Geology of the Kiernan Quadrangle Iron County Michigan

GEOLOGICAL SURVEY BULLETIN 1044

Prepared in cooperation with the Geological Survey Division of the Michigan Department of Conservation

Geology of the Kiernan Quadrangle Iron County Michigan

By JACOB E. GAIR *and* K. L. WIER

GEOLOGICAL SURVEY BULLETIN 1044

Prepared in cooperation with the Geological Survey Division of the Michigan Department of Conservation

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1956

UNITED STATES DEPARTMENT OF THE INTERIOR

Fred A. Seaton, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

**For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $1.50 (paper cover)**

CONTENTS

ILLUSTRATIONS

[All plates in pocket]

TABLES

GEOLOGY OF THE KIERNAN QUADRANGLE IRON COUNTY, MICHIGAN

By Jacob E. Gair and Kenneth L. Wier

ABSTRACT

The Kiernan quadrangle is in eastern Iron County, in the western part of the northern peninsula of Michigan. The area is underlain by Lower and Middle Precambrian rocks, formerly designated as Archean and Huronian rocks, and is extensively covered by Pleistocene glacial deposits. An Upper Precambrian (Keweenawan) diabase dike and a few scattered remnants of lower Paleozoic sandstone are also found in the area.

The major structural feature is a north-northwest axis along which are uplifts of Lower Precambrian rocks in the northwestern and in the southeastern parts of the quadrangle. The northwestern uplift is called the Amasa oval, and the southeastern is called the southeastern greenschist uplift. In the saddle between these two uplifts, particularly near Michigamme Mountain, local cross-folding has produced trends about at right angles to the major axis.

Lower Precambrian rocks, here called the Margeson Creek gneiss, are exposed in the core of the Amasa oval. They consist mainly of banded gneiss of granodioritic to tonalitic composition and granitic rocks ranging in composition from granite to tonalite. The granitic rocks are mainly inequigranular and well foliated; less common are equigranular nonfoliated and pegmatitic varieties. Of minor importance are biotite and sericite schists and amphibolite.

The Lower Precambrian rocks of the southeastern uplift are not exposed in the area, but are known from drill holes in the quadrangle to the south to consist of foliated and crinkled green schist bearing magnetite or martite, and in places oxidized to a red color.

A major unconformity separates the Lower Precambrian rocks from a sequence of layered Middle Precambrian rocks. From their base upward, the rocks of the Middle Precambrian sequence are the Randville dolomite, the Goodrich quartzite (with included fragments of probable Negaunee iron-formation), the Hemlock formation, the Fence River formation, and the Michigamme slate. These formations now form belts bordering the Lower Precambrian rocks, which form the cores of the two major uplifts. Unconformities occur at the base of the Goodrich quartzite and at the base of the Michigamme slate. The unconformity at the base of the Goodrich cuts out much or all of the Negaunee iron-formation from the Kiernan area, leaving only possible remnants of that formation at Michigamme Mountain. The unconformity at the base of the Michigamme accounts for the absence of the Fence River formation in the southern half of the quadrangle.

The Randville dolomite is best exposed in the south-central part of the quadrangle, near the south shore of Michigamme Reservoir, and on the east flank of the Amasa oval. The formation has a maximum thickness of about 1,800 feet

on the flanks of the oval and consists largely of almost pure dolomite. Locally however, phases consisting of quartz-sericite slate, sericite and chlorite schist, feldspathic quartzite, and arkose are developed, and in one place a bed of graywacke is a part of the formation. Quartz-sericite slate is particularly well developed near the bottom and the top of the Randville. A peculiar breccialike quartzitic rock found only in two outcrops is believed to be a silicified phase of the Randville.

The Goodrich quartzite consists mainly of ferruginous cherty magnetic quartzite, exposed only at or near Michigamme Mountain, where magnetic data indicate that the maximum thickness is probably not more than 500 feet. In much of the Goodrich quartzite clastic quartz grains and magnetite lie in a matrix of hematitic recrystallized chert. In places the formation is oxidized and essentially nonmagnetic. Some of the Goodrich contains abundant clastic grains of hematitic recrystallized chert; in general, the relative proportions of clastic quartz, chert, and ferruginous material range widely. The Goodrich quartzite at Michigamme Mountain was formerly thought to be Negaunee iron-formation. A few fragments of material similar to parts of the Negaunee are found in the quartzite, and some of the clastic grains are probably derived from the iron-formation; but the Negaunee is considered to form, at the most, only a small part of the iron-rich rock at the Mountain.

The Hemlock formation is best exposed in the southwestern part of the quadrangle and also on the east side of the Amasa oval. In the latter area its thickness is about 2,300 feet. West of the quadrangle on the west flank of the oval it thickens to about 23,000 feet. The Hemlock is composed mainly of metavolcanic rocks with minor slate and graywacke. The metavolcanic rocks are greenstones, dark schists, and felsites. They include altered basalts, some of which contain ellipsodial and amygdaloidal structures, pyroclastic rocks, biotite-, hornblende-, and epidote-bearing schists, and metarhyolite.

The Fence River formation, although not exposed, is represented by a strong linear north-trending magnetic anomaly crossing the northeastern part of the area, on the east flank of the Amasa oval. The anomaly begins in sec. 27, T. 44 N., R. 31 W., and extends northward beyond the quadrangle to the only known exposure of the formation at the Sholdeis exploration. The formation in that vicinity consists, from the bottom upward, of (1) magnetite-specularite-quartz rock, (2) thinly banded rock rich in quartz, magnetite, hornblende, and epidote, and (3) massive garnet-grunerite schist. No accurate estimate of the thickness of the Fence River formation is possible. Formerly, the Fence River-formation was correlated with the Negaunee iron-formation and was considered equivalent to the iron-rich rock at Michigamme Mountain. Inasmuch as it lies above the Hemlock formation and the iron-rich rock at Michigamme Mountain lies beneath the Hemlock, the two iron-rich rocks are not equivalent.

The Michigamme slate is assumed to underlie much of a broad belt of glacial deposits in the eastern part of the quadrangle. The only Michigamme exposure in the area is an altered volcanic member of the formation east of the Fence River magnetic anomaly on the east flank of the Amasa oval. In adjacent regions the Michigamme is known to consist of mica and garnet schists, graywacke, impure quartzite, and small amounts of metavolcanic rocks. No accurate estimate of the thickness of the Michigamme in the area is possible.

At least two waves of regional metamorphism have affected the rocks of the area. Lower Precambrian rocks underwent at least one period of metamorphism accompanied by granite intrusion and granitization-migmatization prior to uplift and erosion of the Margeson Creek gneiss and deposition of the Randville dolomite. Following deposition of the Michigamme, a late Middle Precambrian period of regional metamorphism attended orogeny and deformation of the Lower and Middle Precambrian rocks. Metamorphic grade increases from southwest to northeast. The rocks near the southwestern corner of the quadrangle are in the chlorite metamorphic zone, those in much of the quadrangle are in the biotite zone, and those near the northeastern corner are probably in the garnet zone.

The Lower and Middle Precambrian rocks of the area are cut by intrusive rocks of different types, and possibly of several different ages. In the Amasa oval the Margeson Creek gneiss is intruded by many dikes or sills of greenstone and quartz porphyry. Some of this rock has been emplaced along faults at the south end of the complex. The Randville dolomite and the Hemlock formation in the south-central and southwestern parts of the quadrangle are intruded by metagabbro and metadiabase, and the Randville is also intruded by trachyte in two places. Two sills in the Hemlock formation contain most of the metagabbro and metadiabase. These sills are here named the West Kiernan sill and the East Kiernan sill. Granophyre and pegmatitic phases of the metagabbro, occurring only along the southwest side of the West Kiernan sill, suggest that the rock was intruded as a flat-lying body that was later tilted to its present position with the original top side facing west or southwest. These intrusive rocks all were metamorphosed during the post-Michigamme late Middle Precambrian orogeny. An unaltered diabase dike in sec. 10, T. 44 N., R. 31 W., is the only later intrusion known in the area.

Economic interest has centered on the iron-rich rocks of the area. The two formations potentially exploitable for iron are the Goodrich quartzite and the Fence River formation. Although neither formation appears to have significant amounts of iron "ore," the rocks of both conceivably might be amenable to beneficiation.

INTRODUCTION

LOCATION, EXTENT, AND ACCESSIBILITY OF AREA

The Kiernan quadrangle is located in eastern Iron County in the northern peninsula of Michigan (fig. 1). It lies between latitudes 46°07′30″ and 46°15′00″ N. and longitudes 88°07′30″ and 88°15′00″ W., and occupies an area of about 51 square miles. It includes most of T. 44 N., R. 31 W., approximately the northern third of T. 43 N., R. 31 W., and narrow strips of adjoining townships on the north and west. Within its boundaries are found Lower, Middle, and Upper Precambrian rocks, rocks of Cambrian age, and extensive glacial deposits of Pleistocene age.

The northern boundary of the quadrangle is about 20 miles south of the west end of the Marquette Range. The southeastern corner of the quadrangle lies on the west side of the Sagola basin [1,2] and is about 18 miles north-northwest of the west end of the Menominee Range. The city of Crystal Falls is 4½ miles southwest of the southwestern corner of the quadrangle. The position of the Kiernan quadrangle in respect to the principal geologic features in the western part of the northern peninsula of Michigan is shown in figure 2.

[1] Pettijohn, F. J., 1951, Geology and magnetic anomalies of T. 42 N., R. 30 W., Dickinson County, Mich., U. S. Geol. Survey, open file report, pl. 1.

[2] James, H. L., Lamey, C. A., Clark, L. D., and others; U. S. Geol. Survey report on Central Dickinson County, Mich. (in preparation).

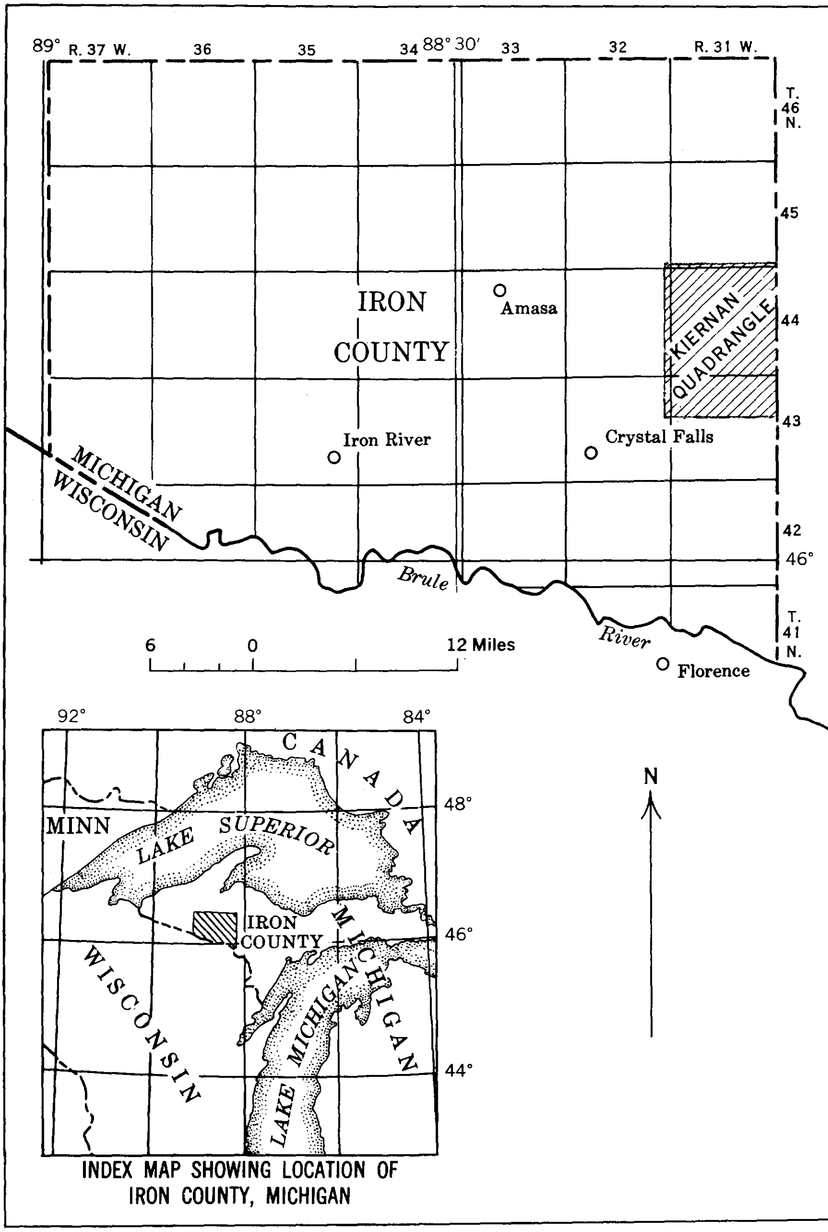

FIGURE 1.—Index map showing location of Kiernan quadrangle, Iron County, Mich.

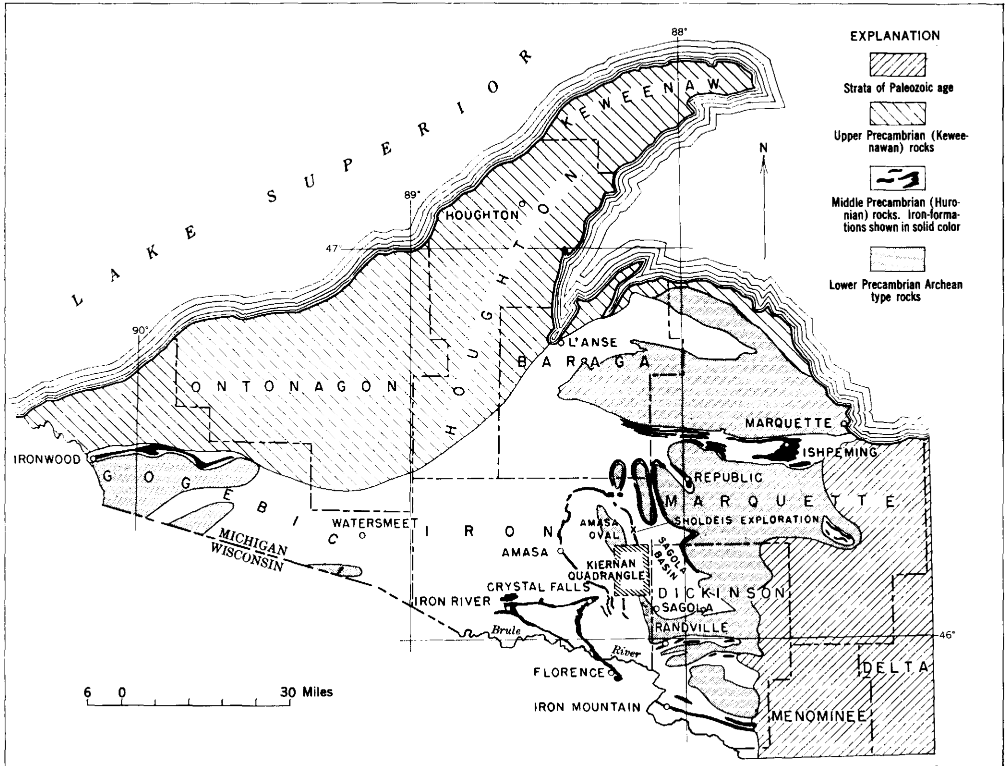

FIGURE 2.—Map of the western part of the northern peninsula of Michigan showing the Kiernan quadrangle in relation to the principal geologic features.

