ORIGIN AND PETROLOGY OF A PORTION OF THE SOUTHERN COMPLEX NEAR PALMER, MARQUETTE COUNTY, MICHIGAN

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ORIGIN AND PETROLOGY OF A PORTION OF THE SOUTHERN COMPLEX NEAR PALMER, MARQUETTE COUNTY, MICHIGAN

by

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ABSTRACT

The writer has mapped a small area south of the New Richmond Mine in Section 34, T47N, R26W, Marquette County, Michigan. The area lies on the hilly, heavily wooded northeastern corner of the Southern Complex at its contact with basal Huronian formations.

The dominant rock in the area is an Upper Precambrian orange granite which intrudes Middle Precambrian green slates and Lower Precambrian gneisses. A Keweenawan olivine diabase dike cuts the granite, placing an upper limit on its age. The granite has undergone one major period of deformation which rendered it slightly gneissose and introduced a well-developed pattern of joints in the area. Hydrothermal agents have been active in altering the feldspar and biotite in the granite.

The slate is schistose near its contact with the intrusion, while the older gneisses had been completely recrystallized before the granite was intruded.

The research revealed no mineralization in the area, but the complex microperthites, complex twin combinations in the plagioclase, and lines of liquid inclusions in the quartz are areas in which future study might be of value.

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INTRODUCTION

Nature and Scope of the Research

The writer first became interested in the Precambrian of Northern Michigan in the summer of 1954 while an undergraduate student at Michigan State University. At the geology field camp under the direction of Drs. Justin Zinn and B. T. Sandefur there was ample opportunity to become familiar with some of the more important geologic problems of the Marquette District. In 1957 when the writer was looking for a problem for the Master's thesis Dr. Zinn suggested mapping a portion of the Southern Complex near Palmer. A small area south of the New Richmond Mine was chosen because it lies near the contact of the Complex with Huronian metasediments.

The research area covers a portion of the Southern Complex south of the Marquette Synclinorium in Section 34, T47N, R26W, Marquette County, Michigan, east of a portion of the Complex called the Palmer Gneiss. If the section is divided vertically into quarters the research area may be defined as that part in the second quarter from the west which lies between Gribben Lake and the old tote road ½ mile north of the lake (Figures 1, 2).

The area can best be reached by the asphalt road which runs east from the town of Palmer to the New Richmond Mine. Southwest of the mine tote roads can be followed by automobile nearly to the line between Sections 33 and 34. From this point it is necessary to walk to the northwest corner of the area.

The terrain consists of low, rough rock-cored hills with many outcrops and a few small cliffs 20 to 30 feet in height. An outcrop which runs along the north shore of Gribben Lake

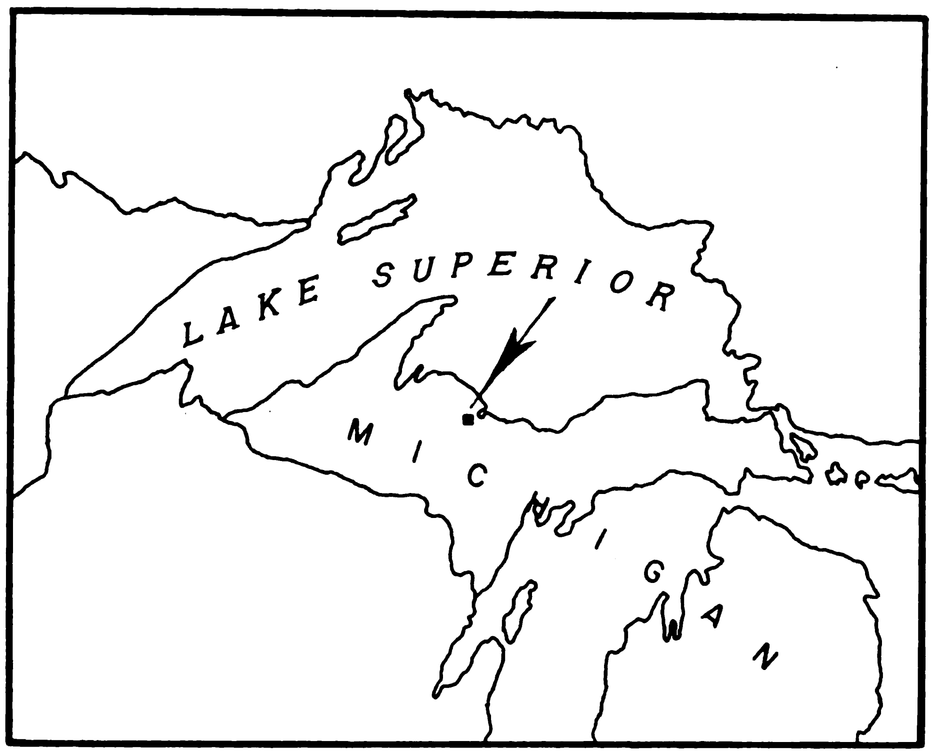


FIGURE I. THE LOCATION OF T47N, R26W IN THE NORTHERN PENINSULA OF MICHIGAN.

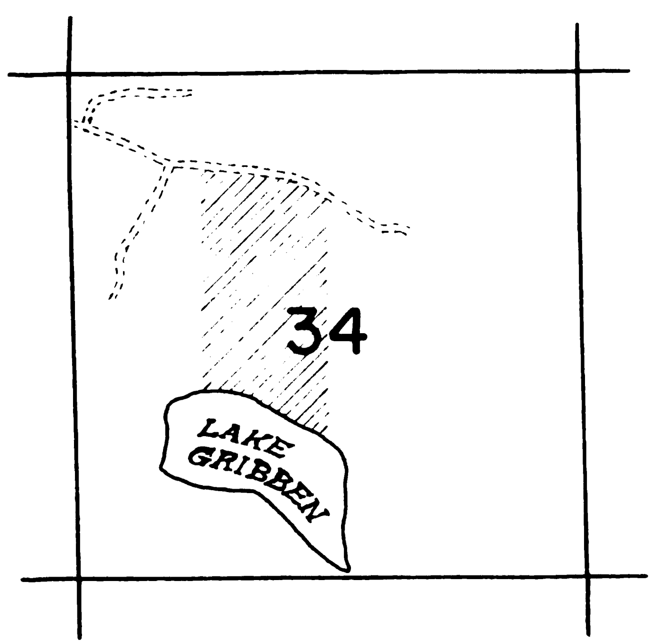


FIGURE 2. THE LOCATION OF THE AREA STUDIED IN SECTION 34, T47N, R26W.

rises from a swamp on the west end to an 80 foot cliff on the east. A few small streams drain eastward into the lake or into the low swampy areas between the hills.

