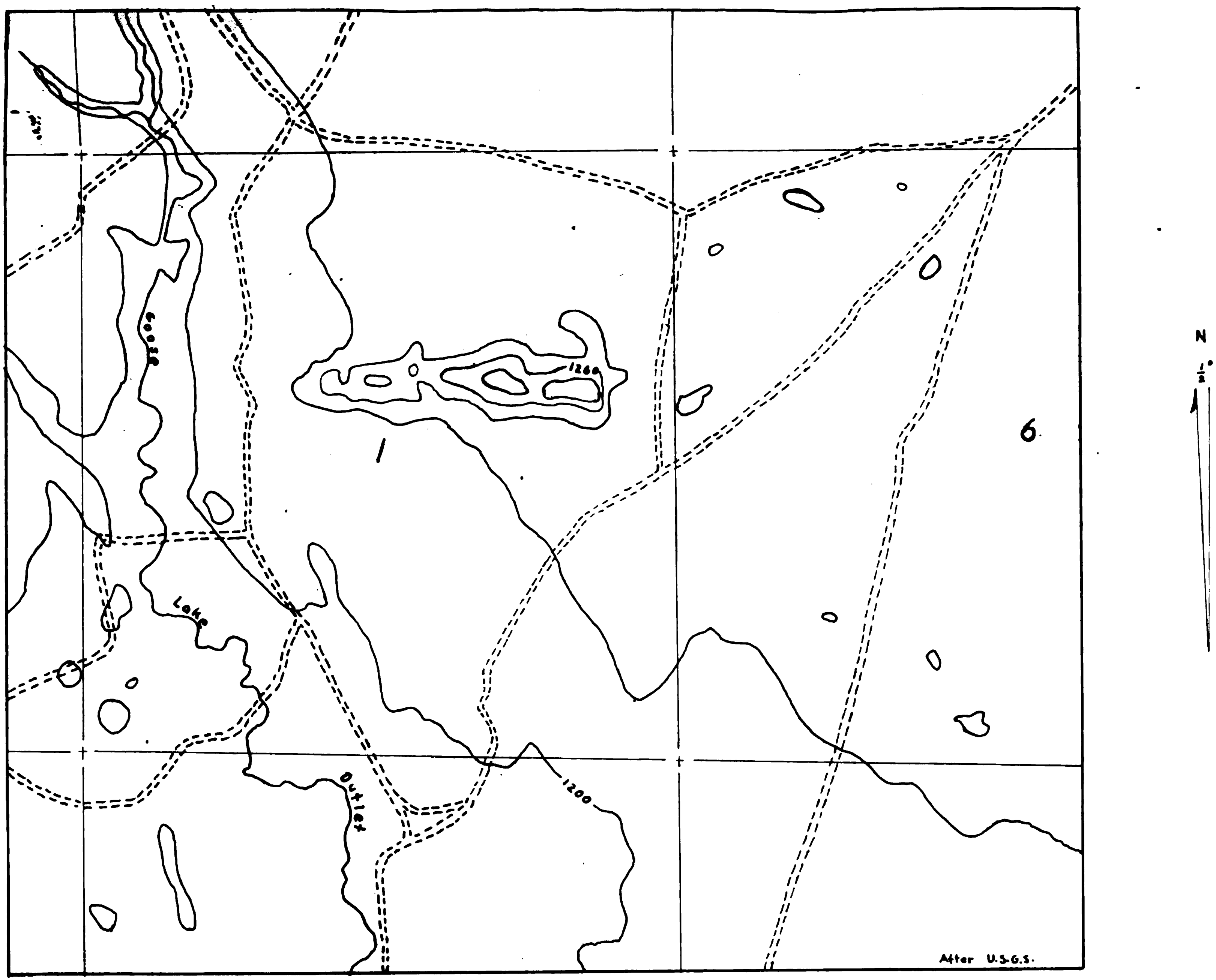


Fig. 2

TOPOGRAPHY
Sec. 1, T46N, R26W & Adjacent
Areas

C.I. = 20'

PHYSIOGRAPHY OF THE PROBLEM AREA

The area studied is near the contact of the flat-lying Paleozoic sediments of the eastern part of the Upper Peninsula with the igneous and metamorphic Precambrian rocks in the west. Indeed, bedrock in portions of the area examined has been erroneously designated Paleozoic on available published maps. The character of the bedrock is reflected somewhat in the topography. Westward, across the Paleozoic-Precambrian contact, a level or gently rolling landscape gradually gives way to the rugged, rock-nob topography typical of Lake Superior Precambrian localities. Glacial processes have modified the landscape here as in other parts of the Great Lakes region.

Drainage

Goose Lake Outlet flows southward through the problem area and joins the East Branch of the Escanaba River. Several small creeks feed into Goose Lake Outlet from the west. The outlet is a tightly meandering, shallow stream, roughly 20 feet wide. The meander belt occupies the entire width of the flood plain.

Sand Plain Topography

A remarkably level sand plain covers most of the area east of Goose Lake Outlet. Infrequently, hills and nobs of bedrock pierce the blanket of sand. This sand plain is a part of the extensive outwash plain drained by the Escanaba River system. Dune-like accumulations of sand have been built up against the larger outcrops. The wind has sandblasted the surfaces of outcrops; hence, outcrops of the hard, resistant "quartzite" exhibit polished, facetted surfaces. No streams, other than Goose Lake Outlet, are found on the sand plain; this, no doubt, reflects the porosity of the sand. Some marshy tracts exist, but they are of little consequence. A few small lakes occur northeast of the problem area.

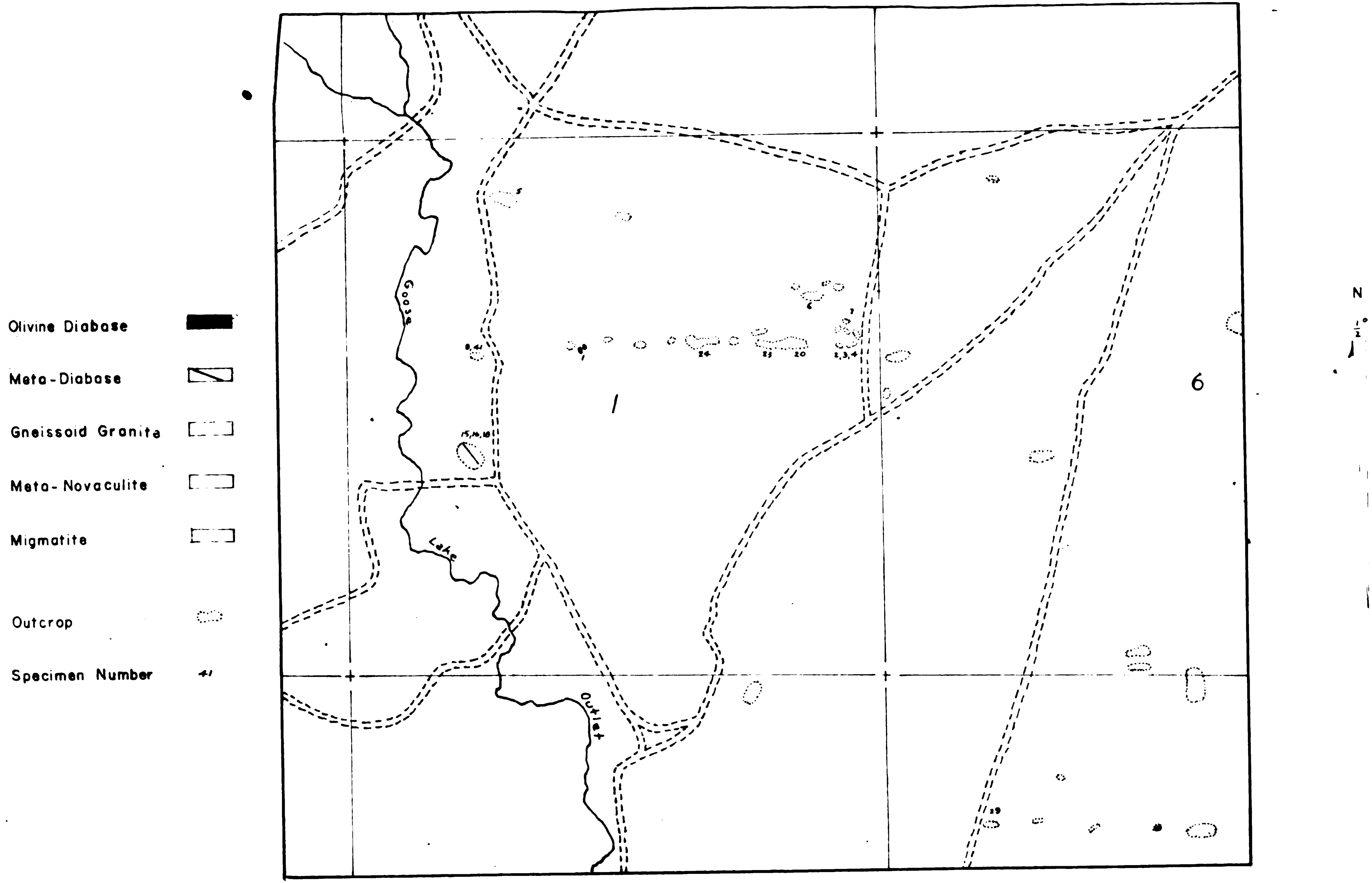
Rock-Nob Topography

Contrasting with the monotony of the sand plain is the hilly area west of Goose Lake Outlet. Sand is the dominant soil here also; but, rather than blanketting the surface, it fills only valleys and depressions and is generally subordinate to bedrock exposures. Here the bedrock determines topographic expression. Numerous shallow, linear valleys, trending N 45 W and N 65 E, are readily seen on aerial photographs of the locality; they suggest the development of a strong master jointing in the bedrock. Less apparent, yet numerous, valleys trend approximately north-south and west-northwest; these are also probably expressions of bedrock jointing and/or faulting. The sharply angular course of the East Branch of the Escanaba River appears to be controlled by these features. It is likely that the courses of all of the streams in this area reflect the structure of the bedrock.