Most of the southern half of the quadrangle is within easy reach of good county roads or can be reached by water. The principal access to the southern part of the area is by the county road extending north from Michigan Highway 69 at Mansfield Township Hall, 3½ miles west of Sagola. This road enters the quadrangle in the NW¼ sec. 14, T. 43 N., R. 31 W., and connects with all other roads in the area south of Michigamme Reservoir. The northern half of the quadrangle is relatively inaccessible and can be entered by automobile on only a few poor roads or by boat from the south side of the reservoir.

The mapping of the Kiernan quadrangle is part of an investigation of the northern Michigan iron districts by the U. S. Geological Survey in cooperation with the Geological Survey Division, Michigan Department of Conservation.

TOPOGRAPHY AND DRAINAGE

RELIEF

The Kiernan quadrangle is characterized by a combination of low-lying, swampy areas of scant relief alternating with locally rugged knobs and hills. The maximum relief of about 280 feet belies the steepness of many slopes of the higher areas and the difficulty of traversing many of the hummocky and knoblike glaciated parts of the region.

The highest altitude in the quadrangle is between 1,580 and 1,600 feet at the top of Michigamme Mountain on the north border of sec. 4, T. 43 N., R. 31 W. The greater altitude of Michigamme Mountain, its isolation in respect to other hills, and its location in more open country make it the most conspicuous topographic feature in the quadrangle. Several unnamed hills in the north-central part of the area, especially in sec. 4, T. 44 N., R. 31 W., rise to altitudes between 1,560 and 1,580 feet. The most rugged topography in the quadrangle is along the Michigamme River in the vicinity of the Michigamme Falls power dam in the SE¼ sec. 7, T. 43 N., R. 31 W.

GLACIAL FEATURES

Glacial deposits of several types cover much of the area and evidently form many of the small hills, particularly east of longitude 88°10′00″ W., a part of the quadrangle devoid of outcrops. The brief description of the several types of glacial material and the determination of their distribution is based largely on Bergquist's studies (1932, 1935), and to a lesser extent on observations made by the present writers.

Bergquist has divided the glacial deposits of Iron County into till sheets, glaciofluvial sediments (outwash), and a terminal moraine. In the Kiernan quadrangle these deposits appear to be represented by till of possible middle Wisconsin age in the southeastern part, by part of the terminal moraine of the Superior ice lobe of late Wisconsin age in much of the eastern and northern parts, and by outwash sands and gravels of still later Wisconsin age that extend from the northeastern part of the area southwestward across the quadrangle. (See fig. 3.)

The till forms a gently undulated surface broken by a few higher areas, particularly in the N½ sec. 4 and in the NE¼ sec. 9, T. 43 N., R. 31 W., where bedrock projects through the glacial deposits. The till consists mainly of clay mixed with gravel, cobbles, and boulders, but in places contains interlayered silt as much as several feet in thickness.

Terminal moraine of the Superior ice lobe forms a topography generally of hummocks and hills characterized further by numerous small kettles and small swampy areas of interior drainage. Many of the areas shown in figure 3 as being occupied by outcrop or thin glacial drift are surrounded by or adjoin areas of moraine, and in respect to glacial deposition, probably should be shown as morainal areas. The moraine is composed of cobbles, boulders, and room-size erratics indiscriminately mixed with generally brownish clayey and sandy material. The coarser material consists mainly of granitic and gneissic rocks, quartzite, dolomite, and greenstone.

The outwash sands and gravels occur principally along a relatively low-lying belt generally following the Michigamme River, Michigamme Reservoir, and the Fence River. Bergquist (1932, p. 367) believes that the larger river valleys, such as the Michigamme, correspond in part to the preglacial drainage system of the area. Small valleys that contain outwash deposits and cross till plains or moraine probably have no relationship to preglacial drainage. The glaciofluvial material was deposited late in the waning stage of glaciation. The outwash material, in some places clearly layered or cross bedded, consists of admixed sand and gravel, or of well-sorted sand, overlain in places by silt.

Many of the upland areas, hills, and isolated knobs in the northern part of the quadrangle are underlain by bosses of granitic or more basic rocks that crop out on the higher parts of the hills where glacial scouring and postglacial erosion have been effective. Many exposures in the southwestern part of the quadrangle are also caused in part by glacial scouring.

STREAMS AND SWAMPS

Surface drainage in the Kiernan quadrangle is dominated by the Michigamme and Fence Rivers. The Michigamme River flows generally south of west across the central part of the area to the vicinity of Way Dam near the north edge of sec. 6, T. 43 N., R. 31 W., and from there generally south and southeast.

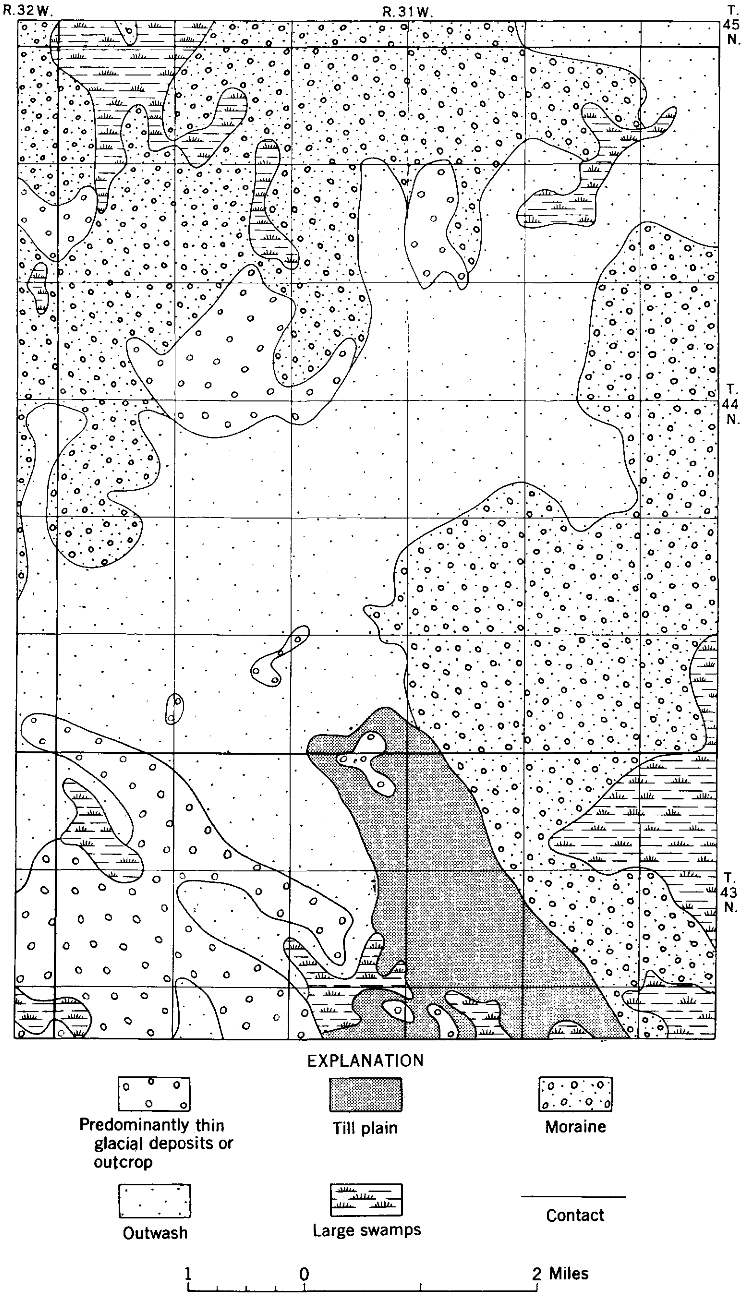

FIGURE 3.—Distribution of glacial deposits in the Kiernan quadrangle. Modified from Bergquist, 1935, map 36.

About half the former course of the river across the quadrangle is now obscured by Michigamme Reservoir above Way Dam. In the reservoir area and along its backwaters, exposures reported by earlier workers have been flooded. In a few places, such as in the N½ sec. 32, T. 44 N., R. 31 W., shore erosion has increased the size and quality of exposures.

The Fence River flows generally southward across the northern part of the quadrangle and enters an arm of the reservoir in sec. 21, T. 44 N., R. 31 W. Erosion of the glacial cover by the Fence River has helped cause the many bedrock exposures immediately west of the lower reaches of the river.

Some of the best exposures in the quadrangle are found along two smaller streams, Margeson Creek and Noyes Creek. Margeson Creek has exposed many excellent outcrops in sec. 7, T. 44 N., R. 31 W., and in sec. 12, T. 44 N., R. 32 W. Erosion along the north side of the valley of Noyes Creek and along some of its intermittently flowing tributaries has exposed granitic rocks and gneiss in secs. 17, 18, 19, and 20, T. 44 N., R. 31 W.

Much of the surface drainage in the area is unintegrated and centers in numerous isolated swamps ranging in altitude from 1,360 to 1,540 feet.

FIELD METHODS

The fieldwork on which this report is based was done between February 1952 and June 1953.

All geologic mapping was done directly on enlargements of the topographic map of the Kiernan quadrangle made by the U. S. Geological Survey. (See pl. 1.) All known outcrops have been plotted on the map.

Outcrops were located by pace and compass traverses from known points and, wherever possible, by direct reference to topographic features. In general, in the search for outcrops most of the quadrangle was traversed along north-south or east-west lines located 250 to 500 feet apart. Many favorable areas of potential outcrop between traverses, such as hillsides or swamp margins, were further examined carefully. In this way, practically all outcrops in the quadrangle were located with a maximum error of about 100 feet.

An area of about 11 square miles centering approximately on Michigamme Mountain was surveyed with magnetometers in an effort to unravel the confusing relationships between the several magnetic formations in that part of the quadrangle. The magnetic data are plotted on an enlargement of part of the Kiernan quadrangle topographic sheet (pl. 2). Field methods and handling of data are discussed in the section of this report dealing with magnetic surveys.

LABORATORY METHODS

The petrographic descriptions in this report are based mainly on examination of about 325 thin sections. Feldspar determinations are based on measurements of the maximum extinction angle of albite twinning, on measurements of the extinction angle to (010) in sections perpendicular to *X* or *Z*, on the determination of optic sign, and by the liquid immersion method using standard 3-place oils.

Volume percentages of minerals were determined by visual estimates, and grain sizes have been measured with an ocular micrometer. In this report, grain sizes less than 0.1 mm are referred to as fine, grains between 0.1 mm and 2.0 mm are called medium, and grains larger than 2.0 mm are considered coarse.

Four complete chemical analyses and a number of partial analyses were made in the laboratories of the U. S. Geological Survey.

ACKNOWLEDGMENTS

Information obtained from drilling done between 1917 and 1923 by the J. M. Longyear Company of Marquette, Mich., and by the Ford Motor Company, especially in and near sec. 3, T. 43 N., R. 31 W., has been of considerable value in formulating a structural interpretation in the vicinity of Michigamme Mountain. The writers appreciate the opportunity afforded by the J. M. Longyear Company and by the Ford Motor Company and the Cleveland Cliffs Iron Company to examine the core from this drilling. The locations of the Longyear ("L" numbers) and the Ford ("F" numbers) drill holes are shown on plate 2. Recent drilling south of the Kiernan quadrangle by Leonard and Virgil Skewes has also provided information of use in the geologic interpretation presented here.

Mr. James D. Hume rendered valuable assistance during the summer of 1952 by making part of the magnetometer survey near Michigamme Mountain and by mapping a portion of the area south of Michigamme Reservoir.

STRATIGRAPHIC TERMINOLOGY

The correlation of bedded Precambrian rocks of the Marquette trough with the type Huronian sequence north of Lake Huron by early workers in the Lake Superior area (Hunt, 1861; Kimball, 1865; Irving, 1885) is now subject to considerable doubt. Applying to the Kiernan area the practice followed during recent Survey work in central Dickinson County, Mich.,[3] crystalline rocks older than the Huronian of former reports are called Lower Precambrian instead of Archean; rocks formerly correlated with the Huronian are now

[3] James, Lamey, Clark, and others, op. cit.

referred to the Middle Precambrian; Precambrian rocks younger than those formerly designated as Huronian are now called Upper Precambrian rocks. Subdivision of Lower, Middle, and Upper Precambrian rocks of the Kiernan quadrangle into formal groups or series has not been attempted in the present report. Wherever necessary for the sake of clarity, specific formations of Middle Precambrian rocks are correlated with the "Lower Huronian," "Middle Huronian," or "Upper Huronian" as used in U. S. Geological Survey Monograph 52 (Van Hise and Leith, 1911).

PREVIOUS GEOLOGIC WORK

The Kiernan quadrangle lies within a broad area that has been the subject of several previous geologic reports and maps. J. M. Clements and H. L. Smyth (1899a, 1899b) studied the Kiernan and adjacent areas in 1892. Most of the principal stratigraphic units were delineated, and a fairly comprehensive description of "Huronian" rocks of the area was presented.

Clements and Smyth recognized two major groups of Precambrian rocks: an older group of crystalline rocks which they identified as rocks of Archean age, exposed in the core of a large uplift east of Amasa (the Amasa oval of this report); a younger group, separated by a major unconformity from the older rocks, and correlated by them with Huronian rocks of the Marquette Range. They divided these later Precambrian rocks into a Lower Huronian and an Upper Huronian series, in conformity with the then-accepted grouping of Huronian rocks of the Marquette area. Included in their Lower Huronian series were, in upward succession, the Sturgeon quartzite, the Randville dolomite, the Mansfield slate, the Hemlock formation, and the Groveland formation considered equivalent to the Negaunee iron-formation of the Marquette Range. The Mansfield slate was believed to pass along its strike into the lower part of the Hemlock formation. Near Michigamme Mountain the Mansfield was supposed to occupy the entire stratigraphic section between the Randville dolomite and the Groveland formation. The Upper Huronian series of Clements and Smyth in the Kiernan area consisted of the Michigamme slate.

Van Hise and Leith (1911, p. 251) recognized three major series within the Huronian sequence in the Marquette area. These were called Lower Huronian, Middle Huronian, and Upper Huronian. Corresponding subdivisions of the "Huronian" rocks of the Kiernan area were established. The Sturgeon quartzite, believed to be represented only by a thin, poorly developed slate, and the Randville dolomite were placed in the Lower Huronian; the Hemlock formation and the Negaunee iron-formation (formerly called Groveland by Clements and Smyth) were placed in the Middle Huronian; and the Michigamme slate was placed in the Upper Huronian series. In addition to these adjustments, Van Hise and Leith reassigned the "Mansfield slate" to the status of a local unit within the upper part of the Hemlock formation. They did not correlate slates near Michigamme Mountain and to the west in sec. 32, T. 44 N., R. 31 W., with "Mansfield slate" as Smyth had done; they merely noted the position of the slates immediately overlying Randville dolomite and underlying Negaunee ("Groveland") iron-formation (1911, p. 295–296). In other respects the relative positions assigned the rocks of the Kiernan area by Clements and Smyth were retained by Van Hise and Leith.