Elevations in the area range from 1215 feet, the elevation of the lake, to 1385 feet. The topographic features have a definite east-west trend, an expression of the regional topography. The area is heavily covered with mixed hardwoods and some pines in the higher portions and spruce and alders in the lower swampy portions. Summers are hot with very cool nights; fall and spring are mild but have a considerable amount of rain. Winters are severe, with heavy snowfall and temperatures that often fall below zero.

The Southern Complex itself covers an area of nearly 1400 square miles and includes Precambrian granites, gneisses, and schists, with associated aplites and pegmatites and a few basic intrusives. It is irregular in shape and is bounded roughly by the towns of Palmer, Beacon, Floodwood, Randville, Foster City, and Gwinn. It is overlain to the east by flat-lying Cambrian sediments, but to the south and southwest granites of the Complex with minor occurrences of other rock types extend for many miles.

The dominant rocks in the Complex are gneissoid granites, dull in color and porphyritic, but in the northeastern part which includes the granite of this study, the granite is red to orange and is not porphyritic. Some of the granite in the Northern Complex north of the Marquette Synclinorium resembles the porphyritic granite in the central portion of the Southern Complex and is generally considered to be part of the same body.

Due to the considerable extent and geological complexity of the area, the Southern Complex has not been mapped in sufficient detail to warrant more than intelligent guesswork as to its age and origin. The Complex is typical of many extensive Precambrian areas which stimulate only academic interest because of their lack of economic minerals.

The writer has mapped a portion of the Complex near its contact with basal Huronian formations of the Marquette District south of the New Richmond Mine in the belief that even a small contribution will be of value if it is detailed and unbiased. The petrology of the igneous and metamorphic rocks of the area of study will be presented with possible interpretations as to their origin and significance. The structures in the area continue beyond the limits of the mapped area and are too extensive to be considered in detail in this study.

The field work was done in May, 1958. The writer set up a base camp on the north shore of Gribben Lake and ran north-south traverses to take advantage of the east-west trend of the topography. Mapping was done by pace and compass, the only practical method for an area so difficult to traverse. Approximate mean declination in the area is $\frac{1}{2}^{o}$W (USGS, 1952), a negligible value for pace and compass work. Backsighting was unnecessary as the Negaunee iron formation ½ mile north of the area had no effect on the needle, so with the lake to the south and the tote road to the north, horizontal control did not present a problem. The USGS topographic map and aerial photographs of the area furnished further control. Traverses were run 100 yards apart and every outcrop was examined and sampled. Outcrops are abundant in the entire area except in the low swampy flats between the hills.

Work in the laboratory included a megascopic study of hand specimens from the area and a microscopic analysis of 27 thin sections prepared from selected samples. Megascopic examination of hand specimens gave an overall picture of the variation in the mineral assemblages of the main rock types, after which a more intense study with the microscope gave textural relationships, data on deuteric and hydrothermal effects, and accurate mineral percentages. Thin section work was done with a standard petrographic microscope. Modal analyses were made on a six-barrel integrating stage, using ten traverses per section.

Previous Investigations in the Area

Van Hise and Bayley (1897), in their monograph on the Marquette District, divide the Archean Basement Complex into the Southern and Northern Complexes. Although they found that the granites of the two areas differ in color, degree of metamorphism and size of porphyritic inclusions, they correlate the granites on the basis of their mineralogy. The granites in both areas intrude hornblende and biotite schists which they believe to be "mashed eruptives".

Van Hise and Leith (1911) correlate the ancient schists of the two areas but state that nowhere are they mappable. They find some evidence which points to a clastic origin for the schists.

Lamey (1933, 1935) did a great deal of work in the area, particularly in a belt of schists and gneisses which is commonly known as the Palmer Gneiss. He states that the Palmer Gneisses are Middle and Upper Huronian sediments and that a portion of the Southern Complex which he names the Republic granite intrudes these sediments, proving that the granite is post-Huronian. Keweenawan dikes which cut the granite place an upper limit on its age.

Dickey (1936), in an attempt to "unravel the sequence of granitic intrusions in the area", found three distinct periods of intrusion: 1) the Keewatin schists intruded by a Laurentian granite to form the Archean injection gneiss; 2) a later Laurentian granite porphyry which makes up the greater part of the Complex; and 3) a post-Huronian, Precambrian granite which he called the Killarney although he could not establish its relation to rocks of Keweenawan age.

In a later article Dickey (1938) described the Ford River granite in the southwest corner of the Southern Complex and dated it post-Lower, pre-Middle Huronian. James (1958) has since shown that the quartzite cut by this granite is not Sturgeon, but is a pre-Huronian quartzite.

Tyler, Marsden, Grout and Theil (1940) attempted to date Precambrian intrusives by the type of zircon present; those containing the hyacinth variety were considered pre-Huronian, those containing malacon, later pre-Huronian or Huronian. On this basis they found four periods of intrusion in the Southern Complex: two pre-Huronian, one Huronian, and one post-Huronian.

Zinn (1959) has done a great deal of mapping in Northern Michigan, particularly in the Marquette and Iron River Districts, and believes that portions of the granite in the Southern Complex are definitely the same age as the granite in the western part of the Northern Complex.

PETROGRAPHY AND PETROLOGY

The outcrops in the research area are shown on the map in the pocket. The dominant rock is a medium- to coarse-grained orange granite which is cut by an olivine diabase dike. Near the tote road to the north the granite is fine-grained and contains a great deal of quartz; near the lake to the south it is grey to black and intrudes ancient schists and gneisses. The fine-grained variety in the northern portion of the area intrudes a green slate whose slaty cleavage strikes E-W and dips 70°N.

In the following description and discussion of the more important thin sections the rock types will be treated under four headings: 1) granite, 2) injection gneiss, 3) slate, and 4) basic dikes.

Granite

Local variations within an igneous body may significantly alter the appearance of the rock, particularly in the area under consideration, in which the granite intrudes two different rock types within 500 yards. Thus we may find variations in color and texture which are expressions of varying conditions within the body during its formation or within the country rock, or which are perhaps due to magmatic or metamorphic differentiation. Further changes may occur locally or selectively after hydrothermal solutions and regional metamorphism have played their part.

The granite ranges in color from light red-orange through a dark orange and black variety to grey and black. The amount of biotite present determines whether the rock is light or dark, a difference in 2 or 3% making a striking difference in the appearance of two samples.

There are four joint planes in the granite which are consistent throughout the area: N-S, 75°W; E-W, 45°N; N50°W, 60°SW; and N35°E, 65°SE. An anomalous E-W plane dipping steeply to the south was found in the granite just north of the lake.

Grain size is medium to coarse except in the fine-grained chilled zone or aplitic samples. Orientation of the biotite gives the rock a gneissoid appearance which is not evident in the field and can be seen only upon close examination of a properly oriented fresh specimen.