GEOLOGY OF THE PROBLEM AREA

Distribution of Rocks

Reddish-orange, gneissoid, porphyritic granite occupies the northern part of the mapped area (fig. 3). Apparent intrusive contacts of this granite with "quartzite" occur at the eastern margin of Section 1. The "quartzite" is exposed for a distance of half a mile west of here, and in smaller, less prominent outcrops elsewhere in the mapped area. Two basic dikes, of differing age, cut the "quartzite". A broad belt of migmatite, or injection gneiss, lies north, east, and south of the "quartzite" and its associated granite. A complex of granite and granite gneiss lies south of the mapped area.



OUTCROP MAP

Fig. 3

4" = 1 mile

Sec. 1, T46N, R26W & Adjacent

Areas

Description of the Rocks

A thorough petrographic study of a rock thin section, supplemented by field data, generally yields sufficient information for an accurate identification of the rock and for reasonable conclusions regarding its origin. In outcrop, the "quartzite", upon which this study is focussed, exhibits little evidence that would aid in its identification; under the microscope, however, the composition, structure, and some of the history of this rock are revealed. Associated rocks often yield pertinent information; this is true of the granite, basic dikes, and migmatite.

A discussion of the petrography of the "quartzite" and its associated rocks follows. It is hoped that the detailed descriptions of a few representative specimens, coupled with data drawn from the field, will provide the reader with a sufficiently clear and accurate picture of these rocks in their field setting.

Granite

Specimen 5

In its northernmost outcrop in the mapped area, the granite is coarse and porphyritic. Large, prominent phenocrysts of reddish-orange feldspar occur in a coarse, granular groundmass composed essentially of quartz and feldspar. The phenocrysts range in size from about 1 cm. to over 7 cm. Grain size in the groundmass varies considerably, but rarely exceeds 5 mm. Thin, irregular seams of ferromagnesian minerals impart a poorly defined gneissoid appearance to the rock. Rather intense deformation of the rock is indicated by numerous shattered phenocrysts. Quartz veins and aplitic dikes frequently cut the granite.

Under the microscope, large masses of potash feldspar appear in a coarse to medium-grained, hypidiomorphic-granular matrix of quartz, albite-oligoclase, some potash feldspar, and small amounts of chlorite.

The potash feldspar often exhibits the quadrille twinning characteristic of microcline; frequently, however, no twinning is apparent. Twinning is commoner in the potash feldspar grains of the matrix than in the phenocrysts. No indisputable evidence was found to indicate that the untwinned potash feldspar is orthoclase rather than microcline; therefore, because of this uncertainty, all non-plagioclase feldspar is called simply potash feldspar. Perthite occurs, but good examples are rare. Occasionally, small poikilitic masses of twinned plagioclase (89-91 % Ab) occur in the microcline phenocrysts, forming patch perthite. The potash feldspar has a very fresh appearance; under plane light the grains are bright, distinct, and only slightly clouded by reddish-brown kaolin. Plagioclase, on the other hand, has a highly altered appearance; every grain is altered in some degree to paragonite. Cloudy masses of sausserite often occur. Cleavage is rarely apparent and grain boundaries are very irregular. All plagioclase exhibits polysynthetic twinning. Albite twinning is very common; combination Albite-Carlsbad twinning is infrequent; and Pericline twinning occurs rarely. Measurements of extinction angles indicate a composition in the range 86-93% Ab, with 88% Ab the most probable; the plagioclase is therefore Albite-Oligoclase.

Quartz occurs in irregular masses filling the spaces between feldspar grains. It contains abundant inclusions, frequently in linear arrangement. Margins of quartz grains are often granulated, and undulatory extinction is almost always present. Secondary quartz occurs as veinlets which often follow fractures that have sliced and offset twinning lamellae of feldspar grains.

Shreds and blades of chlorite occur infrequently. The chlorite appears to be in various stages of alteration from a previous ferromagnesian mineral, probably biotite, although none of the original mineral remains. The chlorite is pleochroic from very light yellow-green to darker green; the intensity of pleochroism is highly variable. Extinction parallel to the cleavage and the anomalous Berlin blue interference color suggest that the chlorite is the variety penninite. Numerous rounded grains of magnetite occur in the chlorite; the magnetite is usually in some stage of alteration to martite. Apatite, in small subhedral grains and long slender prisms, is common throughout the rock and plentiful near chlorite grains. Zircon, probably the malacon variety, occurs in small rounded grains and rare terminated prisms. It generally has a cloudy, altered appearance and is surrounded by a brown, slightly pleochroic halo. Epidote has occasionally developed along chlorite-plagioclase contacts.

The following modal analysis of the rock indicates that it is leucogranite as defined by Johannsen (1932).

<u>Mode of Specimen 5</u>

Quartz..................	28.6%
Potash feldspar..........	38.2
Albite-Oligoclase........	29.6
Apatite..................	0.3

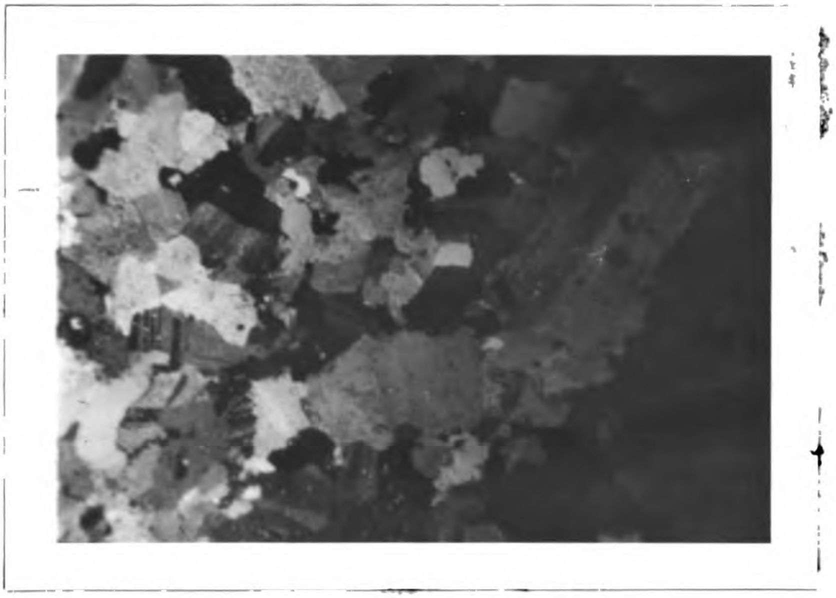


Fig. 4 - Photomicro[illegible] ec. 5 showing hypidio-
morphic-gr[illegible] the granite.

of pot[illegible]

5 mm. in le[illegible]

mass is

Ur[illegible]

inec[illegible]

nou[illegible]

app[illegible]

und[illegible]

hav[illegible]

5 Photomicrograph (20X) of Spec. 6, a more gneissose
facies of the granite

Chlorite................	3.2
Magnetite...............	0.1
Zircon..................	Tr.

Specimen 6

Closer to its contact with the "quartzite" the granite loses its coarse, porphyritic appearance and becomes more decidedly gneissose. The thin seams of dark constituents become straighter and more regularly spaced. Grains of feldspar and quartz in the groundmass are of more uniform size, and appear elongate parallel to the banding produced by the dark seams. Although phenocrysts of potash feldspar are still prevalent, they rarely exceed 5 mm. in length; the average size of grains in the groundmass is about 2 mm.

Under the microscope, the texture is hypidiomorphic-inequigranular. Results of deformation are more pronounced than in the specimen previously described. Quartz appears as inequant grains exhibiting strain shadows, undulatory extinction, and granulation. Feldspar grains have frequently been sliced by cross-cutting fractures, and twinning lamellae are frequently dispaced or warped. Potash feldspar retains a fairly fresh appearance, but inclusions of suassurite and masses of paragonite suggest more prevalent perthitic intergrowths of plagioclase. Plagioclase is usually badly altered to paragonite, and is replaced occasionally by subhedral grains of carbonate. Occasional rounded aggregates of epidote occur, but chlorite is less abundant in this specimen.