Allen and Barrett (1915, p. 25–27) disagreed with conclusions of Van Hise and Leith regarding the lack of correlation of iron formations on the east and west sides of the Amasa oval. Van Hise and Leith concluded that the iron-formation extending southeastward toward Crystal Falls from near Amasa on the west side of the oval was equivalent to the Vulcan iron-formation, then being placed with Upper Huronian rocks in the Menominee Range. They followed Smyth in correlating the south-trending iron-formation that enters the Kiernan quadrangle immediately east of the oval in sec. 34, T. 45 N., R. 31 W., with the Negaunee iron-formation of the Marquette Range and the Republic trough to the northeast. In the tripartite division of the Huronian rocks of the Marquette Range, the Negaunee had been placed in the Middle Huronian. Allen and Barrett supported this correlation but argued that the iron-formation near Amasa on the west side of the oval is correlative with the iron-formation on the east side of the oval and hence also of Middle Huronian age. Their interpretation of the geology within the limits of the present Kiernan quadrangle was in substantial agreement with the conclusions presented by Van Hise and Leith.

The most recent relatively large-scale regional geologic map to include the Kiernan quadrangle is the Geologic Map of Iron County, Mich. (Barrett, Pardee, and Osgood, 1929), published by the State of Michigan. The interpretation and formational patterns in the area of the Kiernan quadrangle differ significantly on this map in two respects from those presented in Monograph 52. The termination, northeast of Michigamme Mountain, of the iron-formation extending southward along the eastern side of the oval was attributed by Barrett, Pardee, and Osgood to a northwest-trending fault. They showed the iron-formation offset to the northwest along the fault and continuing southward from the fault to Michigamme Mountain. Barrett, Pardee, and Osgood also extended the granitic core of the oval about a mile farther south than it had previously been shown, into the area now occupied by the central part of Michigamme Reservoir.

Leith, Lund, and Leith (1935), reviewed the geology of the Lake Superior area in the light of geologic information acquired after the work of Van Hise and Leith. On the small-scale map accompanying the report, the geology in the area of the Kiernan quadrangle is shown substantially as it had been by Barrett, Pardee, and Osgood.

On the geologic map of northern Michigan (Martin, 1936), the interpretation presented by Barrett, Pardee, and Osgood (1929), and by Leith, Lund, and Leith (1935), is retained within the area of the Kiernan quadrangle.

GENERAL GEOLOGY

STRATIGRAPHY

According to the interpretation advanced here, the Lower Precambrian rocks of the Kiernan quadrangle include magnetic green schist, and granitic rocks and gneiss of the Margeson Creek gneiss. Middle Precambrian rocks overlie the Lower Precambrian rocks unconformably; in upward succession they are Randville dolomite with minor associated sericite slates, Goodrich quartzite with some fragments of possible Negaunee iron-formation, Hemlock formation, Fence River formation, and Michigamme slate. Unconformities are believed to exist at the base of the Randville dolomite, at the base of the Goodrich quartzite, and at the base of the Michigamme slate. The Randville is in the Lower Huronian, and the Goodrich, Hemlock, Fence River formation, and the Michigamme slate are in the Upper Huronian of former reports. Upper Precambrian rocks are represented in the area by the single fresh negatively magnetized diabase dike of possible Keweenawan age in the SW¼ sec. 10, T. 44 N., R. 31 W. These units and relationships are indicated in tables 1 and 2.

TABLE 1.—*Past and present usage of stratigraphic terms and formation names in the Kiernan quadrangle*

U. S. Geol. Survey Monograph 52		Present Report	
Keweenawan		Upper Precambrian	Diabase.
Upper Huronian	Michigamme slate		Michigamme slate. Fence River formation. Hemlock formation. Goodrich quartzite (with some fragments of possible Negaunee iron-formation).
Middle Huronian	Negaunee formation Hemlock formation	Middle Precambrian	
Lower Huronian	Randville dolomite Sturgeon quartzite		Randville dolomite.
Archean	Granites and gneisses	Lower Precambrian	Granite rocks, gneiss, migmatite, magnetic green schist.

TABLE 2.—*Rock units in the Kiernan quadrangle*

Age	Rock	Thickness in feet	Remarks
Pleistocene	Glacial deposits	0–300 (?)	Till; moraine; outwash sand and gravel. Mantles most of quadrangle.
		—Unconformity—	
Cambrian	Sandstone	0–50 (?).	Mainly loosely cemented quartz sandstone. Probably forms flat-lying erosional remnants. Found only on test pit dumps in southern part of quadrangle.
		—Unconformity—	
Upper Precambrian.	Diabase		Fresh unaltered dike rock. Cuts Hemlock formation in sec. 10, T. 44 N., R. 31 W. Rock inversely magnetized.
Middle Precambrian (?).	Intrusive rocks: Quartz porphyry.		Strongly foliated quartz-sericite rock with characteristic quartz "eye" phenocrysts. Forms dikes or sills in Margeson Creek gneiss.
	Intrusive rocks: Fine-grained greenstone.		Slaty well-foliated dike rock intruded mainly into Margeson Creek gneiss, particularly along faults and fractures near south end of Amasa oval.
Middle Precambrian.	Intrusive rocks: Metagabbro and metadiabase.		Medium- to coarse-grained rock forming two large sills in Hemlock formation and smaller irregular masses in the Hemlock formation and in the Randville dolomite. West Kiernan sill contains mostly metagabbro and metadiabase, with some pegmatitic rock and granophyre in upper part.
	Intrusive rocks: Trachyte		Light-colored foliated altered feldspar-sericite rock believed to be intrusive into the Randville dolomite.
	Michigamme slate	10,000±	Only exposure in quadrangle is of quartz-biotite schist, metavolcanic in origin, lying near base of formation. Outside quadrangle, formation is known to be predominantly slate and graywacke with some interbedded metavolcanic rock.
		—Unconformity—	
	Fence River formation.	0–250 (?).	Not exposed in quadrangle, but extended into area because of magnetic data. In outcrop 2½ miles north of quadrangle lower part of formation is mainly thin-banded fine-grained quartz-magnetite rock, and upper part is massive garnet-grunerite schist. Formation is strongly magnetic.
	Hemlock formation	2,000–6,000 (?)	Mainly greenstone; predominantly metabasalt in southwestern part, basic schist in northeastern part, and metarhyolite (including sericite slate) in southeastern part of quadrangle. Magnetic in places. Attains thickness of about 20,000 feet west of quadrangle.
	Goodrich quartzite	0–500 (?)	Fine- to medium-grained ferruginous quartzite, typically with abundant clastic quartz grains. Matrix commonly cherty. Contains some fragments of possible Negaunee iron-formation. Strongly magnetic in most places.
		—Unconformity—	
	Randville dolomite	1,800±.	Mainly buff to pink, fine- to medium-grained dolomite with scattered quartz grains. Includes some arkose and quartzite. Slate-schist units near top and bottom of formation. Silica rock in NW¼ sec. 34, T. 44 N., R. 31 W., believed to be silicified dolomite developed on Precambrian erosion surface.
		—Unconformity—	
Lower Precambrian.	Margeson Creek gneiss.	Type of contact unknown?	Mainly foliated gneissic granitic rocks and older banded gneiss.
	Magnetic green schist.		Not exposed in quadrangle. South of quadrangle rock is mainly green chloritic schist with some red sericitic schist. Strongly magnetic in places.

The present interpretation of the relationships between the Middle Precambrian formations within the area of the Kiernan quadrangle differs from those presented in previous publications in the following main respects:

1. The "Negaunee iron-formation" described in previous reports as being present at Michigamme Mountain and vicinity is erosional rubble within the Goodrich quartzite.
2. The Goodrich quartzite at Michigamme Mountain directly overlies Randville dolomite or a thin slate unit at the top of the Randville.
3. The iron-formation causing the belt of magnetic anomaly on the east side of the Amasa oval, and cropping out only north of the quadrangle at the Sholdeis exploration (fig. 2), is younger than the iron-rich Goodrich quartzite at Michigamme Mountain and therefore is an "Upper Huronian" formation. Formerly it was correlated with the "Middle Huronian" Negaunee iron-formation. It is here named the Fence River formation.
4. The Hemlock metavolcanic rocks lie above the Goodrich quartzite at Michigamme Mountain and below the Fence River formation on the east side of the oval. No Middle Precambrian metavolcanic rocks older than the Goodrich have been found.
5. Metarhyolite, not definitely recognized as such before, forms part of the Hemlock formation at Michigamme Mountain and to the northeast.
6. The termination of the magnetic anomaly on the Fence River formation in sec. 27, T. 44 N., R. 31 W., is held to be due to the removal of the formation south of that section by erosion prior to deposition of the Michigamme slate. The termination of this anomaly was attributed to faulting (Barrett, Pardee, and Osgood, 1929, Leith, Lund, and Leith, 1935, and Martin, 1936).

STRUCTURE

Structures in the quadrangle are dominated by two uplifts of Lower Precambrian rocks along a line from the northwestern to the southeastern parts of the quadrangle. The northwestern of these two uplifts is the western or Crystal Falls "Archean oval" or "ellipse" of Clements and Smyth (1899 b) and Van Hise and Leith (1911). This uplift is here called the Amasa oval, the name it is generally given now by geologists in the region. The southeastern uplift consists of an unexposed core of Lower Precambrian magnetic green schist flanked by belts of Middle Precambrian rocks.

Middle Precambrian metasedimentary and metavolcanic rocks dip outward along the flanks of the Amasa oval to form belts roughly parallel to the east and west sides of the core. Randville dolomite forms relatively narrow belts on the east and west sides of the uplift but has a broad area of exposure to the south on the nose of the uplift.

The axis of the Amasa oval uplift plunges south-southeastward from the southern end of the oval in secs. 20 and 21, T. 44 N., R. 31 W., toward Michigamme Mountain where the south-southeast trend is interrupted by several crossfolds. Farther southeast, in secs. 10, 14, and 15, T. 43 N., R. 31 W., the north-northwest to south-southeast structural axis again rises, bringing the magnetic green schist toward the surface. In recent drilling south of the quadrangle in T. 43 N., R. 31 W., this formation was found at the preglacial surface.

METAMORPHISM

At least two periods of regional metamorphism are evident in the rocks of the quadrangle. One, and possibly more than one, general metamorphism occurred prior to the forming of Middle Precambrian rocks. This metamorphism accompanied igneous intrusion or migmatization-granitization of Lower Precambrian rocks exposed in the Amasa oval. The other period of metamorphism—the latest—occurred sometime after the formation of the youngest Middle Precambrian rocks and before the intrusion of the Upper Precambrian diabase. It generally modified the effects of earlier metamorphism.

James (1955) has traced metamorphic zones developed during this latest period of regional metamorphism across the western part of the northern peninsula of Michigan. The modifying effect of the younger metamorphism on the older is attested by the fact that the zones delineated by James pass essentially without deflection from Middle Precambrian rocks across areas of Lower Precambrian rocks. In the Kiernan quadrangle, metamorphic zones trend approximately southeast, and the metamorphic grade increases from the southwestern to the northeastern part of the quadrangle. There is no relationship between the trends of the zones and the contact between Lower and Middle Precambrian rocks, although this is more evident in the large area studied by James than in the relatively small area of the Kiernan quadrangle.

The range of metamorphic grade in the rocks of the quadrangle is from the chlorite zone, as used in the Scottish Highlands (Barrow, 1893, 1912; Bailey, 1923), to the upper part of the biotite zone or the lower part of the garnet zone. The trends and approximate locations of the metamorphic zones in the quadrangle are shown in figure 4. The increase in metamorphic grade to the northeast is best observed in the widely distributed Hemlock formation. Near the southwestern corner of the quadrangle, metavolcanic rocks of the Hemlock contain chlorite, sericite, and pale-green hornblende and are in the chlorite zone or the muscovite-chlorite subfacies of the green schist facies

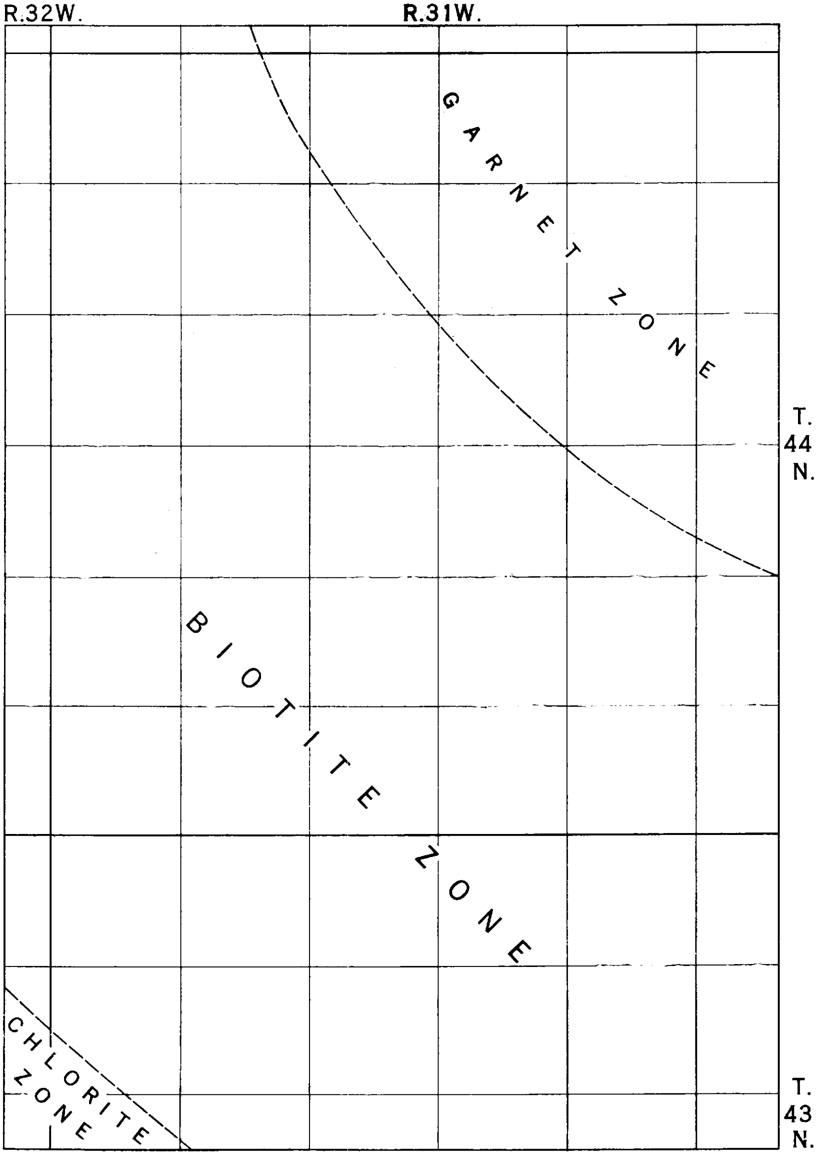

FIGURE 4.—Outline map of Kiernan quadrangle showing approximate location and trends of metamorphic zones.