Four thin sections of the granite are described. Samples 15 and 21 are orange varieties chosen to illustrate local variations in composition, sample 4 is the grey variety near the ancient gneiss, and sample 10 is from the chilled zone.

Minerals evident in the hand specimen are quartz and orange feldspar peppered with aligned flakes of biotite and a few small crystals of pyrite.

In all thin sections containing two feldspars, the microcline is fresh and unaltered while the plagioclase is extensively altered, therefore the few untwinned feldspar crystals present are assigned either to microcline or plagioclase on the basis of their degree of alteration. The possibility that the untwinned "microcline" is orthoclase is a point in question. The probability that orthoclase and microcline can even exist in the same rock is an object of dispute. Johannsen (1932, pp. 137, 185-186) states that they may occur together and gives analyses in which generous amounts of each are present, while Tuttle (1958, p. 98), in a discussion of cooling of magmas, states:

> "Many authors have reported microcline and orthoclase coexisting in granites, apparently on the basis of presence or absence of polysynthetic twinning; in fact, some have reported Rosiwal analyses in which the orthoclase and microcline were differentiated. This criterion for distinguishing the two types is not reliable as untwinned microcline is common, and if some of the grains show a microcline grill probably all the potassium feldspar is microcline."

Current thought seems to favor the order-disorder hypothesis of Barth (1934), in which the Al-Si distribution is ordered in microcline, disordered in orthoclase. Stress may change the crystal from the disordered to the ordered form, marked by a decrease in symmetry from the monoclinic to the triclinic mineral.

Laves (1952) believes that orthoclase is unstable below a temperature somewhere near 700°C and that environmental conditions, particularly time and temperature, favor the transition to microcline. He states that crystals with intermediate optical properties are not uncommon.

The writer prefers the view held by the petrologists to that of the petrographers and includes the microcline and possible orthoclase in his analyses under the single heading "K-feldspar".

Braid and rim microperthites are abundant in some thin sections and are listed as "microperthite" in the analyses; they are not divided into approximate percentages of K-feldspar and plagioclase. The quartz, biotite and other minerals were identified by conventional optical methods which need no explanation here.

Sample 21. In thin section the rock is medium- to coarse-grained with xenomorphic-inequigranular texture (Figure 3).

Figure 3. Photomicrograph of sample 21 showing xenomorphic-inequigranular texture of the granite. Crossed nicols, X54 diameters.

Major constituents include quartz, K-feldspar, microperthite, plagioclase and biotite (Table I). Zircon, apatite, pyrite, magnetite, hematite, paragonite, chlorite, allanite and kaolinite are present in minor amounts.

The quartz occurs in large elongate masses which roughly parallel the alignment of the biotite. Patches of quartz surround and invade the other major constituents and contain remnants of them. Most of the quartz exhibits fracturing and strain shadows although granulation at boundaries is rare.

TABLE I

MODAL ANALYSES OF GRANITE

Analysis	Sample No.			
	21	15	4	10
Quartz	42	33	35	40
K-feldspar	28	17	3	2
Plagioclase (Ab97·An3)	21	30	48	57
Microperthite	3	16	4	
Biotite[a]	4	2	2	
Zircon	tr	tr	tr	tr
Pyrite	tr	tr	tr	tr
Magnetite	tr	tr		
Hematite, martite	tr	tr		tr
Muscovite, sericite, paragonite . . .	tr	tr	8	tr
Chlorite	tr			tr
Apatite	tr	tr	tr	tr
Kaolinite	tr	tr	tr	tr
Calcite		tr	tr	tr
Allanite	tr	tr		
Total	98	98	100	99

[a] Biotite includes the cloudy yellow alteration product.

A number of the quartz grains contain lines of highly birefringent inclusions (Figure 4) which Van Hise and Bayley (1897, p. 210) believe to be liquid inclusions with movable air bubbles, but the writer was unable to detect the movable bubbles. The lines often contain 40 to 50 individual inclusions and are roughly parallel, suggesting a study of planes of liquid inclusions might help in interpreting the metamorphic history of the rock.

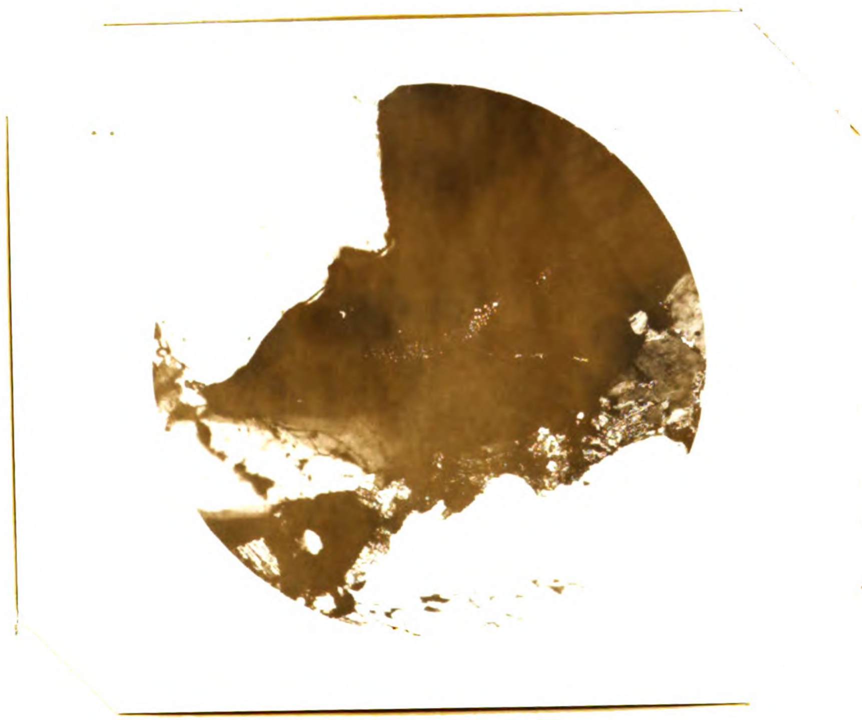


Figure 4. Photomicrograph of sample 21 showing lines of inclusions in the quartz. Crossed nicols, X54 diameters.

A few smaller quartz grains interspersed with feldspar between the larger quartz masses may be earlier quartz but the writer can find no proof of this. There is no evidence of quartz invading quartz nor is there any difference in the appearance of the grains.

K-feldspar occurs in crystals of medium size which are invariably fresh and unaltered. A few untwinned grains are present as are a number which exhibit the twinning only on a small corner, but most show the polysynthetic grid twinning typical of microcline. All but a few contain perthitic intergrowths of plagioclase. These needle-like inclusions are too small to permit determination of their exact composition by ordinary flat-stage methods.