The following modal analysis indicates that the rock is leucogranite. It will be noted that the feldspar content is almost equally divided between alkalic and sodic varieties; hence the rock is close to quartz monzonite in composition.

Mode of Specimen 6

Quartz	29.4%
Potash Feldspar	36.6
Albite-Oligoclase	32.4
Apatite	0.1
Chlorite	1.5
Magnetite	Tr.
Zircon	Tr.

Specimen 7

A striking example of a highly deformed portion of the granite occurs in an outcrop near the "quartzite" contact zone on the eastern margin of Section 1. Thin bands of mashed feldspar and quartz grains lie in a matrix of dark green, chloritic material. The contrast of the dark matrix with the reddish-orange feldspar intensifies the cataclastic appearance of the rock. The chloritic material comprises about 40% of the rock, suggesting that much of this material has been introduced. The relation of introduced chlorite to deformation will be discussed in greater detail later.

Granite and "Quartzite" Associations

Contacts of the granite with the "quartzite" are highly irregular, and never in the form of broad embayments. The granite generally appears to intrude the "quartzite" as small veins and stringers branching out from a larger granite mass. These granite-"quartzite" contacts are sharp and well defined. Many granite intrusions are bordered by chloritic aureoles which impart a green hue to the normally white "quartzite". In addition to the chlorite, an aureole often contains a number of small, blocky masses of reddish-orange feldspar. These "dents de cheval" are in striking contrast with their fine-grained "quartzite" host. Specimens 2, 3, and 4 are representative samples of the "quartzite" and granite from a contact typical of that described above.

In a number of instances, small pods, lenses, and stringers of granite occur as sub-parallel inclusions in the "quartzite". Contacts of these inclusions with the host rock are diffuse, and the inclusions have no visible connections with a larger parent body; although, in places, the inclusions become so numerous that the resulting rock is essentially granite. Specimen 29 is a typical example of this migmatitic association.

Specimens 3 and 4 - Contact Zone Granite

The granite occurring in the contact zones does not have the gneissoid appearance characteristic of those specimens previously described; however, it is similar in most other respects.

Under the microscope, the granite shows a fine to medium-grained, hypidiomorphic texture. Many grains have suffered marked cata clasis, resulting in a wide range of grain sizes. Potash feldspar occurs in much larger grains than does plagioclase. Microcline is present, but most of the potash feldspar exhibits no twinning. The plagioclase is albite-oligoclase (86-91% Ab), most commonly exhibiting albite twinning. Lobate patches of quartz appear to corrode both types of feldspar along grain boundaries and cleavage planes. Small islands of very fine-grained quartz, probably remnants of the "quartzite" host, frequently occur. The most distinctive feature of the contact zone granite is the development of two types of chlorite. Penninite occurs sparsely, and is probably an alteration of the original ferromagnesian constituents. The second variety of chlorite (prochlorite?) is very plentiful, comprising about 7% of the rock. This mineral is light green in color, faintly pleochroic, and has greater relief than penninite. It forms radiating, fibrous clusters which form patches and continuous vein-like masses. It is a late mineral, cutting all other minerals in the rock, and is probably hydrothermal in origin. Hematite (martite?) accompanies this mineral.

With the elimination of the prochlorite (?) and remnants of "quartzite", a modal analysis of specimen 3 demonstrates that the rock is a leucogranite of essentially the same composition as that of the specimens previously described.

<u>Mode of Specimen 3</u>

Quartz	31.3%
Potash Feldspar	36.4
Albite-Oligoclase	31.6

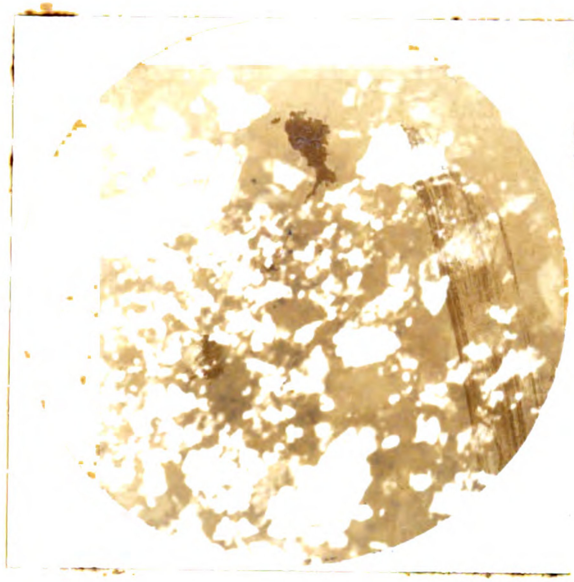


Fig. 6 - Photomicrograph (20X) of Spec. 3 showing granite with inclusion of "quartzite".

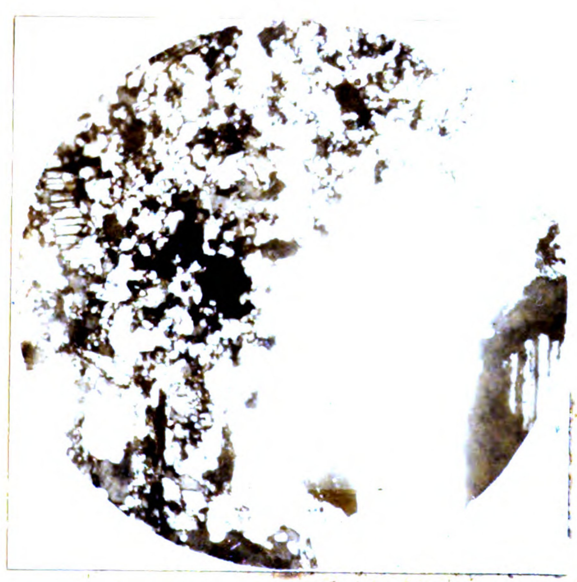


Fig. 7 - Photomicrograph (60X) of Spec. 2 showing "quartzite" with quartz vein and introduced chlorite and feldspar.

Apatite.................	Tr.
Chlorite (Penninite)....	0.6
Magnetite...............	0.1
Zircon..................	Tr.

Specimen 2 - Contact Zone "Quartzite"

"Quartzite" occurring near the granite contact on the eastern margin of Section 1 is a dense, fine-grained, light green, quartzose rock, containing small masses of introduced feldspar, and cut by a network of quartz veins. These quartz veins also cut the granite. As mentioned previously, an aureole is frequently developed in the "quartzite" bordering a granite intrusion. Within several feet of the contact, the normally white "quartzite" assumes a green hue, which intensifies toward the contact. Blocky, reddish-orange masses of potash feldspar are scattered throughout the aureole, and occur with greater frequency toward the contact. These "dents de cheval" often attain a diameter of 1 cm. As seen under the hand lens, they are actually intergrowths of potash feldspar, with lesser quantities of clear quartz and greenish-black chlorite. Furthur examination reveals that they are closely associated with the numerous quartz veins cutting the contact area. Although many of these feldspar masses are enclosed in the quartz veins, the majority appear to be concentrated just outside the vein boundaries.

Microscopically, the "quartzite" is an aggregate of microcrystal line quartz and flakes of chlorite. The clear, unstrained quartz veins, with an average size of 0.02 mm., form a fine, even-textured mosaic. Much smaller flakes of light green, slightly pleochroic chlorite are randomly oriented throughout the quartz mosaic. Many quartz veinlets cut the "quartzite". Vein quartz is readily distinguished from the quartz of the host rock by its coarseness, sutured boundaries, abundant inclusions, and strain shadows. Coarse-grained aggregates of potash feldspar, plagioclase, quartz, and chlorite (the dents de cheval) appear to be closely related to the veinlets. Where they occur as islands in the host rock, the aggregates are surrounded by an envelope of coarse quartz. Potash and plagioclase feldspars are both highly altered. Patchy perthitic intergrowths of plagioclase in potash feldspar are common. Quartz appears to invade the potash feldspar as lobate masses along grain boundaries and cleavage traces. Shreds of chlorite surround many feldspar grains. This chlorite contains many small anhedral magnetite grains. Determination of the plagioclase is difficult because of the lack of sufficient grains in a condition suitable for the required measurements. The probably unreliable results obtained indicate a composition of 92% Ab. The extensive alteration in the specimen suggests that some of the plagioclase is probably secondary.