(Eskola, 1915, 1920; Turner, 1948). Several thousand feet northeast of the southwestern corner, and from there northeastward, biotite occurs indicating that the rock is in the biotite zone or in the biotite-chlorite subfacies of the green schist facies. North of the northeastern shore of Michigamme Reservoir, hornblende is blue green rather than pale green, and the metavolcanic rocks are in the upper part of the biotite zone or in the lower part of the garnet zone (albite-epidote amphibolite facies). Garnet has not been found in the metavolcanic rocks in the northeastern part of the quadrangle; however, it occurs in the rocks a few miles to the north near the Sholdeis exploration in sec. 21, T. 45 N., R. 31 W. By projection from the Sholdeis exploration the garnet zone appears to cross the extreme northeastern part of the quadrangle.

LOWER PRECAMBRIAN ROCKS

MARGESON CREEK GNEISS

Lower Precambrian rocks are exposed in the quadrangle only in the Amasa oval, where they may be seen in small isolated knobs and on many hills. These rocks are named the Margeson Creek gneiss in the present report, after Margeson Creek along which there are many exposures in sec. 12, T. 44 N., R. 32 W.; secs. 6 and 7, T. 44 N., R. 31 W.; and sec. 31, T. 45 N., R. 31 W.

Most of the rocks of the Margeson Creek gneiss are gneissic and granitic, ranging from granite to tonalite (quartz diorite) in composition. There are two principal types of gneissic rock. One type has distinct layers of light and dark minerals parallel to foliation.[4] It is called banded gneiss in this report. It is generally gray and of granodioritic to tonalitic compositions. Biotite- and hornblende-rich phases of the banded gneiss are locally abundant. The other main type of gneissic rock is nonbanded and commonly inequigranular. It has pronounced alinement of minerals, particularly tabular phenocrysts or metacrysts of feldspar, parallel to foliation. This type is here called gneissic granitic rock or foliated granitic rock (fig. 5). It is generally gray to pink and of granitic to granodioritic composition. Among the less common types of rock are nonfoliated granitic and pegmatitic rocks that are generally equigranular. A foliated quartz-sericite rock is found along inferred faults in the southern part of the area of exposures and is interpreted as mylonitized granitic rock. Distinctions between the rocks of the Margeson Creek gneiss are listed in table 3.

Many of the larger outcrops contain both banded gneiss and gneissic granitic rock. Residual layers or tabular inclusions of banded gneiss

[4] As used here, "foliation" refers to a close-spaced planar structure that appears in outcrop as fine irregular, subparallel lines or seams distributed across the rock surface.

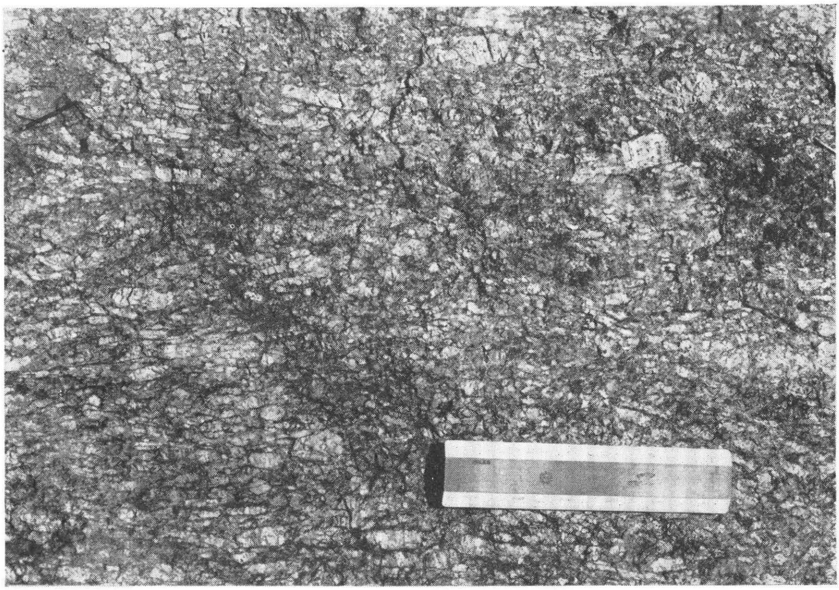

FIGURE 5.—Foliated inequigranular granitic rock of Margeson Creek gneiss. Large tabular feldspars are well alined and form about 50 per cent of the rock. Loc. 3,600 feet north and 1,300 feet west of southeast corner sec. 12, T. 44 N., R. 32 W. Length of scale is 6 inches.

are locally common in the foliated granitic rocks; they are especially well exposed in places in the SE¼ sec. 12, T. 44 N., R. 32 W. In places these inclusions or residual layers are sharply truncated by the surrounding granitic rock, proving conclusively that the banded gneiss formed prior to the granitic rock. Although inequigranular foliated granitic rocks are much more abundant than banded gneiss, exposures of the gneiss are found throughout the southern part of the oval. Because of the intimate association of banded gneiss and gneissic granites and because of their common alternation from one outcrop

TABLE 3.—*Rocks of the Margeson Creek gneiss*

Foliated			Nonfoliated—Nonbanded, Equigranular (generally)
Banded	Nonbanded		
Equigranular	Inequigranular [1]	Equigranular	
Granodioritic to tonalitic gneiss; includes some amphibolite, biotite schist, and sericite schist.	Gneissic granitic rock; mostly quartz monzonite and granodiorite; characterized by large alined tabular microcline.	Gneissic granitic rock; mostly granodiorite and tonalite.	Mainly pegmatitic granite. Commonly grades into surrounding foliated granitic rock.
Medium-grained	Medium- to coarse-grained.	Medium-grained	Medium- to coarse-grained.
Relatively abundant	Abundant	Not abundant	Not abundant.

[1] In this table, does not include mylonitized granitic rock.

to another, it has not been possible to define clear-cut areas of granitic rocks or of banded gneiss. Such distinctions might be made on maps of suitable large individual outcrops, if mapped at a scale considerably greater than 1:12,000.

Migmatite, consisting of an intimate mixture of banded gneiss and nonfoliated granitoid material is widely distributed but not abundant. It is best exposed in the SE¼ sec. 12, T. 44 N., R. 32 W., the south-central part of sec. 17, and the north-central part of sec. 20, T. 44 N., R. 31 W. The migmatite is not a mappable unit. It forms small irregular zones of transitional material between banded gneiss and gneissic granitic rock. Individual exposures of obvious migmatite generally do not encompass areas measuring more than a score of feet in any direction. The commonest form of migmatite in the area is a lit-par-lit arrangement of apparently structureless quartz-feldspar granitic material between gneiss layers. Another form of migmatite consists of medium-grained banded gneiss containing widely separated metacrysts of feldspar, ranging in length from a quarter of an inch to 3 inches.

BANDED GNEISS

General features.—Banded gneiss is found throughout the Margeson Creek gneiss. It consists mainly of foliated grayish rocks with compositions and textures similar to those of granodiorite and tonalite. Bands are commonly on the order of ½ inch to 1 foot in width. Amphibolite, biotite-quartz schist, biotite-feldspar schist, and sericite-quartz schist are minor phases of the banded gneiss. Petrographic data are listed in table 4.

Granodioritic and tonalitic varieties.—Albite-oligoclase, quartz, and biotite constitute most of the granodioritic and tonalitic gneisses. Microcline generally does not exceed 10 percent; orthoclase and perthite are minor constituents. The texture is sheared granitoid or granoblastic in most places. Dark layers and zones containing thin dark-green biotite seams commonly alternate with broader light-colored layers rich in quartz and feldspar. Some larger quartz grains are elongated or flattened parallel to foliation. Shear seams in the light-colored layers are generally filled with fine-grained sericite (or paragonite?) and quartz, and fragmented quartz and feldspar are commonly strung out parallel to shears. The sericite or paragonite is derived by the alteration of sodic plagioclase. Microcline generally is not sericitized. Much of the biotite appears to be primary; some, however, may have formed at the expense of sheared feldspar. The biotite probably was extensively rearranged along shears during deformation.

TABLE 4.—*Petrographic data for rocks of the Margeson Creek gneiss*

[Some minerals fall in more than one of the three percentage columns. Mineral name is in parentheses if that mineral belongs in indicated column in only few specimens]

Rock	Dominant minerals >20 percent	Subordinate minerals 5–20 percent	Minor minerals <5 percent	Predominant grain sizes of dominant minerals, F—<0.1mm, M—0.1 to 2.0mm, C—>2.0mm	Remarks
			Banded gneiss		
Granodioritic and tonalitic.	Albite-oligoclase An_{8-15}	Microcline, biotite, sericite—some or all may be paragonite.	(Biotite), (microcline), orthoclase, perthite, carbonate, kaolinite, epidote, chlorite, ilmenite, leucoxene, apatite, zircon, pyrite.	M and C	Allotriomorphic granular texture. Cataclastic texture along microshears. Stringers and pods of mosaic quartz common.
Amphibolite	Hornblende, oligoclase-andesine An_{28-35}.	Clinozoisite, zoisite, and epidote.	Biotite, chlorite, sericite, kaolinite, carbonate, ilmenite, Apatite.	M	Granoblastic texture. Anhedral rod-shaped hornblende in sutured contact with equant feldspar.
Biotite schist	Biotite, (quartz), (chlorite).	Quartz, chlorite, (feldspar), (sericite).	Feldspar, (chlorite), sericite, carbonate, epidote, ilmenite, leucoxene, pyrite.	F and M	Strong alinement of platy minerals.
Sericite schist	Sericite, quartz	Biotite, (chlorite), (feldspar).	Chlorite, feldspar, carbonate, zircon, apatite, leucoxene, iron oxides.	F and M	Strong alinement of platy minerals.
			Granitic rocks		
Inequigranular	Microcline, albite-oligoclase An_{8-15}, quartz.	Biotite, perthite, (albite-oligoclase) gericite—some or all may be paragonite.	Chlorite, orthoclase, albite, kaolinite, carbonate, (perthite), apatite, zircon, leucoxene, iron oxides.	M and C	Sheared granitoid or allotriomorphic granular to hypidiomorphic granular texture. Carlsbad twins of microcline are common. Aggregates of sericite or paragonite, granular quartz, and biotite along shears, cataclastic zones, and cracks. Much biotite in patchy aggregates between larger feldspar and quartz.
Equigranular	Albite-oligoclase An_{8-15}, quartz, (microcline—dominant only in pegmatitic granite).	Biotite, sericite—some or all may be paragonite, microcline.	Chlorite, kaolinite, carbonate, (sericite), (microcline), apatite, zircon, leucoxene, iron oxides.	M, Pegmatitic varieties are C.	Mainly sheared granitoid or allotrimorphic granular textures. Small amounts of unsheared (nonfoliated) rock, much of which is pegmatitic.
Mylonitized	Sericite, quartz	Feldspar—mainly indeterminate. Some probably orthoclase.	(Feldspar), biotite, carbonate, kaolinite, zircon, leucoxene, iron oxides.	F and M	Feldspar much fragmented and kaolinized. Feldspar and quartz immersed in sericite groundmass. Quartz in unstrained mosaics and in strained segments of original granitic rock.

Amphibolite.—Amphibolite is found in the gneiss in the NW¼ sec. 5 in the NE¼NE¼ sec. 6, and in the SE¼NW¼ sec. 7, T. 44 N., R. 31 W. The rock is dark green. It forms small rounded smooth-surfaced outcrops. On weathered surfaces it has typical "salt and pepper" appearance caused by white altered feldspar between dark-green hornblende crystals. The amphibolite is in places weakly foliated parallel to trends of nearby gneiss; elsewhere it is not foliated. In the outcrops in secs. 5 and 6, it has a pronounced lineation caused by the alinement of prismatic hornblende. The rock consists almost entirely of hornblende and oligoclase or oligoclase-andesine and their alteration products. In the amphibolite in sec. 6, the plagioclase is extensively altered to zoisite and clinozoisite. In the amphibolite in sec. 7, hornblende has been considerably altered to biotite, some of which in turn has changed to chlorite.

The amphibolite appears to represent igneous rock of gabbroic or dioritic composition that was injected into the gneiss or pregneissic sediments and later metamorphosed.

Biotite and sericite schists.—Zones or layers of biotite-quartz schist ranging from a few inches to about 1 foot in thickness have been found in the gneiss in a few small and widely separated outcrops. This rock is dark green to black. It consists mainly of greenish-brown biotite and quartz, with some chlorite and small amounts of other minerals as listed in table 4. The biotite is in well-alined blades and flakes alternating with grains and stringers of quartz. The chlorite has the bladelike form of biotite, grades into biotite in places, and is clearly a result of retrograde metamorphism.

Biotite-feldspar schist and sericite-quartz schist are minor phases of the gneiss known in only a few widely separated localities.

GRANITIC ROCKS

Distribution.—Granitic rock forms most outcrops of the Margeson Creek gneiss. The best exposures are in sec. 12, T. 44 N., R. 32 W., and in secs. 16, 17, 18, 20, and 21, T. 44 N., R. 31 W. Outcrops or parts of outcrops of the Margeson Creek gneiss not otherwise specifically designated on the map consist of granitic rock.

Description.—Outcrops generally are rounded bare knobs of varying size. The glacially scoured surfaces commonly have been darkened by weathering and thin films of organic matter.

The granitic rocks range in composition from granite to tonalite, but about two-thirds of the material examined is quartz monzonite and granodiorite. The fresh rock generally is gray or gray green to pink; in many places the interspersion of the different colored minerals produces a mottled effect. The dominant minerals are sodic plagioclase, microcline, and quartz. The granitic rocks are typically well foliated, and in the inequigranular varieties the larger feldspar crystals are generally alined parallel to foliation. The foliation is marked by thin irregular biotite-bearing seams which in places fray out into a structureless groundmass. In thin section, sheared granitoid textures prevail. Although mineral grains are mostly subhedral to anhedral, some larger microcline crystals approach euhedral form. Petrographic data are listed in table 4, and the common minerals are shown in typical arrangement in figure 6.