The plagioclase is albite with composition Ab97·An3. It occurs in stubby laths which vary greatly in size, all in some stage of alteration to paragonite and kaolinite. Many crystals though irregular in outline are unaltered on their edges, giving the effect of a white zone or reaction rim surrounding the cloudy grain. Albite twinning is very common, sometimes in combination with pericline or Carlsbad twins. In most crystals the twin lamellae are numerous and closely spaced, but an occassional one may be found in which there are only a few widely spaced lamellae. In some of the crystals with unaltered rims the twin lamellae extend into the rim. A few rare islands of K-feldspar may be found in some of the larger albite crystals.

Complex microperthites with the approximate ratio of 1 albite (guest) : 4 K-feldspar (host) are present in small to medium crystals. They are not very abundant and are all unaltered. An occasional micrographic intergrowth of quartz in K-feldspar may be found.

The biotite occurs in large patchy aggregates made up of shreds and laths which occupy the spaces between the quartz and feldspar. Although the shreds are randomly oriented, the large patches are elongated and are aligned in roughly parallel fashion. Most of the biotite appears fresh except for a few pieces which have altered to a yellow-brown cloudy material. Very little chlorite is present. Birds-eye structure and pleochroic haloes around zircon inclusions are common. The other major constituents invade and appear to replace the biotite, shredding and splintering many of the smaller laths.

Small clouded crystals of zircon are plentiful not only as inclusions in the biotite but also scattered throughout the feldspars. Most of the zircons are rounded or football-shaped but a few are euhedral (Figure 5). All are surrounded by a small brown reaction rim. A few tiny needles of apatite and some large euhedral allanite are present.

Figure 5. Photomicrograph of sample 21 showing euhedral zircon. Plain light, X225 diameters.

Magnetite, pyrite, hematite and chlorite appear as alteration products of the biotite. Paragonite and kaolinite occur as alteration products in cleavage cracks and clouding the surface of the albite. A few small particles of pyrite are probably primary constituents of the rock.

Sample 15. The mineral assemblage and textural relationships are similar to those of sample 21. Quartz, K-feldspar, microperthite, albite and biotite are the major constituents. Zircon, pyrite, magnetite, hematite, paragonite, muscovite, apatite, kaolinite, allanite and calcite occur in minor amounts (Table I).

Extensive granulation at boundaries and the great abundance of lines of liquid inclusions in the quartz of this sample distinguish it from the quartz of sample 21. The complex microperthites are more abundant in this sample; some of the K-feldspar shows spotty alteration to kaolinite.

Quartz invasion has splintered and shredded the biotite to a considerable extent. The shreds are more extensively altered than those of sample 21, mainly to muscovite. Small patches of calcite result from alteration of the albite.

Sample 4. The texture of this sample is xenomorphic-inequigranular. The notable absence of large quartz and feldspar masses distinguishes the texture from that of the samples previously described. The mineral assemblage is the same as that of the previous samples (Table I).

The quartz grains are of medium size and show no fracturing or granulation at boundaries although all exhibit undulatory extinction. A few lines of inclusions are present as in sample 21, but they are not nearly as abundant as in sample 15.

K-feldspar and microperthite occur in small to medium unaltered crystals but are the subordinate feldspars in the sample. Albite, much of it untwinned but always with the characteristic positive optic sign, makes up half the rock. It is more extensively altered than in the orange granites, exhibiting surfaces clouded with paragonite and occasional patches of calcite. The white rims around grains are not present in the albite of this sample.

More than half of the biotite has altered to muscovite; the remainder, although extremely shredded, shows no alteration to chlorite. A few tiny grains of pyrite occur with the biotite, but no magnetite or hematite could identified in this sample. A few small rounded zircons are present.

Sample 10. The texture is xenomorphic-inequigranular, nearly aplitic. Quartz, K-feldspar and albite occur with minor amounts of chlorite, kaolinite, paragonite, calcite, hematite, apatite, zircon and pyrite (Table I).

The quartz occurs in two habits, 1) a few medium to large masses which fill the spaces between the feldspars, and 2) numerous smaller blebs and patches which randomly dot the feldspars. The larger interstitial masses appear to have crystallized under normal conditions, but the blebs were caught in the feldspars during rapid crystallization in the final stages of cooling of the rock. Both varieties exhibit marked undulatory extinction, and the larger masses are somewhat fractured. There are no lines of liquid inclusions in the quartz of this sample.

A very small amount of untwinned K-feldspar is present and contains much quartz in stringy patches. The K-feldspar is clouded by secondary mica and by hematite staining. Medium-sized equidimensional crystals of albite make up most of the rock; many are albite-twinned, some in combination with Carlsbad and pericline twins. Alteration to paragonite, calcite and kaolinite and staining by hematite cloud most of the albite.

A very small amount of biotite was originally present but it has been completely altered to a light green pleochroic variety of chlorite which is dark grey-brown under crossed nicols.

A few small crystals of pyrite, some very small rounded zircons, and numerous tiny needles of apatite complete the list of accessories. The section contains a great deal of red opaque hematite staining. Veins of heavily stained calcite cut the rock in an angular pattern which appears to be due to jointing.

Petrologic interpretations. From the petrographic descriptions certain characteristics of the individual minerals and their relationships to one another present themselves and may have a bearing on the interpretation of the origin of the granite. Some of the more significant of these characteristics should be considered. It is difficult to assign an order of crystallization of minerals to a rock which has no constituents which show even subhedral boundaries, but there are certain consistencies worthy of mention.

As the predominant feldspar in the granite is plagioclase, a better term for the rock might be granodiorite. However, this rock and many other granodiorites have been referred to as granites in the literature, so the writer will not confuse the issue by changing the name. As the term granite is less cumbersome and is "deeply entrenched in the literature", there is no reason to argue over names which have no genetic significance.