Specimen 29 - Migmatitic "Quartzite"

At several locations on the eastern margin of the mapped area, abundant stringers, pods, and lenses of reddish-orange granite occur as sub-parallel inclusions in the "quartzite". The resulting rock has a migmatitic appearance. Migmatite, as used here, describes rocks of mixed igneous and non-igneous aspect, implying that igneous material appears to have been injected into the country rock. The granite inclusions are small, never more than a few inches wide and a foot or so long. Abundant potash feldspar occurs in a finer-grained groundmass of plagioclase, quartz, and chlorite. Contacts of these inclusions with the "quartzite" are generally gradational. The "quartzite" is a very fine-grained, dense, white rock. Chlorite appears to develop only in the granite inclusions; aureoles do not seem to develop in the bordering "quartzite". At the locality where specimen 29 was collected, the migmatitic "quartzite" grades into a rock which is so thoroughly saturated with inclusions that it is, for all practical purposes, a granite.

Under the microscope, the migmatitic "quartzite" exhibits a confused jumble of badly altered feldspar, coarse quartz, and chlorite, set in a groundmass of microcrystalline quartz. The feldspar-quartz-chlorite aggregates form vein-like masses and isolated patches. The feldspars are often subhedral, and fracturing and granulation are prevalent. All of the feldspars have altered in some degree to paragonite, and are replaced by chlorite and quartz; however, twinning is still visible. Chlorite contains abundant opaque inclusions. Feldspar grains are usually surrounded by masses of quartz, which often develop a distinctive, radiating comb structure. Much of the coarse-grained quartz occurs in linear, vein-like bodies. The groundmass is an equigranular mosaic of microcrystalline quartz, with an occasional flake of white mica. Grains of the microcrystalline quartz are unstrained, free of inclusions, and of rather uniform size, averaging 0.025 mm.

A Note on Granitization

The development of "dents de cheval" and the

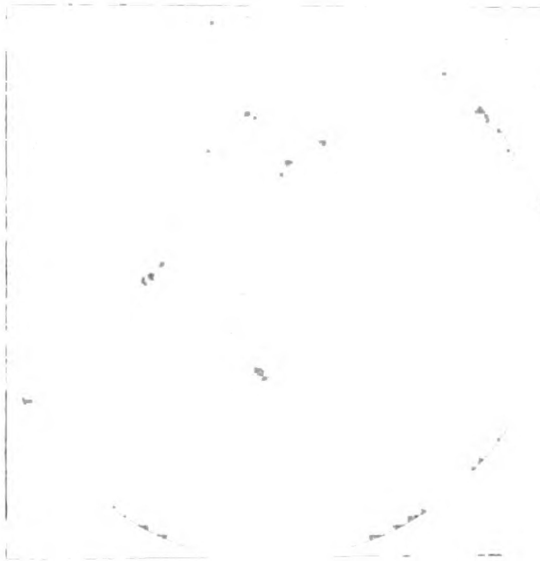


Fig. 8 - Photomicrograph (20X) of Spec. 16 showing the equigranular fabric of typical "quartzite".

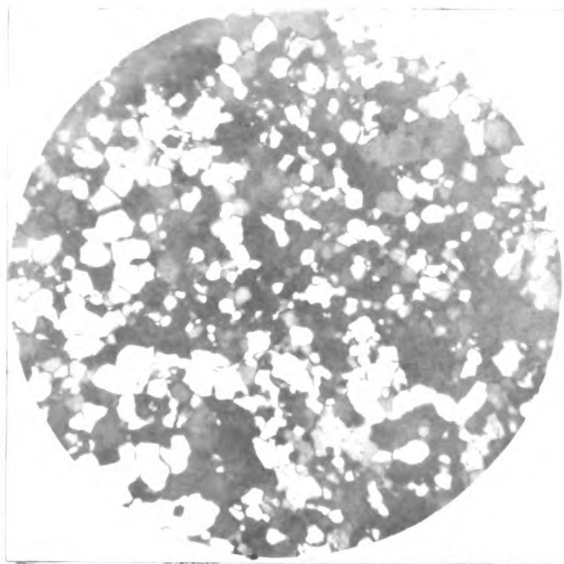


Fig. 9 - Photomicrograph (60X) of Spec. 20 illustrating the mosaic texture of the "quartzite".

migmatitic character of some of the granite-"quartzite" associations suggests that the "quartzite" has been partially granitized. An increase in the effect that the granite produces in the "quartzite" at the contact could terminate in the development of granite, and the present situation may represent an arrested phase in a process of granitization. It has been demonstrated that granitic material has been introduced into the "quartzite", but the present study has not yielded sufficient data to properly evaluate the process by which this was accomplished.

Typical "Quartzite"

Specimens 16, 18, 20, 23, 24

The varieties of "quartzite" previously discussed actually have very limited occurrence in the mapped area. The bulk of exposed "quartzite" is a white, homogeneous, quartzose rock which shows no evidence of feldspathization. This typical "quartzite" forms the ridge trending across the north half of Section 1 and the small hill in the SW¼ of the section.

In outcrop, the "quartzite" is a strongly jointed, massive rock, thoroughly cut by a network of quartz veins. Hematite staining frequently imparts a dull red color to the rock. The "quartzite" shows no evidence of bedding or foliation. Several zones were noted in which the rock was strongly sheared and brecciated. Throughout most of its exposure, the "quartzite" has a remarkably uniform, fine-grained appearance. Exposed surfaces have acquired a dull polish, which accentuates the sub-conchoidal fracture of the rock. Broken surfaces exhibit a fine, sugary texture. Individual grains are not easily distinguished, even with a handlens. Close examination of a broken surface discloses numerous small, angular cavities lined with a coating of hematite. These vugs are small, the largest rarely exceeding 1 mm. in diameter. They probably mark the occurence of an easily soluble mineral, such as a carbonate, which has since been dissolved. Hematite staining, developed in minute fractures and any available pore space, is always present, often prevalent. Quartz veins vary in size from a fraction of an inch to several feet. Quartz crystals are well developed in the larger veins.

Microscopically, the rock is a fine-grained aggregate of microcrystalline quartz. The crudely polygonal quartz forms an equigranular mosaic fabric. Essentially all of the 500 grains measured in 5 thin sections of typical "quartzite" fall within the 0.025-0.050 mm. size range; grains in the 0.0125-0.025 mm. and 0.050-0.075 mm. ranges comprise only 3% of the total measured. There is no noticeable variation in grain sizes between specimens. The quartz is usually free of inclusions, although some grains contain dust-like material (hematite?). Individual grains exhibit uniform extinction under crossed; undulatory extinction and strain shadows do not appear. Linear to strongly bifurcating quartz veinlets are abundant in all specimens studied. Vein quartz is distinctive and easily distinguished from the microcrystalline quartz of the groundmass. The grains are large and, as a rule, at least five times larger than the microcrystalline quartz grains. Inclusions are numerous and heterogeneous, with hematite dust the most common. Vein quartz grain boundaries are generally sutured, in contrast with the sharp, straight boundaries of quartz veins in the groundmass. A rudimentary cockscomb structure is developed in the larger veinlets. Strain shadows are prevalent. Sericite, hematite, and rare chlorite are the only other minerals of significance in the "quartzite". All appear to be secondary. Small sericite flakes occasionally occur in the quartz mosaic; more commonly, the sericite fills thin seams which randomly cut the fabric of the rock. Hematite, in concentrations of dust-like particles and small anhedral grains, occurs in the vein quartz and as a coating in cross-cutting fractures. In several instances, hematite was observed in long, slender, pinch-and-swell concentrations, apparently following minute fractures. An interesting, but uncommon, occurence of hematite is as dust-like concentrations outlining a hollow rhombohedral form, superimposed on the quartz mosaic. It is possible that the rhombohedral outlines are relics of a now completely replaced carbonate. This is substantiated by the frequent angular cavities visible in hand specimens. It is difficult to determine whether such a carbonate was an original constituent of the "quartzite" or was later introduced. It may be significant that the outlines appear to have no definite relation to the present veinlets. Chlorite appears in specimen 18, which was collected from the outcrop on the SW¼ of the mapped area. The chlorite occurs in patches of small, light green, slightly pleochroic flakes which have formed along fractures in the rock.

In summary, the typical "quartzite" is a fine-grained, equigranular, massive rock containing 97.5 - 99.5% microcrystalline quartz; 0.5 - 2.0% hematite; trace - 0.5% sericite; and 0 - 1.5% chlorite. Vein quartz is abundant in all samples.