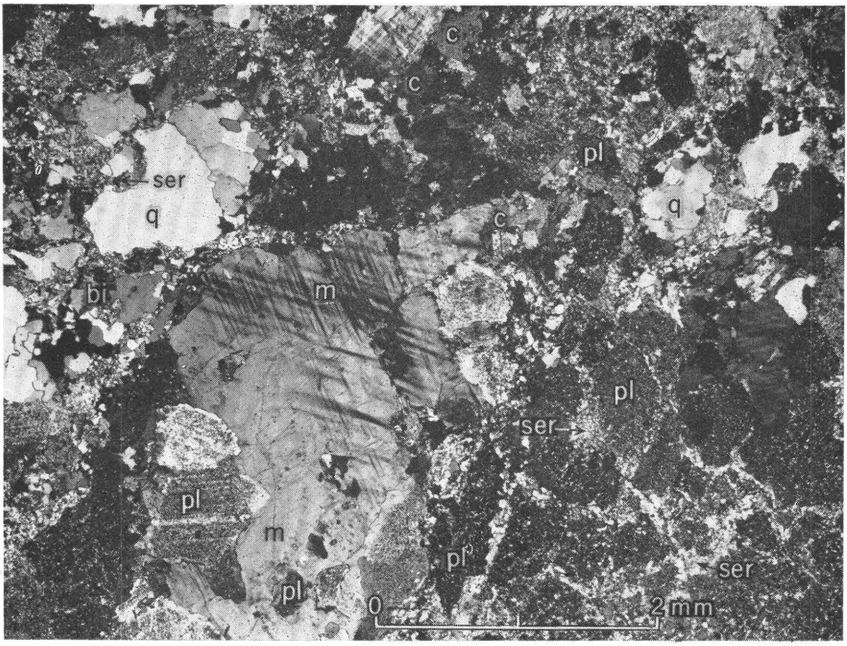

FIGURE 6.—Photomicrograph of typical granitic rock in Margeson Creek gneiss. Microcline is much fresher than sodic plagioclase. Sodic plagioclase is sericitized extensively. Crossed nicols. Loc. 4,200 feet north and 200 feet west of southeast corner sec. 20, T. 44 N., R. 31 W. (*m*) microcline, (*pl*) plagioclase, (*ser*) sericite, (*q*) quartz, (*c*) carbonate, (*bi*) biotite.

The chief mineralogic distinction between the equigranular and inequigranular granitic rocks is the dominance of sodic plagioclase in the equigranular rocks and microcline in the inequigranular rocks. In the inequigranular rocks, sodic plagioclase is abundant only in the groundmass. Sericite clouds much of the sodic plagioclase in both equigranular and inequigranular rocks. Microcline constitutes most of the large crystals of the inequigranular rocks and forms about one-third to one-half of the material in the rocks. Percentages of the large crystals are difficult to estimate because, at most, only a few such crystals occur in any one thin section. The microcline occurs principally as phenocrysts or metacrysts, 3 millimeters to 5 centimeters in length. The fresh microcline contrasts strikingly with the altered plagioclase of the groundmass. Minor amounts of fresh groundmass-size microcline may have resulted from the fragmentation of larger crystals. The freshness of the microcline in respect to sodic plagioclase may indicate (1) that the microcline grew in place after the sodic plagioclase of the host rock had already been altered or (2) selective alteration of sodic plagioclase to sericite in rock also containing microcline. Other features discussed below in the section on "origin" (p. 25–26) give some support to the idea that the microcline is younger than the plagioclase.

In some specimens large tabular microcline has changed in part to perthite or has been considerably replaced by albite (fig. 7). Along

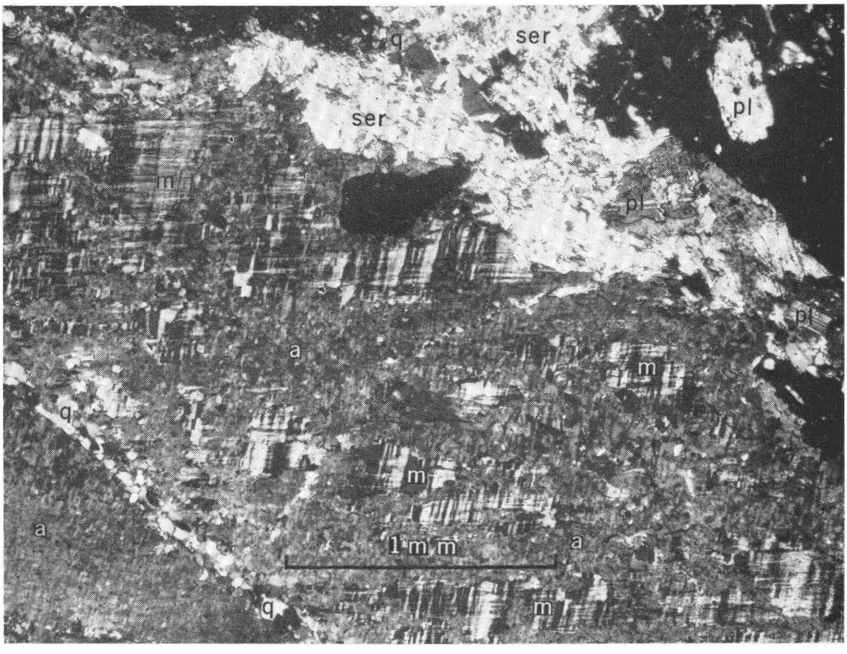

FIGURE 7.—Photomicrograph of microcline crystal partly replaced by albite. From foliated inequigranular granitic rock of Margeson Creek gneiss, 600 feet north and 600 feet west of southeast corner sec. 36, T. 45 N., R. 32 W. All isolated relict patches of microcline extinguish simultaneously. Albite has faint chessboard structure. Quartz veinlet crosses microcline-albite crystal in lower left part of photograph. Patches of sericite (or paragonite?) lie between many of larger feldspar crystals of rock. Crossed nicols. (*m*) microcline, (*a*) albite, (*ser*) sericite, (*q*) quartz, (*pl*) plagioclase.

the albite-microcline interface in one of the partly replaced crystals, stringers of albite project into the microcline to form a replacement perthite.

Orthoclase and perthite are minor or subordinate constituents of some of the granitic rocks. (See table 4.) In the inequigranular rocks perthite forms both medium-size angular grains in the groundmass and coarse tabular crystals, some of which have carlsbad twinning.

Large phenocrysts or metacrysts of albite occur in small amounts in the inequigranular granitic rocks. The albite is commonly fresh looking (unsericitized) and untwinned, although some is rather mottled or has chess-board structure. It may have formed by the replacement of potash feldspar in the manner of the partial replacement of microcline by albite described above and shown in figure 7.

Although the soda necessary for these actual and inferred replacements may have been derived from outside the rock, it seems more likely that the soda was derived by unmixing in the observed crystals and in nearby potash-soda feldspars. Possibly the unmixing was a response to shearing and crushing of the rock, as postulated by Emmons and Gates for somewhat similar rocks in northern Wisconsin (Emmons, and others, 1953, p. 56, 71). Chayes (1952) has noted a possible relationship between granulation and unmixing in the formation of perthite. It is not clear whether the albitization of the microcline occurred late in the period of Lower Precambrian granite intrusion or granitization in which the microcline formed or whether it is a result of later deformation, such as the uplift of the Amasa oval.

Quartz occurs in equant or elongated strained crystals, lensoid pods with mosaic texture, and as fine granular aggregates. Small granular quartz is generally interspersed with sericite and biotite. Biotite forms patchy aggregates between feldspar and quartz grains. Much of the biotite may have been primary, but if so, it was mobilized and recrystallized during shearing of the rock.

ORIGIN

The principal rocks of the Margeson Creek gneiss are banded gneiss and inequigranular granite. In most places, the contacts between these rocks are gradational and their mutual relationships vague. Locally, however, the structure of the gneiss is truncated by the granite, and it seems reasonable to conclude that the gneiss is the older rock. The well-developed layering in the gneiss suggests further that it has been derived from an original bedded rock of somewhat similar composition. The gneiss, therefore, may be considered to represent an originally layered country rock in which the granite was emplaced.

The structural and textural relationships between the gneiss and the granite lead to the conclusion that the granitic rocks originated by a combination of metasomatic growth of feldspar phenocrysts in the gneiss (or its precursor) and local magma injection. The relative importance of these two processes is difficult to evaluate; and, of course, they are by no means mutually exclusive. The idea of magmatic emplacement is supported by the homogeneity of some areas of granite, by the local truncation of gneissic structure (with foliation in the crosscutting granite parallel to the contact), and by the local development of coarse-grained unfoliated pegmatite "patches." Metasomatism is indicated by the common occurrence of gradational contacts and by the local growth of tabular feldspar metacrysts athwart sharp contacts. Furthermore, widely separated feldspar metacrysts similar to those in the granite are common in the banded gneiss, and it seems evident that more extensive growth of such metacrysts would yield a rock similar in every way to the inequigranular granite that is the dominant rock type in the Margeson Creek gneiss.

MYLONITIZED GRANITIC ROCK

Mylonitized granitic rock has been found in two narrow and elongate zones now marked by north- and northwest-trending gullies crossing exposures of granitic rock in the southern part of the Margeson Creek gneiss. One such zone—the main one—centers about 2,200 feet west and 900 feet south of the northeast corner sec. 20, T. 44 N., R. 31 W. The other zone centers about 1,950 feet west and 800 feet south of the same corner. A small area of mylonitized material in granitic rock occurs 2,680 feet west and 1,200 feet south of the above-mentioned section corner.

The mylonitized granitic rock is moderately schistose. The strike of foliation conforms locally with trends of the gullies along which the rock is found. Outcrops are small and elongate or roughly tabular in shape; their form appears to be controlled by the steeply dipping foliation. The rock is gray or mottled pink and gray. The dominant minerals are sericite and quartz, with subordinate feldspar. Although the rock is granulated and extensively recrystallized, phases transitional between the typical mylonitized material and normal granitic rock have been recognized. Petrographic data are listed in table 4.

AGE RELATIONS

The rocks of the Margeson Creek gneiss, occupying the core of the Oval, were described by Clements and Smyth (1899b), and by Van Hise and Leith (1911) as being unconformably beneath the Randville dolomite and were considered "Archean" in age. The present study corroborates these conclusions, although the term "Archean" is not used here.

Although the actual contact of the dolomite with rocks of the complex is nowhere exposed in the quadrangle, the following points indicate conclusively that the gneiss and granitic rocks are pre-Randville in age:

1. The general north to northwest trend of foliation in the banded gneiss and in the gneissic granitic rocks persists to the very southern end of the exposed complex. The Randville dolomite

therefore truncates the foliation of the gneissic and granitic rocks in secs. 20 and 21, T. 44 N., R. 31 W.
2. The rocks of the complex have undergone much greater mechanical deformation than has the Randville dolomite.
3. Granitic or pegmatitic offshoots have not been found in the Randville dolomite.
4. No contact metamorphic effects have been found in dolomite close to the contact with granitic rock.

The Margeson Creek gneiss, unconformably beneath the Randville, is in a position analogous to Lower Precambrian granitic and gneissic rocks of Dickinson County [5] although it does not necessarily correlate with these rocks.

MAGNETIC GREEN SCHIST

DISTRIBUTION

The magnetic green schist is not exposed in the Kiernan quadrangle. The rock has been traced magnetically from the vicinity of Sagola in west-central Dickinson County, Mich., where it has been correlated with rocks of the Lower Precambrian Dickinson group. [6] [7] From there it goes northwestward across the Lake Mary quadrangle [8] into the Kiernan quadrangle in sec. 14, T. 43 N., R. 31 W. (See pl. 2.) The rock is known only from a few outcrops and test pits near Sagola and from drill holes in the Lake Mary quadrangle.

DESCRIPTION

The magnetic green schist is mainly a green fine-grained schistose to slaty rock, deeply oxidized in places. Felsite schist or slate has been found in some drill holes. The rocks are chloritic and sericitic schists, locally rich in magnetite or martite. Foliation planes are commonly crinkled and lineated. Secondary carbonate minerals, probably calcite or dolomite, and quartz are distributed through the rock and in places carbonate minerals form seams parallel to foliation. The rock is probably altered volcanic material, mainly of basic composition.

AGE RELATIONS

The magnetic crest representing the green schist is bordered on the east and west by Randville dolomite. The dolomite on both sides of the magnetic crest is flanked by the Hemlock formation. Drilling in the N½ sec. 10, T. 43 N., R. 31 W., shows Randville dolomite

[5] James, H. L., Lamey, C. A., Clark, L. D., and others; U. S. Geol. Survey report on Central Dickinson County, Mich. (in preparation).

[6] Pettijohn, F. J., 1951, Geology and magnetic anomalies of T. 42 N., R. 30 W., Dickinson County, Mich., U. S. Geol. Survey, open file report, pl. 1.

[7] James, Lamey, Clark, and others, op. cit.

[8] Bayley, R. W., 1956, Preliminary report of geology of Lake Mary quadrangle, Iron County, Mich., U. S. Geol. Survey, open file report.

371023—56——3

flanked to the east and west by the Hemlock. The indicated structure along the green schist-magnetic line is a northwestward-plunging anticline in which the green schist underlies the Randville dolomite.

The southeastward extension of the green schist in west-central Dickinson County is probably correlative with a Lower Precambrian metavolcanic and metasedimentary sequence named the Dickinson group.[9] The rocks of the Dickinson group rest unconformably on granite gneiss, but in turn were cut by batholithic granite prior to Middle Precambrian time. Inasmuch as the relationships between the Margeson Creek gneiss, the pre-Dickinson gneiss, and the post-Dickinson granite are not known, the age relations of the Margeson Creek rocks and the magnetic green schist are unknown.

MIDDLE PRECAMBRIAN ROCKS

RANDVILLE DOLOMITE

The Randville dolomite was first named for exposures near Randville, in west-central Dickinson County, Mich. (Van Hise, 1899, p. 9–16). In the Kiernan area the Randville consists mainly of pure to slightly quartzose dolomite. In addition, however, the formation contains dolomitic quartzite, feldspathic quartzite, dolomitic arkose, arkose, sericite slate and schist, slaty graywacke, and a reddish quartzitic breccialike rock that is probably silicified dolomite. In two places a probable intrusive trachytic rock has been found in the belt of dolomite and is interlayered with dolomite in at least one of the two localities. The minor members and variations of the formation generally have been found in isolated irregularly distributed outcrops and have not been delineated as units on the map.

The Randville dolomite occupies two main belts. The largest and best exposed belt extends around the southern part of the Amasa oval to as far south as the SE¼ sec. 4, T. 43 N., R. 31 W. On the east side of the oval the minimum thickness of the formation across this belt is about 1,800 feet. The breccialike rock, believed to be silicified dolomite, is exposed in the NW¼ sec. 34, T. 44 N., R. 31 W., and is probably brought to the surface on a small anticline.

The other main belt flanks the southeastern green schist uplift and is known only from a few exposures of arkose in sec. 10 and from dolomite and arkose drilled in sec. 10 and south of the quadrangle. Although this belt is not thought to be as wide as the main belt to the north, there is insufficient evidence to provide an accurate estimate of thickness.

[9] James, Lamey, Clark, and others, op. cit.

DOLOMITE

Good exposures of dolomite are found in the N½ and SE¼ sec. 32 (fig. 8), the W½ sec. 33, T. 44 N., R. 31 W., and the NW¼ and SE¼ sec. 4, T. 43 N., R. 31 W. Outcrops of dolomite on the flanks of the oval are relatively scarce and widely scattered, especially on the west side.

Most of the Randville in the area is a relatively pure buff to pink dolomite. It forms knobby outcrops, typically with weathered cracks that give the rock a blocklike aspect (fig. 8). In places the rock has thin silty layers.