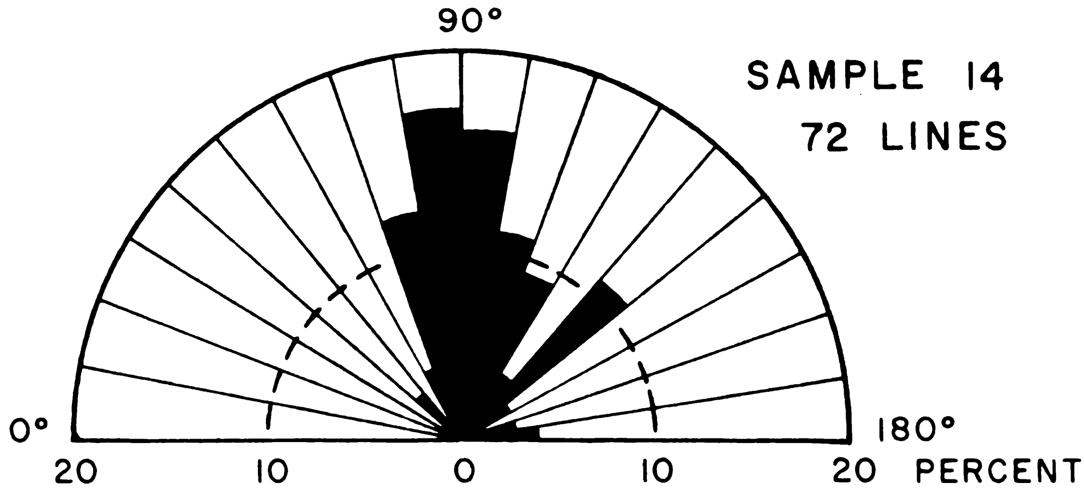
The large quartz masses appear to be the only quartz present in the granite and to invade and replace the feldspar and biotite. The few smaller masses of quartz in some of the samples do not differ from the larger in such properties as extinction, granulation or inclusions and probably are part of the same generation. Blebs of quartz in the feldspar of the chilled zone are merely remnants of a nearly solid granite which cooled too quickly to permit its last liquid constituents to differentiate in the normal manner.

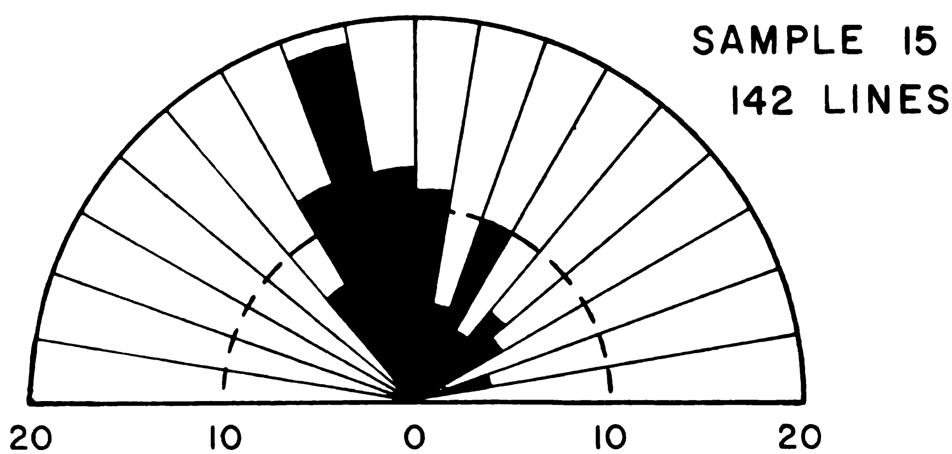
The orientation of the quartz masses parallel to the alignment of the biotite indicates a deformational stress near the area with sufficient power to render the rock gneissose. Further evidence of stress lies in the lines of liquid inclusions which exhibit a striking consistency in their orientation within each thin section. The writer has plotted the linear orientation of the lines of inclusions in each of three samples. As shown in Figure 6, the maxima of 17, 19 and 14% in 10° intervals with corresponding percentages near these maxima, and the large areas nearly devoid of shading, illustrate the pattern. The three samples are not oriented with respect to one another so the writer can only note the trend and suggest that someone make a more intense study of these inclusions in the future.

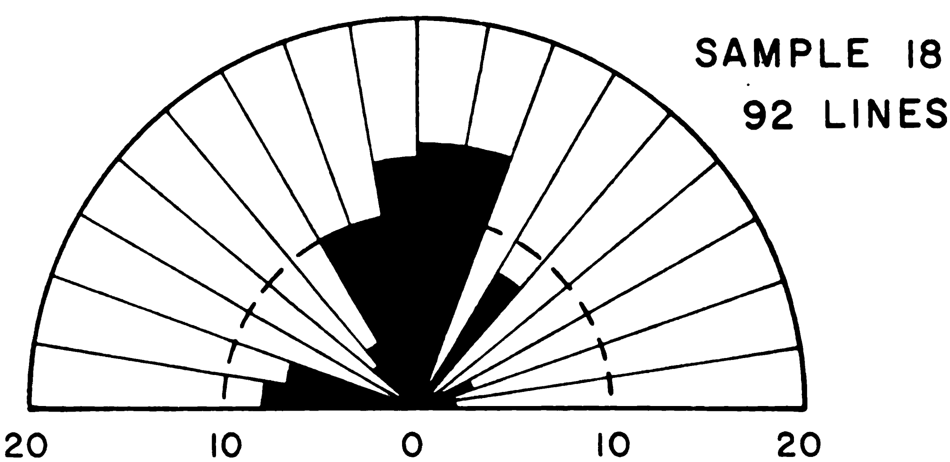
The K-feldspar question has been considered in an earlier portion of the paper to explain the writer's feldspar classification. Until more work is done on the orthoclase to microcline transition there is no reason to separate the two as earlier petrographers have done. If there are intermediate stages between the two, the K-feldspar in this granite which contains so many crystals twinned only on a small corner may be an example of one of those stages.

Much of the plagioclase has only the albite twinning although combination Carlsbad-albite twins are fairly plentiful, and an occasional Carlsbad-albite-pericline twin may be found. Gorai (1950) and Turner (1951), in separate studies, found

Figure 6. Orientation of lines of inclusions in quartz in three samples of the granite.







that there is a tendency for the plagioclase of rocks of metamorphic origin to exhibit simple twinning, while plagioclases in igneous rocks are more complexly twinned. Metamorphic plagioclase usually is untwinned or is twinned simply according to the Albite Law while igneous plagioclases show albite twinning in combination with Carlsbad and pericline twins, and occasionally with the rarer Baveno and Mannebach twins.

Certainly many more granites will have to be studied and demonstrate a fairly rigid pattern before the twinning criterion can be used without reservation, but if it is found to be valid the petrologist will have a handy tool at his disposal. The theory is offered here as a tentative argument in favor of a fluid stage sometime in the history of the granite of the present study. If the theory is not valid and complex twin combinations commonly exist in granites of metamorphic origin, it is probable that a force of sufficient magnitude to align the quartz and biotite can induce Carlsbad and pericline twinning in the plagioclase.

The narrow white rims on the albite may indicate a later addition of sodic material. Emmons and Mann (1953, p. 53) state that these rims are common in roof phases of granites and probably post-date the twinning, as some grains may be found in which the twinning does not enter the rims. They state that the rims are of the same composition or are more sodic than the crystal itself.