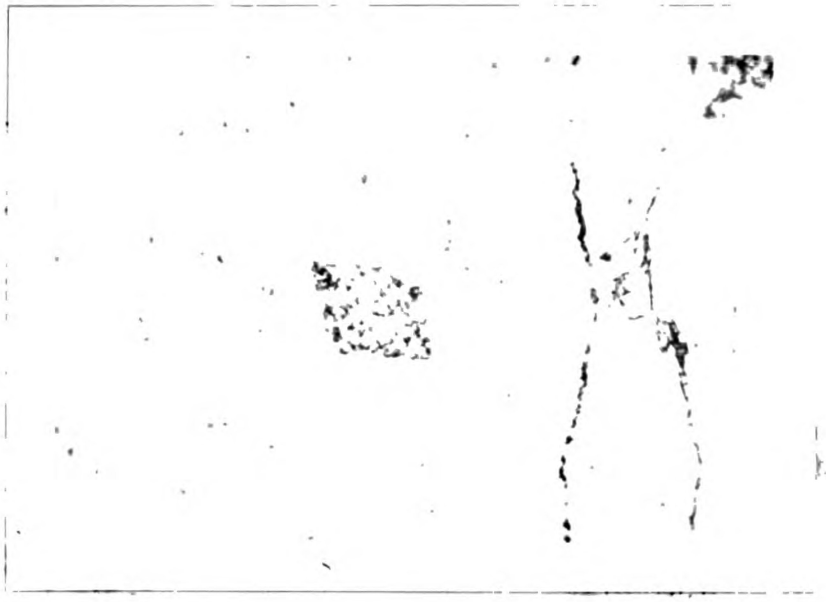


Fig. 10 - Photomicrograph (100X) of Spec. 23 showing modes of occurrance of hematite (black) in the "quartzite" (grey). The rhombic outline may represent a relic carbonate crystal.

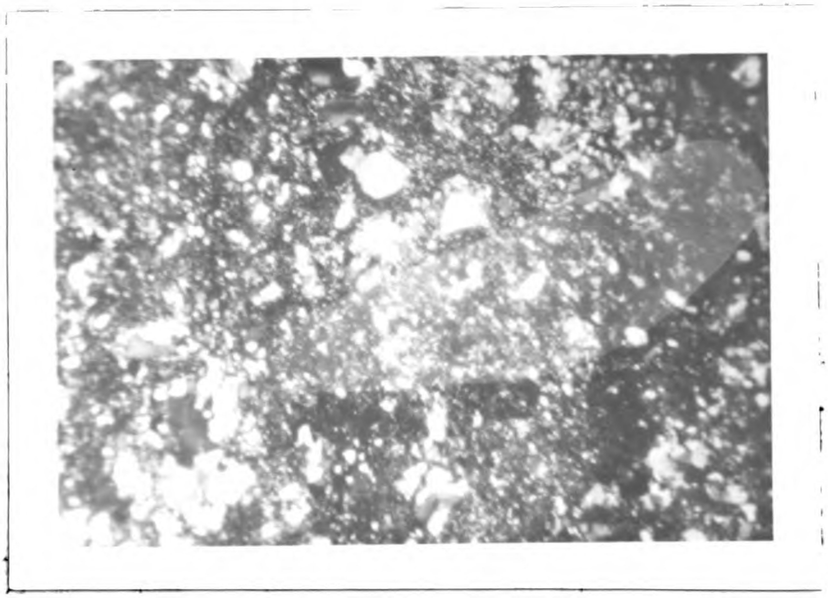


Fig. 11 - Photomicrograph (32X) of Spec. 41 showing the cataclastic nature of the groundmass of the pseudoconglomerate.

Deformed "Quartzite"

Specimens 9 and 41 - Pseudoconglomerate

Intense deformation of portions of the "quartzite" body is indicated by zones of a distinctive, highly brecciated rock. This rock resembles a badly deformed conglomerate and is called, for convenience, pseudo-conglomerate. An excellant example of a deformation zone containing pseudoconglomerate is exposed west of the ridge, in the western portion of the mapped area.

A zone of pseudoconglomerate, approximately 5 feet wide, strikes roughly east-west and dips steeply to the north. The zone is flanked on both sides by typical "quartzite". Contacts are gradational and appear to be irregular, both laterally and vertically. Angular to rounded fragments of white "quartzite", in a great variety of shapes and sizes, lie in a greenish, fine-grained matrix. The matrix weathers easily, causing the "quartzite" fragments to stand out in bold relief. The fragments appear to have a vague E-W lineament.

Under the microscope, the rock is seen to be composed of angular to subrounded fragments of "quartzite" strewn about in a fine matrix of granulated quartz and small flakes of chlorite and sericite. The marginally granulated fragments of "quartzite" clearly demonstrate the cataclastic deformation of the "quartzite". Undulatory extinction has developed in some of the quartz grains of the fragments, but it has developed to a much greater degree in the fine quartz grains of the matrix. The fine quartz grains of the matrix appear to have resulted from the milling and crushing of the rock; they are exceedingly fine-grained, generally smaller than 0.0125 mm. The chlorite occurs in small flakes and radiating, fibrous clusters; it comprises as much as 20% of some of the specimens examined. It is the same chlorite previously described as prochlorite. An X-ray powder diffraction pattern discloses d spacings of 13.9 Å, 1.54 Å, and 7.08 Å, indicating that the mineral is a chlorite. The mineral has probably been introduced, and is prevalent in those portions of the "quartzite" which have suffered deformation. Sericite occurs in thin seams and scattered flakes throughout the matrix. Lamination, which would be expected in the matrix of so deformed a rock, does not appear; it may have been destroyed by the development of the introduced minerals.

Dike Rocks

Two cross-cutting, basic dikes occur in the "quartzite". Rock in one of the dikes is schistose and highly altered, but the rock in the other is undeformed and fresh in appearance. The lack of deformation and alteration in the latter suggests that this dike is much younger than the altered dike.

Specimen 15 - Meta-diabase

The older dike occurs on the small hill in the SW¼ of Section 1. The rock is deeply weathered, and the location of the dike is now marked by a trench-like depression in the "quartzite". The 7 foot wide dike strikes N 45 W and dips approximately 70° NE. Boundaries of the dike are irregular, no doubt a reflection of the deformation the rock has undergone.

The rock is a dull, green-weathering, fine-grained, schistose meta-diabase. Abundant dark grains of ore minerals pepper the fine-grained chloritic matrix of the hand specimen.

The rock reveals its altered character especially well under the microscope. Infrequent, large laths of altered feldspar and abundant grains of magnetite and rutile are imbedded in a felty groundmass of chlorite, altered feldspar, quartz, and albite. The large, relic feldspar laths, occasionally 2 mm. long, are now an aggregate of abundant carbonate, sericite, some epidote, and albite (?). The groundmass is composed almost entirely of secondary minerals; the opaque minerals also show signs of alteration. Rounded magnetite grains often alter to martite, and the twinned rutile needles are frequently surrounded by cloudy masses of leucoxene.

Specimen 1 - Olivine Diabase

The younger dike occurs in the western part of the "quartzite" ridge in Section 1. Contacts of this dike with the "quartzite" are not revealed; but the rock is typical of the brown-weathering, olivine diabase dikes which occur as the latest Precambrian intrusives throughout the Lake Superior region. The rock has a very fresh appearance and shows no evidence of deformation.

Quartz Veins

Quartz veins are prevalent throughout the mapped area. They range in width from fractions of an inch to over 3 feet. Generally, the veins are strongly bifurcate, and cut the country rocks randomly; some of the thinner veins in the "quartzite" appear to follow old joint patterns. As a rule, the veins are composed of subhedral to euhedral crystals of clear to milky quartz, always with

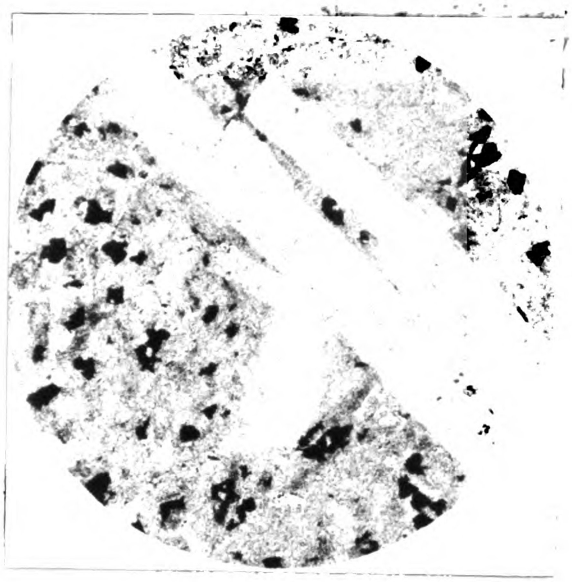


Fig. 12 - Photomicrograph (60X) of Spec. 15, from the meta-diabase dike, showing relic feldspar laths in a groundmass of saussurite, rutile, and martite.