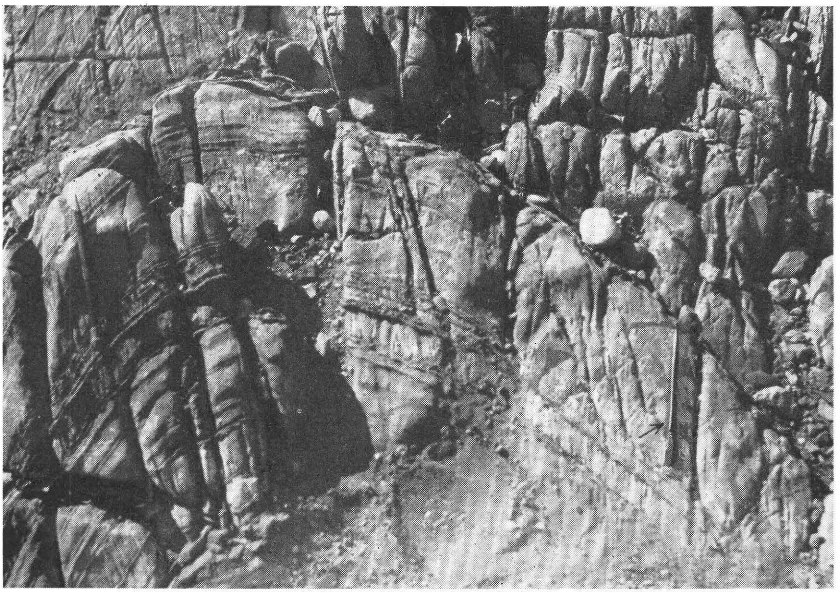

FIGURE 8.—Fold in Randville dolomite. Bedding marked by thin silty layers. Note slightly fanning cleavage. Pencil at lower right gives scale. Loc. 3,800 feet north and 4,700 feet west of southeast corner, sec. 32, T. 44 N., R. 31 W.

The Randville consists mainly of abundant dolomite, with subordinate or minor amounts of clastic quartz (table 5). Oolites, some with mosaics of quartz near their centers, have been found in the NE¼NE¼ sec. 32, T. 44 N., R. 31 W. (fig. 9).

Locally quartzose layers of dolomite contain as much as 50 percent clastic quartz. Clastic quartz stands out strikingly on weathered surfaces.

TABLE 5.—*Petrographic data for the Randville dolomite and the Goodrich quartzite*

[Some minerals fall in more than one of the three percentage columns. Mineral name is in parentheses if that mineral belongs in indicated column in only few specimens]

Rock	Dominant minerals >20 percent	Subordinate minerals 5–20 percent	Minor minerals <5 percent	Predominant grain sizes of dominant minerals, F—<0.1 mm, M—0.1 to 2.0 mm, C—>2.0 mm	Remarks
Randville dolomite					
Dolomite	Dolomite	Quartz	(Quartz), feldspar, sericite, hematite, magnetite.	F and M	Recrystallized mosaic texture. Some scattered lenses rich in clastic quartz. Hematite in dusty films along bedding surfaces in some places.
Feldspathic quartzite	Quartz	Feldspar—mainly microcline and perthite.	Dolomite, sericite, chlorite, iron oxides.	M and C	Quartz and feldspar fragments, and mosaics of recrystallized quartz (1–4 mm) in matrix of fine- to medium-grained quartz, sericite, chlorite, dolomite, and iron oxides. Sericite-coated shears.
Dolomitic quartzite	Quartz	Dolomite	Feldspar, sericite, iron oxides.	M and C	Glassy clastic quartz in matrix of dolomite and minor minerals.
Arkose	Quartz	Feldspar—mainly microcline and perthite, Sericite.	Hematite	M and C	Matrix is fine to medium grained and strongly sheared. Sericite of matrix well alined.
Dolomitic arkose	Quartz, feldspar—mainly microcline and perthite, some albite.	(Feldspar), dolomite	Sericite, chlorite, epidote, iron oxides.	F and M	More or less elongate fragments of quartz and feldspar set in sheared, strongly alined matrix of quartz, sericite, dolomite, and hematite.
Sericite slate and schist	Quartz, sericite		Martite, biotite, chlorite, carbonate.	F	Most grains less than 0.02 mm. Martite easily seen with naked eye.
Slaty graywacke	Quartz, chlorite		Sericite, leucoxene, iron oxides, pyrite.	F	Good alinement of platy minerals. Pyrite partly altered to limonite.
Silicified dolomite (?)	Quartz		Hematite	F and M	

Goodrich quartzite

Ferruginous cherty variety.	Quartz, chert, magnetite.	Hematite (quartz), (magnetite), (sericite).	Sericite, chlorite, (hematite)	F and M	Clastic quartz in sheared matrix of recrystallized chert, hematite, and magnetite. Some specimens have clastic grains of recrystallized chert.
Chert-rich variety	Chert		Quartz, hematite, magnetite	F	Little or no sheared material. Chert entirely recrystallized. Minor quartz is in clastic grains.
Chert-poor variety	Quartz	(Magnetite), (hematite), (chert).	Magnetite, hematite, chert	M	Dominant quartz is in clastic grains. Only small amount of matrix material, mainly recrystallized chert somewhat darkened by iron oxides.

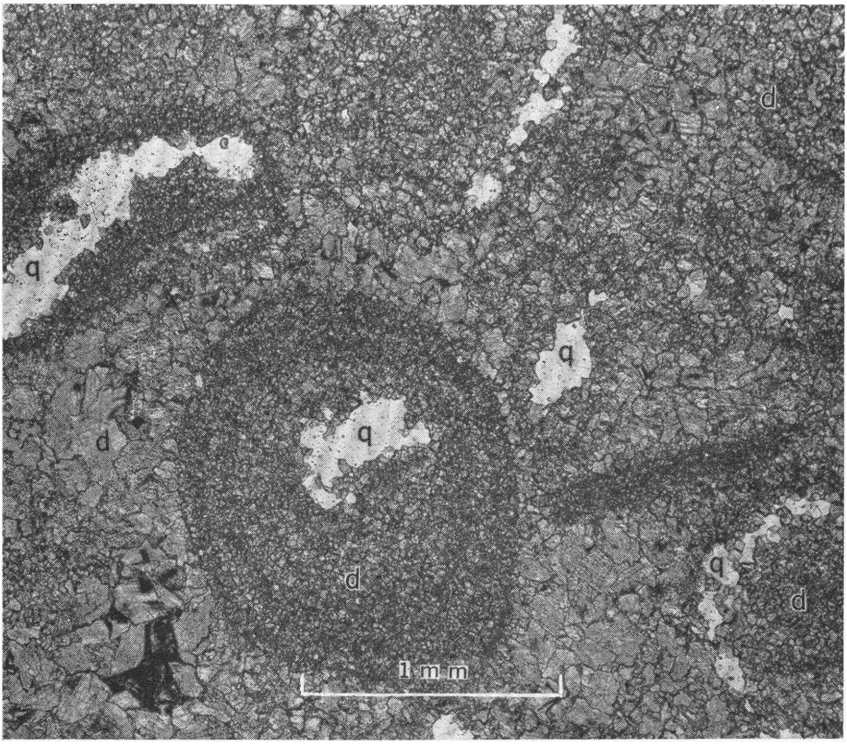

FIGURE 9.—Photomicrograph of oolitic Randville dolomite from 4,800 feet north and 1,000 feet west of the southeast corner, sec. 32, T. 44 N., R. 31 W. Mosaic-textured quartz, probably recrystallized, at centers or near rims of oolites. Plane light. (*d*) dolomite, (*q*) quartz.

FELDSPATHIC AND DOLOMITIC QUARTZITES

Thin feldspathic and dolomitic quartzite members of the Randville crop out in the NW¼ and the SE¼ sec. 4, T. 43 N., R. 31 W., and near the southeast cor. sec. 32, T. 44 N., R. 31 W. The feldspathic quartzite is generally pale pink or mottled pink and gray. Typically, it consists mainly of quartz with subordinate amounts of feldspar and minor amounts of other constituents. (See table 5.) The dolomitic quartzite is a reddish rock in which clear glassy quartz grains are surrounded by a matrix of red dolomite. Feldspathic and dolomitic quartzites grade into varieties containing about equal amounts of feldspar and dolomite.

ARKOSE

Arkose and dolomitic arkose are exposed in the south-central part of sec. 10 and in the SE¼ sec. 4, T. 43 N., R. 31 W. Arkose has been found by drilling in the central part of sec. 10, and about a mile south of the quadrangle in the NW¼ sec. 23, T. 43 N., R. 31 W.

The arkose is a pink, granitic-looking rock containing fragments of quartz and feldspar in a matrix mainly of quartz and sericite (table

5). The dolomitic arkose is generally similar to the arkose except for its 10 to 15 percent dolomite and its grayish-green and red-mottled appearance.

The stratigraphic position of the arkose within the Randville is unknown. Drilling south of the quadrangle in secs. 23 and 26, T. 43 N., R. 31 W., shows arkose interbedded with dolomite, so possibly arkose occurs at more than one horizon in the formation.

SERICITE AND CHLORITE SLATES AND SCHISTS

The sericite slate and schist phases of the Randville are found in two relatively important localities, one on the east side of the oval near the center of sec. 16, T. 44 N., R. 31 W., and the other in sec. 32, T. 44 N., R. 31 W., westward from the central part of the section. Thin layers of sericite and chlorite slates and schists also occur in the NE¼ sec. 32, in drill holes and test pits in the S½ and the NW¼ of sec. 33, T. 44 N., R. 31 W., and in the NE¼ sec. 4, T. 43 N., R. 31 W.

The gray quartz-sericite schist and slate along the Fence River in sec. 16 contains about equal amounts of quartz and sericite and small amounts of martite, biotite, and chlorite. (See table 5.) The martite is concentrated in thin scattered zones. Biotite occurs mainly adjacent to martite, especially in "shear shadows." The slate is generally somewhat phyllitic.

The quartz-sericite slate found westward from the center of sec. 32 is gray to black and commonly has crenulated layers alternately rich in quartz and sericite. Many of the quartzose layers are pod shaped or otherwise variable in length and thickness.

Other slates and schists in the Randville are dark to light gray green to buff. They have highly varying amounts of sericite, chlorite, quartz, and dolomite.

The quartz-sericite schist and slate exposed along the Fence River is at the base of the Randville (pl. 1). They were placed in the Sturgeon quartzite by Clements and Smyth, (1899b, p. 430–431). They differ from typical Sturgeon quartzite, however, and are similar to quartz-sericite rocks elsewhere in the Randville. The thickness ranges from 50 to possibly 400 feet.

The sericite slate west of the center of sec. 32 is in at least one narrow east-west synclinal trough in an area otherwise underlain by dolomite. The slate is therefore either an upper member of the dolomite or a distinct unit above the dolomite. (See p. 75–76.) Smyth correlated this rock with the "Mansfield slate" at Mansfield on the Michigamme River south of the quadrangle and considered it a sedimentary facies essentially equivalent to the entire volcanic unit of the Hemlock. When Van Hise and Leith (1911, p. 295–296) made the "Mansfield slate" at Mansfield a local unit in the upper part of the

Hemlock formation, they evidently realized that it could not be correlative with the slate in sec. 32, which lies just above dolomite and occupies a position inferior to the Hemlock formation.

SLATY GRAYWACKE

A layer of graywacke, about 10 feet thick, is interbedded with dolomite in the east central part of sec. 32, T. 44 N., R. 31 W. The rock is dark greenish gray, coarsely foliated, and consists mainly of clastic quartz, and chlorite (table 5).

SILICIFIED DOLOMITE(?)

An unusual siliceous rock, unlike any of the others in the quadrangle, is exposed in two places in the NW¼ sec. 34, T. 44 N., R. 31 W. Similar rock has been drilled near the north end of the hill in the SW¼ sec. 27. This rock, because of its resemblance to silicified and probable silicified dolomite in other parts of northern Michigan, is correlated tentatively with the Randville dolomite.

In outcrop the rock is reddish to yellow brown, with numerous irregular and tabular fragments of white chertlike material in a granular, ferruginous quartzitic-looking matrix. Small vugs coated with earthy iron oxides are common. The rock is massive with no apparent structure other than faintly alined but discontinuous breccialike zones. It bears a striking resemblance to parts of the silicified Randville dolomite 1 mile north of Norway, in eastern Dickinson County, Mich. Leith (1925) related the silicified dolomite near Norway to silicification along a Precambrian erosion surface. The rock in sec. 34 is also similar to exposures that are probably silicified dolomite at Sheridan Hill, 5 miles southwest of Iron River in south-central Iron County, Mich.[10] (Allen, 1910, p. 40). In thin section it has medium-grained quartz mosaics surrounding widely scattered fragments or patches of fine-grained quartz or recrystallized chert with disseminated hematite. Possibly pseudomorphous replacement of recrystallized dolomite by silica produced the present quartz mosaics.

AGE RELATIONS

The dolomite formation of the Kiernan area was first correlated with Randville dolomite of the Felch district of Dickinson County by Clements and Smyth (1899a, p. 10–11). The correlation was based on similarities of lithology, thickness, and stratigraphic position. The dolomite dips outward from the core of the Amasa oval and is separated from the underlying gneissic and granitic rocks of the

---

[10] James, H. L., Dutton, C. E., and Pettijohn, F. J., U. S. Geol. Survey professional paper on the Iron River district, Mich. (in preparation).

Margeson Creek gneiss by a major structural unconformity (pl. 1, Structure section *A–A′*).

In Dickinson County, Sturgeon quartzite quite commonly lies between Randville dolomite and the older granitic rocks, whereas in the Kiernan area there is no equivalent quartzite in the section. Its absence is noteworthy because in the Pine Creek area of south-central Dickinson County, 30 miles southeast of the quadrangle, it has a thickness of as much as 2,000 feet. However, quartzite is not absent from the section only in the Kiernan area. In the Turner area (NE¼SE¼ sec. 15, T. 43 N., R. 29 W.), about 12 miles east of the quadrangle, for example, dolomite is exposed directly overlying older granite gneiss. Quartzite may be absent either because of nondeposition of the Sturgeon or because of the equivalence of the Randville with both the Sturgeon and the Randville elsewhere. The Randville is the oldest Middle Precambrian formation of the Kiernan area.

GOODRICH QUARTZITE

The Goodrich quartzite was named by Van Hise and Bayley (1895, p. 591) for exposures of quartzite at the Goodrich mine in the Marquette Range. Most of the Goodrich quartzite exposed in the Kiernan quadrangle is a magnetic cherty [11] quartzite with much clastic quartz. Other varieties of the Goodrich (1) may consist largely of recrystallized chert, (2) may be poor in iron, or (3) may have little chert. Outcrops of the Goodrich are found only on Michigamme Mountain and at two places in sec. 4, T. 43 N., R. 31 W. Reddish siliceous rock on the east side of the road, 1,450 feet north of the southwest corner of sec. 3, T. 43 N., R. 31 W., may be Goodrich quartzite. The identification of the rock is uncertain, and its location cannot be readily explained. Possibly a small unrecognized fault or a limited reversal in the southeastward plunge of the major structural axis accounts for the outcrop.