Braid and rim microperthites of the type present in this granite are commonly attributed to exsolution, while the tiny perthitic blades in the K-feldspar may have a simpler replacement origin or may be the final remnants of the exsolution process. Tuttle (1952) describes his "exsolution series" in which we can follow the evolution of the feldspars from anorthoclase through X-ray perthites and cryptoperthites to the familiar microperthites, perthites, and finally the completely differentiated plagioclase and K-feldspar. He states that exsolution perthites containing approximately equal amounts of albite and microcline are "prima facie evidence of magmatic ancestry".

One point in favor of an exsolution origin for the complex perthites is the fact that albite rims partially surrounding grains in many granites tend to be located almost exclusively between K-feldspar and plagioclase while very few are located between other combinations of grains. Tuttle (1952, p. 116) found in a study of six granites which had these rims that over 90% of the rims lie at Or-Pl boundaries, while only a few lie at Or-Or, Pl-Pl and Pl-Q, and none lie at Or-Q and Q-Q. This would indicate that the plagioclase rim has unmixed from the K-feldspar.

There are not enough of these partial rims in the granite of the present study to allow the writer to make a similar tabulation, but Tuttle's study does offer convincing proof that braid and rim microperthites indicate exsolution. If they also indicate a magmatic ancestry as he states, the microperthites in the granite of the present study might point to an igneous origin.

The biotite is generally unaltered or altered only to chlorite or muscovite so offers no clues to the history of the rock but does appear to be invaded and replaced by the quartz and feldspars in all cases. Its occurrence in large aligned aggregates of smaller individuals is another indication of the stress which must have acted upon the granite at one time.

The pegmatites which may be a late phase of the granite are composed of massive untwinned K-feldspar with veins of milky quartz. A possible explanation for the lack of twinning in the K-feldspar may be the fact that the deformational stress changed the orthoclase in the granite to microcline soon after solidification and the pegmatites were introduced later, perhaps from another granite intrusion.

In each sample of the granite there are a few micrographic intergrowths of quartz in feldspar which suggest exsolution. One sample contains a small grain of albite with the unusual chessboard structure, which Starkey (1959) attributes to stress. A thorough search of each of the thin sections revealed only this one grain with well-developed chessboard structure (Figure 7).

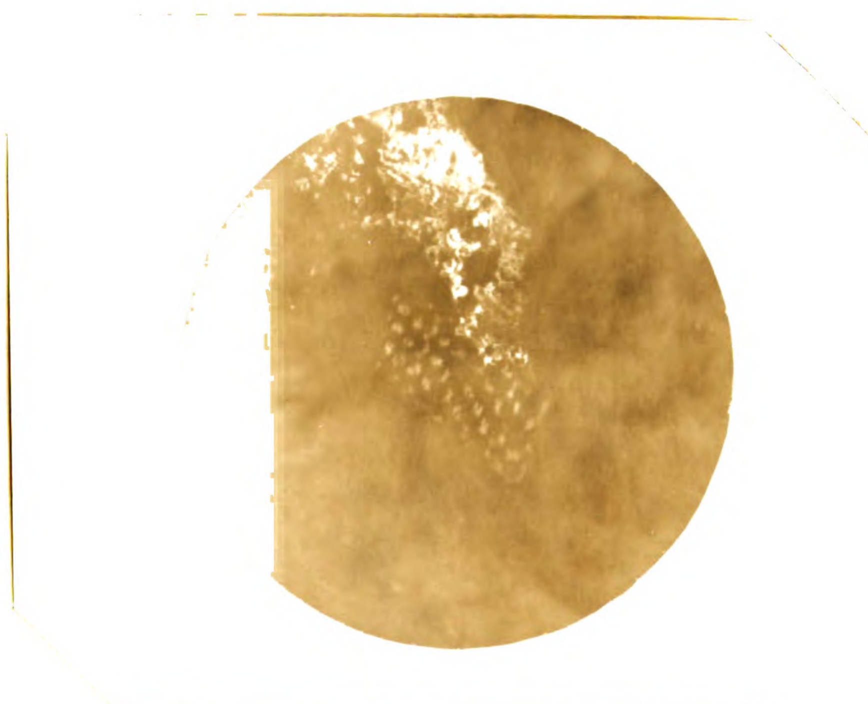


Figure 7. Photomicrograph of sample 25 showing chessboard structure in albite. Crossed nicols, X225 diameters.

Injection Gneiss

Near the north shore of Gribben Lake the granite intrudes ancient Archean schists and gneisses to form younger injection gneisses. The invading material has approximately the same composition as the main intrusion and is part of the same body. The ancient schists and gneisses are the "hornblende and biotite schists" or "mashed eruptives" of Van Hise and Bayley (1897), and the "Keewatin schists intruded by Laurentian granite to form Archean injection gneiss" of Dickey (1936). They are highly deformed banded rocks and are cut by each of the granites in the Southern Complex. As they predate the granite and have no bearing on its origin they are not discussed in detail. Sahakian (1959) describes them thoroughly in his study of the area two miles east of Gribben Lake.

The only good exposure of the younger injection gneiss is on the face of a large cliff just north of the lake in the eastern half of the area. Most of the exposure is inaccessible but there are places near the top and bottom of the cliff where it is possible to get a good look at the rock types.

At the top of the cliff stringers of granite and pegmatite cut across a highly altered basic dike which apparently intruded the Archean rocks. The rock near the bottom of the cliff is made up of thin alternating bands of orange granitic material and black biotite schist in typical lit-par-lit structure. Small orange feldspar crystals are scattered throughout the biotite stringers. As nearly as the writer can determine, the banding and schistosity strike nearly E-W and dip to the north. The following description of a thin section of a 3/4-inch band of the granitic material will give the reader an idea of the mineral assemblage in one of the injected lenses.

Sample 3. Large elongate masses of quartz lie in a groundmass of K-feldspar, microperthite and plagioclase. The quartz masses are aligned parallel to the lit-par-lit structure and exhibit no cataclasis or granulation at boundaries although the usual undulatory extinction is present. Lines of liquid inclusions are plentiful in the quartz and show a preferred orientation which obliquely cuts the direction of banding.

K-feldspar, microperthite and plagioclase are present in the groundmass in approximately equal amounts and exhibit a striking lack of twinning, only an occasional grain showing traces of a grid or the parallel albite structure. The K-feldspar is unaltered but the albite grains and stringers in the microperthite are extensively altered to muscovite, paragonite and kaolinite.