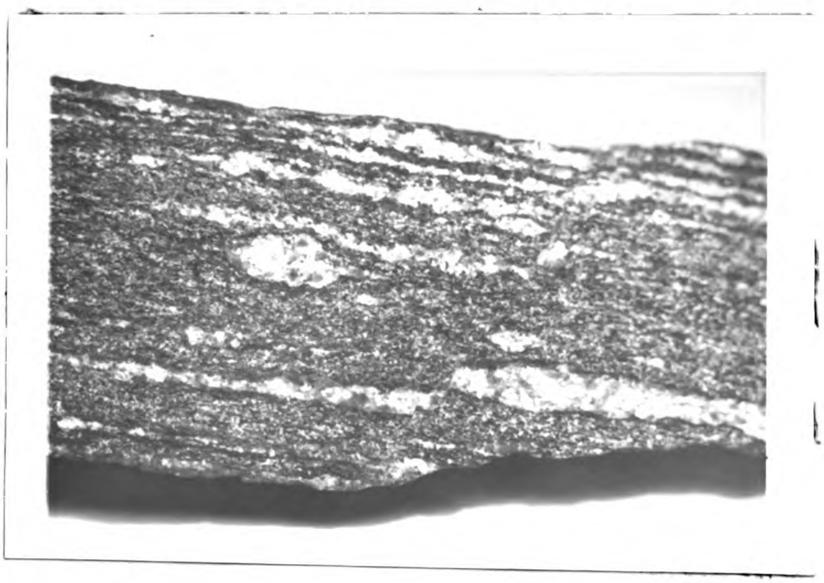


Fig. 13 - Photograph (0.5X) of typical migmatite showing bands of light quartzo-feldspathic minerals alternating with dark ferromagnesian bands.

some hematite mineralization. Frequently, the hematite is so common that it coats the quartz, producing beautiful red quartz crystals. Radiating clusters of greenish-black tourmaline crystals occur in one of the veins examined. Quartz veins occurring at the granite contact previously discussed contain feldspar; these veins are probably silexite. Field relations indicate varying ages of quartz veins. Further study will probably disclose several genetic types of quartz veins in the area.

Migmatite

A broad belt of migmatite lies north, east, and southeast of the "quartzite" outcrops. The migmatite is characterized by alternating bands of ferromagnesian and quartzo-feldspathic minerals, giving the rock a gneissic appearance. The proportion of light and dark constituents is highly variable within short distances. Banding is always steeply dipping, and examples of complex folding are numerous. The reddish-orange porphyritic gneissoid granite is found cutting the migmatite in Section 36.

The major constituent of the ferromagnesian bands is medium to coarse-grained, subhedral to euhedral hornblende; biotite, chlorite, and feldspar are of minor importance. Plagioclase feldspar is prominent in the light bands; quartz, potash feldspar, and some chlorite appear less frequently.

Examples of migmatite from Section 36 are described by Sahakian (1959); he calls the rock an injection gneiss; and considers it to be an injected Keewatin-type greenstone schist.

Granite and Gneiss

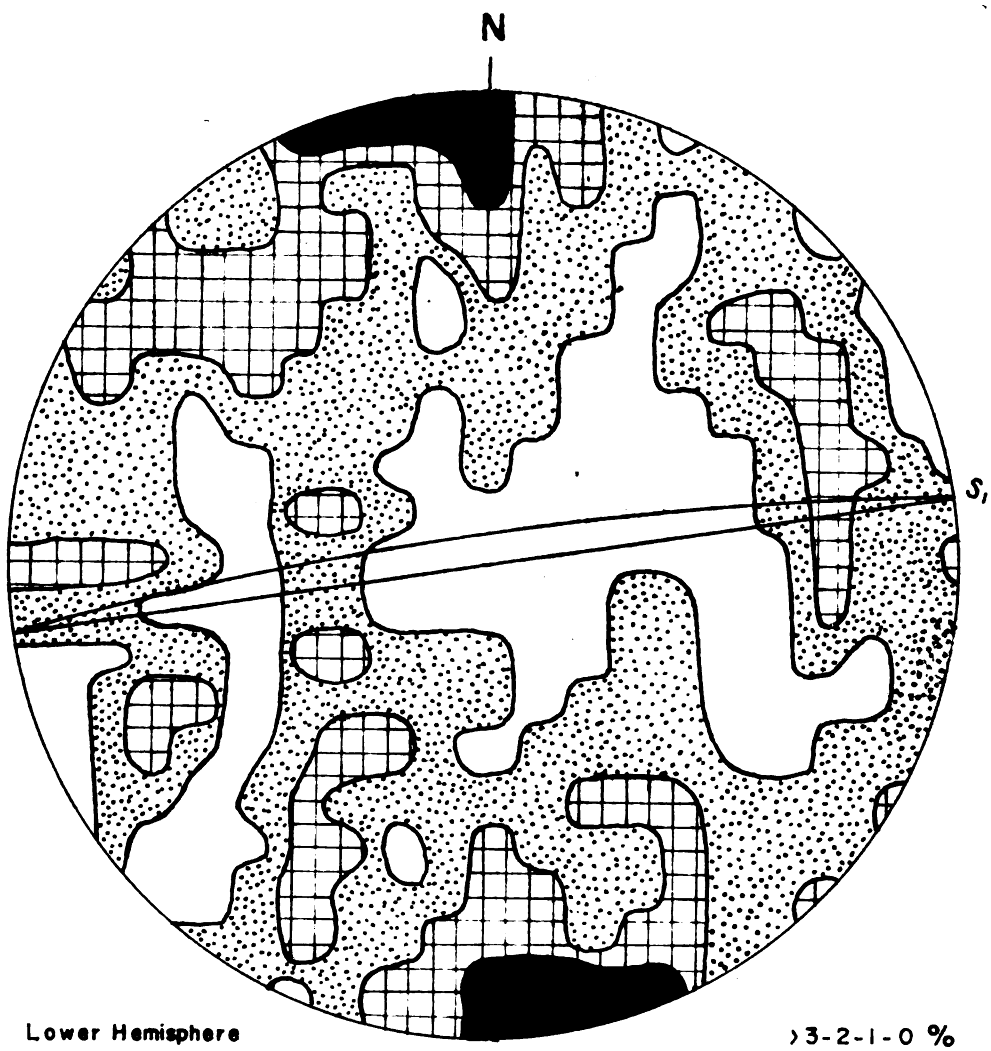
A complex of granite and granite gneiss lies south of the mapped area; these rocks were not examined in detail during the present study. Several varieties of rock occur, and field relations are complex. Some of the granite gneiss is probably migmatite.

Structural Inferences

A detailed study of the structure of the area was not attempted in the present investigation. The regional structure is undoubtedly complex, and local structural elements are seldom sufficiently revealed to permit valid interpretations without detailed study. The following discussion is, for the most part, a compilation of inferences based on widely scattered observations.

The "quartzite" exhibits no definite foliation, bedding, lithologic variations, or other planar elements that would aid in determining its structural setting. The linear, east-west aspect of most of the "quartzite" outcrops may reflect the strike of the formation. It is interesting to note that, although the migmatites are highly contorted, they occur in a belt which curves in a gentle arc, enclosing the area of "quartzite" exposures. The "quartzite" may be part of the same sequence as the migmatites.

The "quartzite" is strongly jointed; but, with the exception of prominent E-W, vertical joints, no pattern is apparent. A detailed study would probably disclose such a pattern. Strong master jointing in the district is readily seen on aerial photographs. No direct evidence of faulting is found in the area studied, but the highly deformed nature of some of the rocks indicates that faulting may have played a prominent role in the structural development of the area. Faults of considerable magnetitude occur in the Palmer area. Shear zones deform the "quartzite" at several places. Figure 14 is a diagram of quartz c-axis orientation in the mylonitic groundmass of the rock from one of these zones. The diagram shows a weak preferred orientation of quartz with respect to the plane of the shear zone.



COMPOSITE DIAGRAM

ORIENTATION 600 QUARTZ C-AXES

Spec. 9a,b

Figure 14.

Metamorphic Rank

All of the rocks examined in the present study bear evidence of metamorphism. The occurrence of chlorite in the granite, migmatite, and dike rocks, and the fine grain size of quartz in the "quartzite", indicate low rank metamorphism typical of the chlorite zone.

ORIGIN OF THE "QUARTZITE"

Lack of diagnostic or distinctive features, such as bedding or relic structures, precludes a ready identification of the "quartzite"; and it is necessary to consider a number of alternatives from among known highly quartzose rocks. Field relations suggest that the "quartzite" might be interpreted as

1. An igneous rock
2. A large mass of vein quartz
3. True quartzite
4. Silicified tuff
5. Recrystallized chert

In the following discussion, each interpretation is considered in light of the data derived from the present study, and conclusions are drawn regarding the feasibility of each interpretation.

An Igneous Rock

Highly quartzose rocks of igneous aspect, although rare, have been noted at various localities. Johannsen (1932, p. 4-25) discusses many examples of such rocks. He states (p. 4) that:

> "they occur in the form of dikes, segregated masses (sometimes quite large), and replacements, but do not form typically plutonic or extrusive bodies."

With the exception of greisen, which is simply an altered granite, the quartzose igneous rocks described by Johannsen have the same mode of origin as pegmatites; that is, they are of "aqueo-igneous magmatic origin."

Tolman (1931) reviews available literature concerning possible igneous quartz masses. He remarks on the paucity of precise and detailed descriptions of the field relations of supposedly igneous quartz bodies; he lists very few criteria which could be considered definitely diagnostic of igneous quartz masses; yet (p. 297), he appears to favor the idea that there is a complete gradation, with increasing quartz content, from typical igneous rocks, through pegmatites and quartz-rich rocks, to hydrothermal quartz veins.