Fragments lithologically similar to parts of the Negaunee iron-formation of the Marquette and Republic areas (Van Hise and Bayley, 1897, p. 328–407) are found in the Goodrich quartzite in several places on the north side of Michigamme Mountain. The material similar to the Negaunee is very scanty. It is best seen 1,500 feet west and 100 feet north of the southeast corner of sec. 33, T. 44 N., R. 31 W., where several platy fragments of jaspilite and oölitic iron-formation occur in ferruginous Goodrich quartzite. The fragments are about 2 to 10 inches long and ½ to 1 inch thick. There are pebble size and smaller fragments of material similar to the Negaunee in a thin conglomeratic zone about at the contact between Goodrich quartzite and metarhyolite, 1,700 feet west and 300 feet north of the

[11] The so-called chert of these rocks has all been recrystallized to fine-grained quartz.

southeast corner of sec. 33, T. 44 N., R. 31 W. These fragments consist mainly of tan chert and steel-gray hematitic rock. Some thin sections of the quartzite (fig. 10) contain clastic grains of recrystallized

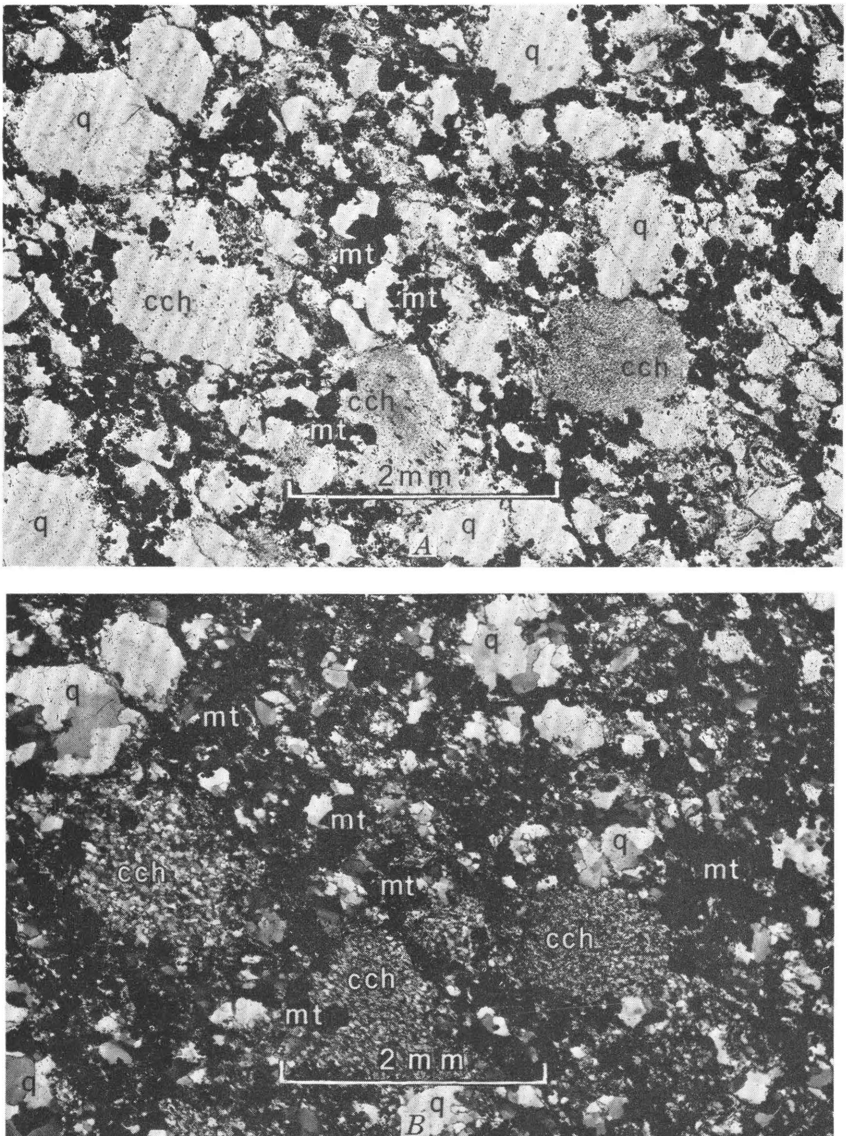

FIGURE 10.—Photomicrographs of ferruginous cherty Goodrich quartzite. Clastic chert grains and cherty parts of matrix darkened by dusty hematite. Clastic chert possibly derived from Negaunee iron-formation. Magnetite protrudes into clastic quartz grains. Loc. 5,050 feet north and 800 feet west of the southeast corner, sec. 4, T. 43 N., R. 31 W. (*A*) Plane light. (*q*) clastic quartz, (*cch*) clastic chert, (*mt*) magnetite. (*B*) Same as (*A*) with crossed nicols. Differences between clastic quartz and clastic chert clearly discernible.

chert that may have been derived from chert of the Negaunee iron-formation.

The Goodrich quartzite has been placed northward from the mountain on the basis of magnetic data (pl. 2). Nonmagnetic iron-rich rocks on test-pit dumps in the NW¼ sec. 34, T. 44 N., R. 31 W., are probably Goodrich quartzite. The position of the Goodrich has also been extended by magnetic data southward from the mountain about one-half mile and thence by magnetic and drilling data northeastward on an anticlinal structure into the NW¼ sec. 3, T. 43 N., R. 31 W. The anticline is rather poorly defined by magnetic data because much of the quartzite there is nonmagnetic, as revealed by drilling. Structures in the vicinity of Michigamme Mountain are shown in cross sections on plate 3, constructed from data presented in plate 2 and from logs of the Ford and Longyear drilling in sec. 3.

The magnetic data suggest that the Goodrich quartzite is distributed in irregular pods rather than as a continuous layer. The apparent podlike distribution could be the result of original variations in thickness of the Goodrich, irregular development of magnetic phases of the quartzite, or erosion of the formation from most of the area.

The maximum thickness of the Goodrich near Michigamme Mountain probably is not more than 500 feet.

DESCRIPTION

Ferruginous cherty quartzite occurs in most of the outcrops and test pits on Michigamme Mountain. Much of the quartzitic rock drilled east of the mountain in sec. 3 is also of this general type.

The rock is dense and commonly deep red. It contains clastic quartz in a matrix of abundant recrystallized chert with subordinate or minor amounts of other minerals. (See table 5.) The matrix is generally sheared. Some of the ferruginous quartzite drilled in sec. 3 is strongly oxidized and hematitic and contains virtually no magnetite. Fine particles and irregular aggregates of hematite are distributed rather evenly through the matrix of the Goodrich quartzite, although there is some tendency for hematite to concentrate along small, closely spaced shear surfaces. In some of the Goodrich, clusters of magnetite are elongated parallel to elongated quartz grains and shear surfaces in the matrix (fig. 11). Magnetite lies astride shear planes without any noticeable deflection of the shears (fig. 12). In many places magnetite has grown partly around or into clastic quartz grains (fig. 10*A*). In a few places it is concentrated along small undeformed quartz veinlets transecting the quartzite. The magnetite in its present development is therefore late deformational or postdeformational in age. Although it may have formed originally from the reduction of hematite during diagenesis, evidently it was mobilized later during or after deformation. Evidently some recrystallization of quartz or chert occurred after the formation of much of the magnetite. Blades of quartz have grown out perpendicularly from the faces of many magnetite crystals, generally parallel to the traces of shears in the matrix.

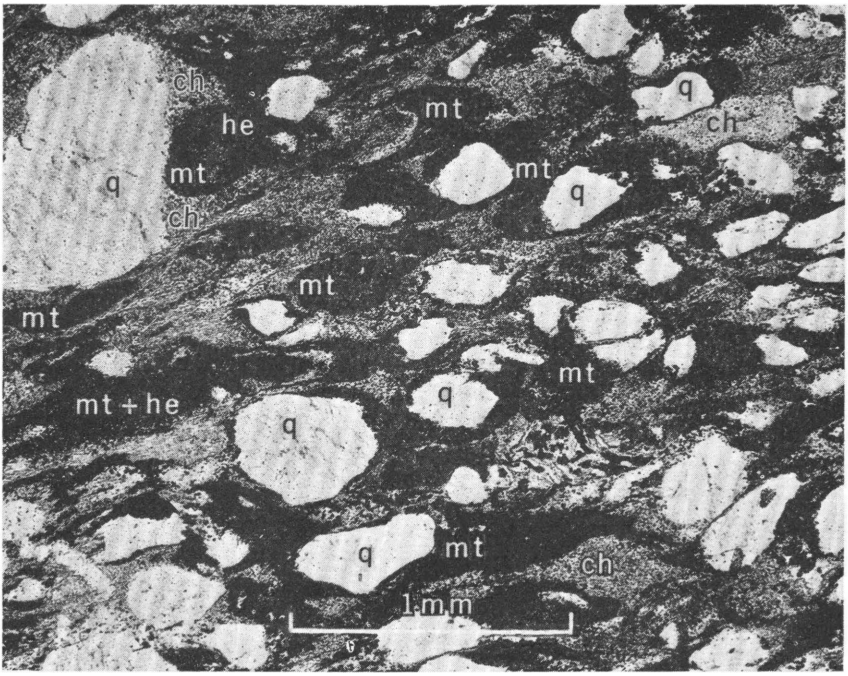

FIGURE 11.—Photomicrograph of ferruginous cherty Goodrich quartzite. Clastic quartz in sheared matrix of sericite, magnetite, hematite, and recrystallized chert. Considerable concentration of magnetite and hematite in "shear shadows" of clastic quartz. Loc. 200 feet north and 2,150 feet west of the southeast corner, sec. 33, T. 44 N., R. 31 W. Plane light. (*q*) clastic quartz, (*ch*) chert, (*mt*) magnetite, (*he*) hematite.

Quartzite consisting mainly of recrystallized chert with a little clastic quartz and hematite is found on the high bare knob on the west side of the mountain in the northern part of sec. 4, T. 43 N., R. 31 W., and in several smaller outcrops extending southeastward from the knob for a few hundred feet. The rock forms massive outcrops. It is not banded or layered in the manner of the chert-rich iron-formation of the Negaunee type.

A small part of the exposed Goodrich of the area consists of cherty quartzite with only a few percent of iron oxides, and ferruginous to nonferruginous quartzites with very little chert.

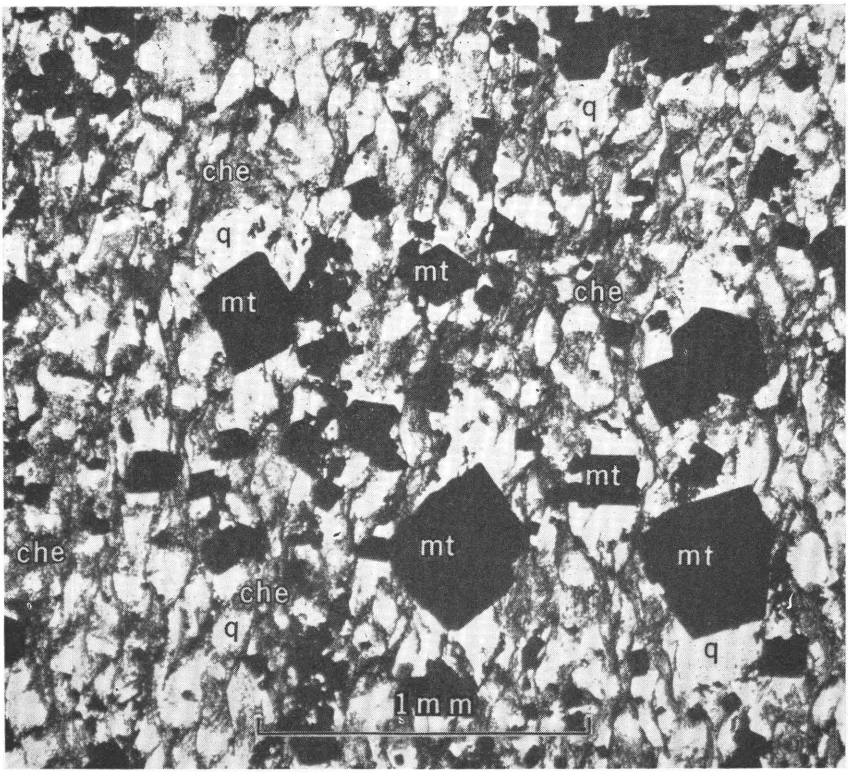

FIGURE 12.—Photomicrograph of ferruginous cherty Goodrich quartzite. Closely packed clastic quartz in cherty hematite matrix. Magnetite recrystallized following deformation, growing astride shear planes and clastic quartz. Loc. 300 feet north and 1,700 feet west of the southeast corner, sec. 33, T. 44 N., R. 31 W. Plane light. (*q*) clastic quartz, (*mt*) magnetite, (*che*) mixture of chert, hematite, and sericite.

AGE RELATIONS

The magnetic quartzite at Michigamme Mountain was formerly thought to be Negaunee ("Groveland") iron-formation of "Middle Huronian" age. In the present report it is correlated with Goodrich quartzite, which unconformably overlies the Negaunee in the Republic trough. The principal reasons for this correlation are that (1) the rock at Michigamme Mountain is lithologically similar to parts of the Goodrich and bears no lithologic resemblance to typical Negaunee, (2) the quartzite at the mountain contains fragments and clastic grains of material similar to the Negaunee, and (3) the quartzite appears to occupy a stratigraphic position between underlying Randville dolomite or underlying Negaunee iron-formation (remnants in the quartzite), and an overlying series of volcanic rocks. In its stratigraphic relationships, the quartzite is analogous to the Goodrich in the western part of the Marquette Range.