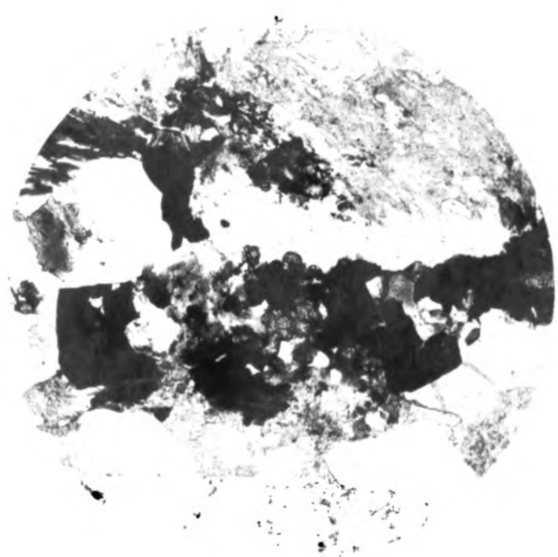


Figure 8. Photomicrograph of sample 3 showing biotite alteration aggregate. Plain light, X54 diameters.

Large aggregates of magnetite and associated chlorite, zircon and pyrite result from the alteration of biotite (Figure 8). A few tiny needles of apatite and small pyrite cubes with red hematite borders are present in the feldspars.

Slate

In the northern portion of the area the granite intrudes a green slate with well-developed slaty cleavage which strikes E-W, dips 70°N. Lacking any evidence of bedding, a better name for this rock might be "brown-weathering sericitic chloritic schist", but the rock has no aligned minerals which are evident even with the hand lens. Only in one outcrop in the north central portion of the area has the slate been altered to a schist with schistosity which strikes N70°W and dips 56°NE. The slate contains a good deal of pyrite and is intruded by tiny stringers of granitic material.

Lamey (1935) states that the Palmer Gneiss including this slate is Huronian, the slate being either Siamo (Middle Huronian) or a slaty member of the Mesnard quartzite (Lower Huronian). If he is correct, the slate would help to date the granite, but Vickers (1956) believes that these rocks are pre-Huronian.

Basic Dikes

Two basic dikes were found in the map area. One is an altered olivine diabase which cuts the granite in the north central portion of the area, the other is an older highly altered hornblende schist which is cut by the granite on the large cliff near the lake. A description of each rock type follows; sample 23 is the olivine diabase, sample 12 is the hornblende schist.

Sample 23. Megascopically the rock is a fine-grained brown-weathering black diabase. It is peppered with small pyrite crystals and contains numerous epidote aggregates with an average diameter of 2mm.

In thin section the rock is an aggregate of calcic plagioclase and basic alteration products with typical diabasic texture. No quartz is present. The plagioclase, labradorite with approximate composition Ab43•An57, occurs in short laths and in large subhedral crystals. The laths are partially altered to epidote and paragonite and exhibit undulatory extinction and albite twinning, many in combination with Carlsbad or pericline twins. The larger crystals have been completely altered to an aggregate of epidote and paragonite except on a few fresh edges, suggesting zoned calcic crystals with more sodic borders.

The remainder of the rock consists of serpentine, talc, chlorite and magnesite (Table II), products of the complete alteration of the former basic constituents, probably olivine, pyroxene and biotite. Ilmenite partially altered to leucoxene occurs in skeleton crystals; pyrite and apatite are present in minor amounts.

With the exception of the labradorite all the major constituents have been altered to such an extent that it is impossible to determine the exact nature of the original rock. In hand specimen the rock resembles the brown-weathering Keweenawan diabase which is a common dike rock in the Marquette district. The great abundance of serpentine in sample 23 tends to support this observation; it is unlikely that a quartz-free diabase with this much serpentine did not originally contain olivine. At any rate the rock has undergone extensive alteration of most of its major constituents

TABLE II

MODAL ANALYSES OF THE BASIC DIKES

Analysis	Sample No. 23	Sample No. 12
Quartz		2
Plagioclase	34	44
Biotite		27
Serpentine, talc	57	
Hornblende		21
Epidote	4	tr
Chlorite	2	1
Magnesite	tr	
Calcite		tr
Muscovite, paragonite	2	4
Apatite	tr	tr
Pyrite	tr	tr
Ilmenite	tr	tr
Leucoxene	tr	tr
Saussurite		1
Total	99	100

and has undergone a major deformation as shown by the strain shadows in the labradorite so is at least as old as the latest period of deformation in the area.

<u>Sample 12</u>. In hand specimen the rock is dark green to black, schistose, and is composed mainly of hornblende and biotite with some feldspar and pyrite. In USGS Bulletin 62, Williams (1890, p. 225) shows a drawing of a thin section of a similar rock which came from Gabbro Ridge below Lower Quinnesec Falls, Menominee River, Michigan. Williams, in his explanation of the drawing, says,

> "The original structure of this rock has been completely changed, in spite of its still massive character. It is now composed of pale green, fibrous hornblende, saussurite, quartz, calcite, chlorite, ilmenite and leucoxene. Most of the constituents are of secondary origin, and in the process of their formation the form of the primitive minerals has been so completely obliterated that it is now impossible to say whether the mother-rock was a diabase or a diorite."

And on page 81,

> "As the new minerals have formed they have wandered from the position occupied by the older ones and have thus produced a fine-grained and confused aggregate in which the remains of larger rectangular feldspars or hornblende crystals are only rarely discernible."

In the schist of the present study only a little saussurite is present and most of the feldspar, oligoclase with approximate composition $Ab_{72}An_{28}$, is fresh and is in general untwinned. In addition to the minerals listed by Williams in his sample, the schist of this study contains muscovite, biotite, epidote and apatite (Table II, Figure 9). Lacking definite information on the nature of the original rock, the writer can only state that structurally it postdates the

Archean gneisses and predates the granite of this study and that its completely recrystallized character points to a late Archean age.