Many workers dispute the existance of a truly igneous rock composed almost wholly of quartz. Furnival (1935, p.505) summarizes this view, stating that:

> "no occurrence of a body of quartz which has undoubtedly formed by the action of magmatic process, that is by direct crystallization from an igneous magma, has been described in the literature."

Furnival considers such quartz masses, as well as pegmatites, hydrothermal in origin.

The present writer agrees essentially with Furnival. The terms silexite and esmeraldite, as defined by Johannsen, are used in the succeeding paragraphs with this qualification: they are igneous rocks only in the sense that they were formed by solutions, perhaps relatively viscous, which emanated from a magmatic source.

Greisen

Association of the "quartzite" with granite suggests that the rock may be a greisen. Johannsen (p. 6) describes greisen as:

> "quartz-mica rocks which originated along fissures in granite by alteration of some of the minerals of the pre-existing rock."

The essential constituents are quartz and mica, with quartz generally in excess. The quartz is similar to that of granite; the mica is generally zinnwaldite. Feldspar, when observed, is greatly altered. Cassiterite often occurs. Greisen exhibits a typically granitic texture.

The secondary nature of greisen is usually apparent, and gradational contacts with the pre-existing granite are frequently exhibited.

If the "quartzite" were greisen, remnants of the pre-existing granite should occur within the "quartzite" mass; however, nowhere were such features observed. There is no evidence that the "quartzite" is derived from a granite older than the present intrusive. Contacts of the "quartzite" with the present granite are not typically gradational. Where contacts are gradational, as in the migmatitic "quartzite", granite appears to develop in fractures in the "quartzite"; the situation would be reversed in a greisen; furthermore, the granite is younger than the "quartzite". Finally, the fine-grained, mosaic texture of the rock is not a texture typical of greisen.

Silexite

Johannsen (p. 11-17) describes silexite as an igneous rock composed essentially of primary quartz, practically free of pneumatolitic minerals such as muscovite and tourmaline, and containing no more than 5% feldspar. He states that the difference between silexite and vein quartz lies in the origin of silexite from juvenile (magmatic) waters. It is very difficult to separate the two types of quartz;

> "only by tracing the connection in the field from pegmatitic rocks, through members poor in feldspar, to pure quartz rocks can the origin (of silexite) be definitely established."

Johannsen further describes the rock as exhibiting alliotropic granular texture, approaching the sutured. The quartz is typically igneous, containing many inclusions which often lie in straight lines. Bodies of silexite are not large; generally, the rock occurs as veins, dikes, or inclusions in granite masses.

Miller (1919) describes a typical occurrence of this rock with its aplitic and pegmatitic associates. The masses of silexite which he describes are quite small, being measured in tens of feet. They have the aspect of inclusions in the main granite mass. Gradational contacts of the silexite with granitic rocks frequently occur.

Although the composition of the "quartzite" is similar to that of silexite, the rock does not appear to be silexite for a number of reasons. The fine-grained mosaic texture of the "quartzite" does not resemble the jumbled aggregate of irregular grains characterizing the texture of silexite; feldspar is not present as a primary constituent of the "quartzite"; the quartz does not contain the abundant inclusions so characteristic of the quartz of silexite; no gradation of the "quartzite" with known granitic rocks is apparent; and, finally, the great size of the "quartzite" masses is not typical of known silexite occurrences.

Esmeraldite

Johannsen (p. 19) describes esmeraldite as:

> "those quartz-muscovite rocks which occur as diaschistic masses of large bodies or as diaschistic dikes, and which may be the result of original differentiation or of resorption processes antedating the complete consolidation of the rock."

Esmeraldite is a fine to coarse-grained rock composed essentially of quartz and muscovite. The quartz and mica exhibit typical igneous characters and occur in varying proportions. The rock often occurs as a border phase of granite.

Much the same arguments as were used in the case of greisen and silexite can be used to show that the "quartzite is not esmeraldite. The "quartzite" simply does not exhibit an igneous character. In addition, the "quartzite" does not contain abundant primary mica, such as one would expect in esmeraldite.

A Large Mass of Vein Quartz

"Quartzite", which is more resistant to erosion than the surrounding rocks, forms the long, linear ridge extending across Section 1 in the mapped area. The strongly linear aspect of this occurrence resembles that of a large quartz vein. Such a quartz vein would have a minimum width of 150 feet and a length of over half a mile. Quartz veins of such magnitude are rare, but do occur. Furnival (1935) describes large quartz veins occupying fault zones at Great Bear Lake, which attain maximum widths of up to 1000 feet and lengths measured in miles. He states (p. 847) that the veins

> "generally consist of two parts; the main part is composed principally of quartz with minor amounts of vein breccia; this is flanked by stockworks of quartz stringers on one or both sides...Minerals other than quartz are sparse. They are specularite, bornite, chalcopyrite..."

He finds that the quartz of the veins is of two main types: massive and banded. The banded quartz is either milky or transparent and colorless; banded quartz is coarse-grained. The massive quartz is medium to coarse-grained and milky, showing no uniformity in texture. He also notes chalcedonic quartz, which is a matrix for quartz fragments.

Adams (1920) discusses the microscopic features of the varieties of quartz which occur in hydrothermal vein deposits. Most of the varieties he describes exhibit properties, such as comb structure, which are typical of minerals growing in open spaces.

Aside from the linear nature of the outcrops, there is little evidence that the "quartzite" is a vein deposit. No banding or stockworks, as described by Furnival, are found; and the rather uniform grain size of the "quartzite" contrasts with the wide grain size variation in the massive quartz at Great Bear Lake. Comb structure, coarseness of grain, and other evidence of open-space growth is lacking. No diagnostic hydrothermal minerals are associated with the quartz. Quartz veins which cut the "quartzite" exhibit typical properties of vein quartz, and are in marked contrast with the fine, even-grained texture of the "quartzite".

A True Quartzite

Quartzite, in the strict sense used here, is a metamorphosed sandstone. The pre-existing sandstone has been partially or completely recrystallized to form a granular metamorphic rock consisting essentially of quartz. The composition of quartzite reflects that of the pre-existing sandstone; thus, the abundant quartz in a quartzite is accompanied by small amounts of feldspar and other detrital minerals. Cementing material of the sandstone may be re-crystallized in the quartzite, and new minerals may be introduced by solutions. Original structures of the sandstone, such as bedding, cross-bedding, and ripple marks may be preserved in the quartzite. Where metamorphism has not been intense, a quartzite can be treated in the field as a sedimentary rock. With increased metamorphism and deformation, quartzite gradually loses its sedimentary character, foliation develops, and the rock gradually becomes a quartz schist, then a quartz gneiss.

Under the microscope, quartzite generally exhibits a sutured or mosaic texture. The rounded grains of the sandstone have been squeezed together and enlarged by secondary growth. When a mosaic texture has developed, the original rounded grains may appear as nuclei in the new polygonal grains. Assuming that no large-scale fracturing or granulation occurs, the range in grain size of a quartzite should reflect that of the prior sandstone. Increased deformation causes a development of lenticular grains arranged in sub-parallel fashion, and undulatory extinction and strain shadows become prevalent. Intense granulation and mylonitization sharply reduce grain size.

Although the "quartzite" is similar mineralogically to a very pure quartzite, few of its remaining properties closely resemble those of a true quartzite. Evidence of primary sedimentary features is lacking in the field and in thin section. Even if such structures had been destroyed by metamorphism, relic bedding, in the form of foliation, might be expected. The "quartzite" has no visible foliation. Under the microscope, the "quartzite" exhibits a fine, equigranular, mosaic texture; close examination discloses no evidence of original rounded grains. Virtually all of the grains in the rock are below 0.08 mm. in size; thus, disregarding secondary enlargement, original sedimentary grains would have to have been close to silt size. It is improbable that a formation as thick, pure, and uniformly textured as the "quartzite" would have developed from very fine-grained clastic material. The euhedral, unstrained nature of the quartz, and the lack of foliation or recognizable orientation do not suggest the development of the fine grain size by deformation.

Silicified Tuff

It is possible that the "quartzite" and the migmatites are part of the same sequence, although the present study discloses no direct evidence of such a relation. Nevertheless, the "quartzite" occurs in a terrain dominated by the migmatites; field relations demonstrate that the reddish-orange granite is not genetically related to either rock. The high proportion of ferromagnesian constituents and the relict foliation in the migmatite render it likely that the rock has been a greenstone schist. A volcanic character is inferred, warranting consideration of the "quartzite" as a possible silicified volcanic rock.

Silicified volcanic rocks occur in the Precambrian of many regions, notably in Scandinavia. Sederholm (1930) describes the gradation of strongly metamorphic leptite into slightly metamorphic hälleflinta. Leptites are fine-grained, schistose, quartz-feldspar rocks derived principally from acid volcanics. Hälleflinta is a fine-grained metamorphic rock of volcanic derivation, and is essentially a silicified tuff.

Pettijohn (1957, p. 336) discusses the alteration of tuffs:

> "One of the earliest changes in tuffs is the deposition in them of hydrated silica-opal and chalcedony. Complete silicification leads to the conversion of the friable, porous tuff to a dense flinty rock which closely resembles rhyolite, novaculite, jasper, and so forth. Tuffs may be mistaken for such rocks in the field. In thin section, however, the vitroclastic character may remain and this feature together with the composition and form of the associated crystals and their chemical composition will serve to prove their pyroclastic origin...Devitrification commonly accompanies the alteration...Careful study in ordinary light may disclose shards, threads, cusps,

> vesicles, and the like, of the original glass. The devitrification produces a montmorillanite clay...Metamorphism superimposed on other alterations may completely obscure the original nature of the deposit."

Pettijohn (1943), in his excellent treatise on Archean sedimentation, describes the alteration of Archean volcanics in the southern Canadian Shield. He mentions that, although mineral changes are pronounced, the megascopic textures and structures are well preserved.

Adams (1920, p. 642) finds that in silica replacement of rocks

> "where there is a variation in the character of the original contituents, the grain of replacing silica may change according to the particular portion of the rock attacked. Thus feldspar silicified in a tuff may be replaced by coarser grained quartz than the groundmass."

The geologic environment of the "quartzite" is considered favorable for the development of volcanic rocks, and it is possible that the "quartzite" is a silicified tuff. Granitic rocks of several ages are present in the district, and may represent magmatic sources for the silica. It is possible, if the "quartzite" and migmatite represent pre-existing tuff and lava, that the same agent which formed the migmatite also silicified the tuff. Conclusive evidence of a volcanic origin of the "quartzite" is lacking, however. Structures resembling relicts of the glass, crystal fragments, and rock debris which would be inherited from a pre-existing tuff were not observed in the fine, equigranular fabric of the "quartzite". The unstrained quartz grains and the non-foliate character of the "quartzite" fabric do not indicate deformation of a magnitude sufficient to destroy relic tuff structures such as lamination. The extreme purity of the "quartzite" would not be expected in a silicified tuff; significant amounts of alumina, soda, and lime should appear.

Recrystallized Chert

Chert is a dense, highly siliceous rock composed of chalcedony and cryptocrystalline quartz. Young cherts contain opaline material which gradually loses its water content and becomes crystalline. Under the microscope chert is a colorless, extremely fine-grained, microcrystalline rock. Carbonates, clay minerals, or iron oxides may be present as admixtures in the chert. Metamorphism of chert induces recrystallization to a fine-grained quartz mosaic. All Precambrian cherts exhibit recrystallization.

The present study has shown that the "quartzite" is a massive, dense, highly quartzose rock, the fabric of which is a fine-grained mosaic of quartz.

It is evident that the "quartzite" exhibits the petrographic properties of recrystallized chert; however, petrographic similarity alone does not prove that the "quartzite" was originally deposited as chert. Chert typically occurs in the Precambrian of northern Michigan as nodular inclusions in various meta-sedimentary rocks or as a rhythmically banded, thin-bedded iron formation facies. In contrast, the massive "quartzite" forms a thick body showing no evidence of a rhythmic, thin-bedded character. Therefore, a conclusion that the "quartzite" was originally deposited as chert must be based on a satisfactory explanation of the anomalous thick, massive character of the formation.

The properties of a sedimentary rock reflect the tectonic environment in which it was deposited; hence, the thin-bedded iron formation cherts may form in an environment different from that in which a thick, massive body of chert might form. Pettijohn (1943) and James (1954) have shown that the meta-sedimentary and volcanic rocks of the Lake Superior region can be grouped into orogenic and epeirogenic facies.

The epeirogenic facies is typical of stable shelf and restricted basin environments. Carbonates and well-worked clastic sediments are deposited in seas which transgress low, slowly subsiding landmasses. The development of restricted basins or the extreme planation of a landmass may be marked by major chemical deposition of iron and silica-rich sediments. It is in this environment that rhythmically banded, thin-bedded cherty iron formation is deposited.

The orogenic facies is a characteristic of the rapidly subsiding, volcanic, eugeosynclinal environment. Poorly sorted clastic sediments pour into a rapidly sinking basin, and are interbedded with lavas and pyroclastic sediments. Pillow lavas, associated with radiolarian cherts, argillites, and graywackes, occur in the deeper protions of more rapidly subsiding eugeosynclines. Kay (1951, p.86) mentions that some eugeosynclines may have great thicknesses of carbonates and abundant chert when sinking of the basin was independent of any rising of positive belts. Thick formations of bedded chert occur in many known eugeosynclinal belts, for instance, as in the Fransiscan belt of California and the Ouachita system of Arkansas and Oklahoma. The occurance of novaculite in the Ouachita system is of particular interest. Novaculite is a dense, highly siliceous rock, essentially a thickly bedded chert. Griswold (1890, p.94) states:

> "Five or six hundred feet is the most common thickness of the novaculite formation, which generally includes some flinty shales and soft shales or sandstones. The novaculites proper

> are the prominent members of the formation, however, and occur in massive beds from a few inches to twelve or fifteen feet in thickness...The massive beds are so closely associated that there often appears to be no parting between them, but stratification lines are indicated in quarries by thin seams of clay."

It is evident from the above discussion that the thick, massive character of the "quartzite" is a property also of novaculite. The anomalous nature of the rock is simply an expression of its origin in an environment differing from that of the typically thin-bedded chert occurring in northern Michigan. A description of the "quartzite" as recrystallized novaculite best explains all observations made on the rock during the present study. The term meta-novaculite is suggested to describe the "quartzite" more adequately.

AGE OF THE META-NOVACULITE

Radioactive age determinations of the granites in the district are not available, and the writer must rely on more qualitative methods in an attempt to establish the age of the meta-novaculite.

Pre-Keweenawan age is indicated by the presence of the olivine diabase dike.

Pre-Clarksburg age is probably indicated by the sheared, meta-diabase dike. This dike represents two deformational periods, and is obviously older than the undeformed olivine diabase dike.

Pre-Huronian age is suggested by several lines of reasoning:

The present study has established that the malacon-bearing, reddish-orange, gneissoid, porphyritic granite is younger than the meta-novaculite. The presence of malacon indicates a later pre-Huronian or Huronian age according to Tyler et al (1940). Most workers recognize only pre-Huronian and post-Huronian granites in the district (James, 1958). It is improbable that post-Huronian granite would have the highly deformed character exhibited by the reddish-orange granite because its emplacement would have been contemporaneous with the latest orogeny in the area. The writer considers the reddish-orange granite to be of highly probable pre-Huronian age.

Van Hise and Bayley (1897, p. 239-240) note the occurrance of chert and "quartz rock" fragments in a conglomerate at Pelissier Lake, about 5 miles NNE of the thesis area. They mapped the conglomerate as basal Mesnard, and note that chert pebbles are not found in the basal Mesnard on the north rim of the Marquette synclinorium. It is possible that the meta-novaculite is the source of the chert and "quartz rock" fragments mentioned by Van Hise and Bayley;

and, if the conglomerate is truly basal Mesnard, a pre-Huronian age of the meta-novaculite would be indicated.

The writer postulates a eugeosynclinal depositional environment for the meta-novaculite. Deposits characteristic of this environment occur in the Marquette district, but they are restricted to the Upper Huronian slate-graywacke-volcanic sequence. It is doubtful that the meta-novaculite is that young. Lower Precambrian terranes of the Lake Superior region are typically of the eugeosynclinal facies (Pettijohn, 1943).

Possible Contemporary Rocks

Friedman (1959) describes a recrystallized chert facies in a greenstone-tuff-shale environment north of Lake Huron. This occurrance is similar in many respects to the meta-novaculite.

Lamey (1935, p.1153) describes quartzite occurring in part of the Palmer Gneiss belt. Although he considers this to be Mesnard quartzite, his description of the rock is sufficiently similar to that of deformed portions of the meta-novaculite to warrant a closer examination of that occurrance.

James (1958, p.31) mentions inclusions of quartzite in a strongly deformed Lower Precambrian granite gneiss occurring in Dickenson County.

CONCLUSIONS

The present study discloses that the "quartzite" occurring in the Southern Complex near Palmer, Marquette County, Michigan is a massive, fine-grained, highly siliceous rock that is essentially an equigranular fabric of microcrystalline quartz.

It is concluded that the "quartzite" is a recrystallized novaculite, called meta-novaculite, of probable Lower Precambrian age.

SUGGESTIONS FOR FURTHUR STUDIES

The northeastern portion of the Southern Complex is virtually unmapped, and the many square miles of complex igneous and metamorphic rocks present a challenge to the Precambrian geologist. Aside from general mapping of the Complex, the writer reccommends the following:

1. Close mapping of the migmatites to establish their relation to the meta-novaculite.
2. An examination of the quartzite occurring in the Palmer Gneiss belt to determine whther it is meta-novaculite.
3. A study of the granitization and contact phenomena at meta-novaculite-granite contacts.

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