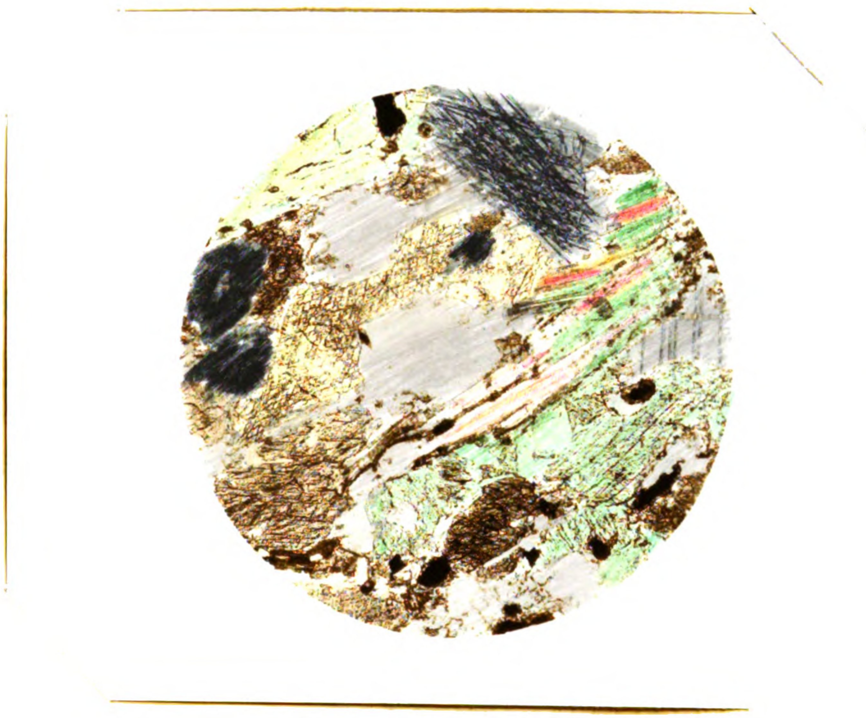


Figure 9. Tinted photomicrograph of sample 12 showing feldspar, muscovite, quartz, biotite, hornblende and ilmenite. Crossed nicols, x54 diameters.

METAMORPHISM

The field and petrographic studies of the granite and associated rocks reveal certain features which may be helpful in the interpretation of the metamorphic history of the research area. Although the study does not embrace an area of sufficient magnitude to include well-defined metamorphic zones or aureoles, each of the rock types in the area exhibits features which are consistent with current theories on the effects of an intrusion upon the country rocks.

The granite and diabase dike are the youngest rocks in the area and show only the effects of hydrothermal alteration and a single deformational stress. The slight alignment of constituents and the presence of the alteration products serpentine, epidote, muscovite and paragonite point to a low metamorphic rank and may not in themselves be of sufficient significance to warrant classifying the granite and diabase as other than altered igneous rocks.

The slate in the northwestern corner of the area (see map in pocket) shows little effect of the intrusion of the granite other than the fact that the intrusion probably changed it from a shale to a green slate, but an outcrop in the north central portion of the area shows the granite and a schistose phase of the slate in direct contact. Here the slate has been altered to a greenschist made up mainly of aligned flakes of chlorite, placing it in the greenschist facies. Thus a gradational contact may be inferred from the limited number of outcrops present although we cannot determine the exact configuration of the contact or detect the presence of high temperature minerals.

The Archean gneiss and associated hornblende schist contain hornblende, K-feldspar, quartz, oligoclase or andesine, and biotite or chlorite, each in major amounts, with minor occurrences of accessories. This mineral assemblage, placing the rocks in the amphibolite facies, and the completely recrystallized nature of the rocks point to a higher metamorphic rank than that of the other rocks in the area. In particular, the fact that the rocks near the lake can be classified in a higher metamorphic facies than the greenschist points to the fact that they may have been through more than one period of intrusion and deformation and so are probably older than the slate.

CONCLUSIONS

From the study of the structural relationships and petrologic characteristics of the rock types in the area, the writer has reached the following conclusions:

1) The sequence of geologic events in the area is as follows:

a) deposition of the ancient Archean sediments or eruptives

b) fluid invasion of the Archean rocks to form schists and gneisses.

c) intrusion of the highly altered dike (hornblende schist)

d) folding of the schists and gneisses

e) deposition of the shale (green slate)

f) intrusion of the granite

g) intrusion of the olivine diabase dike

h) deformation of the area

2) The granite is igneous, not metamorphic, in origin. There is no petrologic or structural evidence in the area to indicate a metamorphic origin; petrologic relationships point to the normal crystallization of a fluid magma, and the intrusion of the magma must have metamorphosed the shale to form the green slate. Stringers of the magma form the injection gneisses by invading the Archean gneiss and hornblende dike.

3) The exposed granite is the upper portion of the intrusion. This particular granite intrusion appears at

first sight to be small in size; it is bounded by the lake to the south[1] (Vehrs, 1959) and is on the northeastern corner of the granite complex. This appearent size factor, the presence of the large chilled zone near the tote road to the north, the variations in composition (Table I), and the presence of sodic rims around much of the plagioclase (Emmons and Mann, 1953) indicate that the exposed portion of the granite is near the roof of the intrusion.

4) The granite is post-Huronian. Structural evidence indicates only that it is post-Archean, pre-Keweenawan but the petrologic evidence indicates that it is the Killarney Granite of Dickey. Little or no cataclasis, moderate alteration of constituents, and evidence of having undergone only one period of deformation lead the writer to this conclusion; earlier granites of known age in the Lake Superior Region are more cataclastic, are more highly altered, often contain large feldspar phenocrysts, and have usually been subjected to more than one major period of deformation.

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1. South of the lake in sections 34 and 3 Vehrs encountered Archean gneisses invaded by stringers of the granite.

RECOMMENDATIONS FOR FURTHER STUDY

In the course of this study certain problems which warrant further study have become apparent. Research on the following field and petrologic problems might shed more light on the origin and history of the granite.

1) Mapping in Sections 32 and 33 would help to determine the extent of the intrusion and its relation to the rocks of the Palmer Gneiss. A study of the age of these former sediments would help in determining their place in our present time classification of the rocks of the Lake Superior Region.

2) Absolute age determination by radioactive dating in the granites of the Southern and Northern Complexes might facilitate the problem of correlating the sediments of the Marquette District with those of other districts. Scarcity of outcrops in the major portion of the Southern Complex hampers the study of the structural relationships of its granites with each other and with the surrounding metasediments.

3) Further research on the orthoclase-microcline transition might help to unravel the complex geologic history of many Precambrian intrusions.

4) Much more information is needed on twinning and zoning in the plagioclases of igneous and metamorphic rocks. The work of Gorai (1950), Turner (1952), and the Wisconsin geologists led by Emmons (1953) is a start in the right direction.

5) Little is known of the extent to which metamorphism, particularly through ionic diffusion, may alter the acidic

constituents of rocks. Particular emphasis in this area should be placed on perthitic phenomena such as those exhibited in the granite of the present study.

6) A petrofabric study of the planes of liquid inclusions in the quartz might add a further structural element to our knowledge of the area.

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OUTCROP MAP OF THE PROBLEM AREA

LEGEND

UPPER PRECAMBRIAN	ALTERED OLIVINE DIABASE
MIDDLE PRECAMBRIAN	APLITIC GRANITE "CHILLED ZONE"
	GRANITE
	SLATE
LOWER PRECAMBRIAN	HIGHLY ALTERED HORNBLENDE SCHIST
	ANCIENT GNEISS

Symbols

Area of outcrop	
Location of sample	△5
Strike and dip of slaty cleavage	67
Strike and dip of joint	66
Strike and dip of foliation	69

SUBDIVISION OF THE PRECAMBRIAN AFTER JAMES, 1958.