Smyth's original correlation of the magnetic quartzite at Michigamme Mountain with the Negaunee iron-formation was based on correlating the magnetic iron-formation at the Sholdeis exploration on the east side of the Amasa oval both with the rock at the mountain and with the Negaunee of the Republic trough (Clements and Smyth, 1899b, p. 453–456). The iron-formation at the Sholdeis exploration was traced magnetically as far south in the Kiernan quadrangle as sec. 27, T. 44 N., R. 31 W., and projected from there about a mile southwestward to Michigamme Mountain. However, the relationships between the iron-rich rocks and the Hemlock formation were not recognized. The Hemlock underlies the iron-formation at the Sholdeis exploration, but it overlies the magnetic quartzite at Michigamme Mountain. (See figure 13; also, the section below on the age

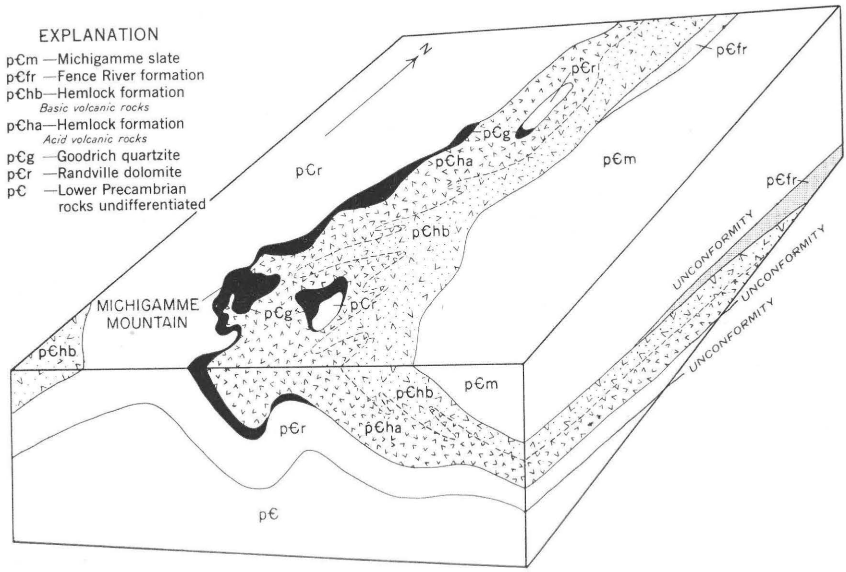

FIGURE 13.—Block diagram showing stratigraphic and structural relations in vicinity and northeast of Michigamme Mountain.

relations of the Hemlock formation.) The iron-rich rocks at the Sholdeis exploration and at Michigamme Mountain therefore cannot be correlative. The present correlation of the bulk of the magnetic quartzite at the mountain with "Upper Huronian" Goodrich quartzite invalidates the correlation of the younger iron-rich rock on the east side of the oval with the "Middle Huronian" Negaunee.

HEMLOCK FORMATION

GENERAL FEATURES

The Hemlock formation was named from extensive exposures along the Hemlock River on the west side of the oval, northwest of the Kiernan quadrangle and northeast of the town of Amasa (Clements and Smyth, 1899a, pt. 3, p. 45–63; Clements and Smyth, 1899b, p. 73). Leith, Lund, and Leith (1935) changed the name of the formation to "Hemlock greenstone." This name, however, is too restricted to include all the units of the Hemlock; the name Hemlock formation is here reinstated.

The Hemlock formation consists mainly of a thick series of altered basic volcanic flow rocks, tuffs, and agglomerates, forming massive to schistose and slaty greenstone. Narrow belts of slate are interbedded with the volcanic rock. Graywacke, probably near the base of the Hemlock, has been found on the south side of Michigamme Mountain. Graywacke interbedded with sericite slate of the Hemlock formation was found in drill holes in sec. 3, T. 43 N., R. 31 W. In places the basic rocks give way to or are interbedded with altered rhyolite tuffs or flows.

The Hemlock formation occupies a belt that completely surrounds the oval. The general dip of the formation is outward from the core of the uplift (pl. 1, section *A–A'*). On the east flank of the oval the Hemlock belt is well defined, but south of the center of sec. 22, T. 44 N., R. 31 W., it is poorly defined. Between the north shore of Michigamme Reservoir in the southern part of sec. 22 and the northern part of the hill in the SW¼ sec. 27, T. 44 N., R. 31 W., magnetic greenstone gives way, in part, to metarhyolite. The magnetic profiles in plate 4 clearly show the thinning out of the magnetic Hemlock between the Sholdeis area and sec. 27, T. 44 N., R. 31 W. The writers believe this to be caused mainly by the appearance of metarhyolite in the section. Near Kiernan, a mile south of the mountain, the Hemlock formation occupies the saddle between the major uplifts to the northwest and to the southeast. The broad belt of Hemlock in the southwestern part of the quadrangle trends generally northwest along the west flanks of both uplifts, as shown by strikes of foliation planes, by the elongation of ellipsoidal structures in the north-central part of sec. 18, and by the strikes of bedding in slate in secs. 7 and 17, T. 43 N., R. 31 W.

The great change in the thickness of the Hemlock from the west to the east side of the oval is one of its striking features. On the east side of the oval it forms a belt one-half to three-quarters of a mile wide. Foliation dips eastward about 65°, and is about conformable with dips of bedding in the underlying Randville dolomite to the west, indicating a minimum thickness of the Hemlock of about 2,300 feet. Some 6 miles east of the oval, on the east side of the Sagola basin, the Hemlock apparently has disappeared altogether. West of the oval and largely outside the Kiernan quadrangle, in a region including the type area, the Hemlock belt is up to 10 times broader than it is on the east side of the oval. The broader belt on the west appears to be truly representative of greatly increased thickness. All available evidence of top directions as deduced from ellipsoidal structures and the differentiated sill, in the Kiernan and adjoining areas [12] indicates a continuous rise in the stratigraphic section to the southwest. Further detailed work west of the oval may reveal structural complications, but for the present the increase in width of the Hemlock belt from east to west across the oval is assumed to be due largely to an original thickening of the volcanic sequence to the west and not substantially to repetition of the section by folding or faulting. The centers of eruption during Hemlock time apparently were to the west of the Kiernan quadrangle. The abundance of ellipsoidal flows in the exposed rocks indicate that the volcanism was at least in part submarine.

Volcanic rocks of the Hemlock formation in the quadrangle are crossed by the biotite isograd of regional metamorphism and probably also by the garnet isograd (James, 1955, pl. 1). The metamorphic grade increases northeastward across the area (fig. 4). The metamorphism of the basic volcanic rocks appears to be of the "normal" type described by Wiseman (1934) in the Scottish Highlands.

METABASALT

Metabasalt is widely distributed in the Hemlock belt (pl. 1). Isolated patches of Hemlock are enclosed in metagabbro of the West Kiernan sill in several places, particularly in the SE¼ sec. 6, in the NE¼ sec. 7, and in the NE¼ sec. 17, T. 43 N., R. 31 W. Good examples of metabasalt with ellipsoidal structures occur in sec. 18, particularly 3,300 feet west and 2,000 feet south of the northeast corner of the section. Amygdaloidal rock is found in secs. 17 and 18. Some of the schists in sec. 10, T. 44 N., R. 31 W., may have been basalt or diabase, but metamorphism has so obliterated original textures as to render determination impossible.

The metabasalt commonly forms knobby outcrops. The rock is massive and dense and generally has conspicuous joints. Weathered and glacially scoured surfaces are dark gray green to greenish black. The fresh rock is commonly dull green.

---

[12] Bayley, R. W., op. cit.

Altered ellipsoidal basalt, described so well in Monograph 36 (Clements and Smyth, 1899b, p. 112–124), is now considered indicative of submarine extrusion. On weathered surfaces thin seams of fine-grained material or narrow grooves mark the original (palagonitic?) shells around individual pillows. The pillows in sec. 18, T. 43 N., R. 31 W., are somewhat elongated parallel to the northwest strike of the foliation. The more convex surfaces of individual pillows and the openings of angles between adjacent pillows indicate top directions consistently toward the southwest.

Most of the metabasalt appears originally to have had fine- to medium-grained subdiabasic texture. Rocks with coarser ophitic and diabasic textures have been mapped as basic intrusive rocks. Typical textures and mineralogy of the metabasalt are listed in table 6. In much of the greenstone there is only a suggestion of original texture because of the destruction of primary fabric during metamorphism. Estimates of original grain size are therefore generally difficult or impossible to make.

The most abundant minerals in the metabasalt are secondary pale-green hornblende, chlorite, clinozoisite, and plagioclase (table 6). Twinned plagioclase, similar to labradorite or calcic andesine in form and textural relationships, is almost invariably poor in lime even when not of strongly altered appearance. The anorthite content is generally about 10 percent but ranges from about 8 to 34 percent.

Partial chemical analyses of greenstone from the Hemlock formation and other Middle Precambrian greenstones, and of metagabbro, from the Kiernan and other areas studied by the U. S. Geological Survey in this part of northern Michigan (see table 7) show Na:Ca ratios for the most part typical of calc-alkaline basic rocks (Turner and Verhoogen, 1951, p. 68). The now-predominant sodic plagioclase of the Hemlock can not have been primary in normal calc-alkaline basic rocks. However, there is no indication, in view of the relatively low soda content of the rocks, that the present plagioclase is a result of soda metasomatism. The original feldspar must have been calcic plagioclase. During essentially isochemical metamorphism, much of the lime of the calcic plagioclase must have gone into minerals of the epidote group as the feldspar became richer in soda.

The common alteration products associated with the albite-oligoclase and apparently derived from the original plagioclase are clinozoisite with some epidote, quartz, carbonate, sericite, kaolinite, and chlorite. Aggregates of clinozoisite may be well defined by the original feldspar boundaries or the clinozoisite may form a nearly continuous groundmass where the aggregates have merged.

TABLE 6.—*Petrographic data for rocks of the Hemlock formation*

[Some minerals fall in more than one of the three percentage columns. Mineral name is in parentheses if that mineral belongs in indicated column in only few specimens]

Rock	Dominant minerals >20 percent	Subordinate minerals 5–20 percent	Minor minerals <5 percent	Predominant grain sizes of dominant minerals, F—<0.1 mm, M—0.1 to 2.0 mm, C—>2.0 mm	Remarks
Metabasalt	Hornblende, clinozoisite, (chlorite) (albite-oligoclase).	Albite-oligoclase, chlorite, (clinozoisite).	Epidote, quartz, biotite, sericite, carbonate, kaolinite, apatite, leucoxene, iron oxides, pyrite.	F and M	Most of rock probably had original intergranular or subdiabasic texture. Hornblende in needles, blades, clumps. Some chlorite-rich varieties of rock have no hornblende. Some chlorite has anomalous blue or lavender interference colors. Most of iron oxide is magnetite.
Metatuff and meta-agglomerate (few original crystals).	Chlorite, (quartz)	Sericite, quartz	Feldspar, hornblende, kaolinite, carbonate, epidote, biotite, leucoxene, magnetite.	F	Chlorite fine-grained and probably derived from glassy base. In addition to sericite, the minerals kaolinite, quartz, carbonate, and epidote may also be alteration products of feldspar.
Metatuff (abundance of crystals).	Albite-oligoclase An_{8-12}, hornblende.	Chlorite	Leucoxene	M	Only one known locality. Rock considerably sheared, with hornblende drawn out between feldspar fragments.
Biotite-hornblende-, and epidote-bearing schists.	Biotite or hornblende, (epidote), (quartz)	Epidote, quartz, chlorite, (albite-oligoclase), (hornblende or biotite), (carbonate).	Albite-oligoclase, carbonate, (chlorite), leucoxene, magnetite, (hornblende or biotite).	F and M, Porphyroblasts M and C.	Strong mineral alinements in most of rocks. Fabric in places is a felt of biotite-quartz or hornblende-quartz. Either biotite or hornblende may be absent or scarce in rocks with a dominant amount of the other. Small aggregates of fine granular epidote common in groundmass.
Metarhyolite	Quartz, sericite	(Chlorite), (feldspar—microcline, albite, orthoclase), biotite—only at one locality.	Feldspar—microcline, albite, orthoclase, leucoxene, hematite, magnetite, apatite, zircon.	F and M	Beta-quartz "eyes" and quartz pods with mosaic texture form 1 to 10 percent of rock. Matrix generally strongly sheared. Little or no feldspar left in most specimens. Quartz-sericite pseudomorphs after feldspar commonly merge with matrix due to shearing and overgrowths of quartz and sericite along boundaries of pseudomorphs. Dusty hematite generally concentrated along shears.

Slate	Quartz, sericite, (chlorite).	Chlorite, biotite (sericite), (quartz), leucoxene.	(Leucoxene), iron oxides, zircon.	F	Thin layers with abundant fine-grained clinozoisite and tremolitic hornblende in one specimen.
Graywacke	Chert—clastic fragments, sericite, biotite.	Chlorite, quartz	(Chlorite), leucoxene, hematite, ilmenite, magnetite.	F and M	In coarser grained layers, most of grains are angular fragments of recrystallized chert. Some chert fragments have disseminated iron oxide. Peripheral growth on some clastic quartz grains. In places, cut-and-fill of thin layers on microscopic scale. Sorting poor.

371023—56——4

TABLE 7.—*Partial analyses of greenstone and metagabbros from Kiernan quadrangle and adjacent areas of northern Michigan, showing weight percentages and molecular proportions of* CaO, Na_2O, *and* K_2O.

[Analyses made by rapid methods. Analyst: Joseph M. Dowd, U. S. Geological Survey.]

Sample No.	Weight Percent			Molecular proportions		
	CaO	Na_2O	K_2O	CaO	Na_2O	K_2O
1	8.4	2.4	0.30	0.150	0.039	0.003
2	8.4	3.1	.33	.150	.050	.0033
3	8.0	2.7	.74	.143	.044	.0074
4	5.6	3.9	.58	.100	.063	.0058
5	8.9	2.2	1.2	.159	.035	.013
6	6.9	2.8	.12	.123	.045	.0012
7	10.8	2.2	1.4	.193	.035	.015
8	11.3	1.9	.14	.202	.031	.0014
9	8.7	3.0	1.4	.155	.048	.015
10	7.3	3.2	1.0	.130	.052	.011
11	7.8	2.6	.87	.139	.042	.0097
12	5.4	3.8	.42	.096	.061	.0042
13	9.5	2.3	.28	.170	.037	.0028
14	3.1	2.8	1.1	.055	.045	.012
15	9.4	2.6	.83	.168	.042	.0093
16	8.9	2.6	1.3	.159	.042	.014
17	10.4	2.4	.70	.186	.039	.007
18	5.1	3.4	.16	.091	.055	.0016
19	8.8	2.7	.54	.157	.044	.0054
20	7.4	.90	2.1	.132	.015	.022
21	4.2	1.8	2.3	.075	.029	.024
22	8.7	2.8	.41	.155	.045	.0041
23	5.7	2.6	1.0	.102	.042	.011

1. Fine-grained schistose greenstone. Kiernan quadrangle, Michigan; 3,200 feet north and 3,600 feet east of southwest corner of sec. 9, T. 43 N., R. 31 W.
2. Metagabbro. Kiernan quadrangle, Michigan; 800 feet north and 2,200 feet east of southwest corner of sec. 9, T. 43 N., R. 31 W.
3. Metagabbro. Kiernan quadrangle, Michigan; 400 feet south and 3,600 feet east of northwest corner of sec. 17, T. 43 N., R. 31 W.
4. Metagabbro. Kiernan quadrangle, Michigan; 200 feet north and 4,600 feet south of southwest corner of sec. 31, T. 44 N., R. 31 W.
5. Greenstone dike or flow. Kiernan quadrangle, Michigan; 1,050 feet south and 3,900 feet east of northwest corner of sec. 18, T. 43 N., R. 31 W.
6. Schistose greenstone. Kiernan quadrangle, Michigan; 1,550 feet north and 2,450 feet east of southwest corner of sec. 10, T. 44 N., R. 31 W.
7. Greenstone. Quarry north of Crystal Falls, Mich.; NE¼NE¼ sec. 20, T. 43 N., R. 32 W.
8. Diabasic greenstone. Iron County, Mich.; NW¼NE¼ sec. 13, T. 43 N., R. 35 W.
9. Dense massive greenstone. Paint River traverse; NW¼ sec. 11, T. 43 N., R. 33 W.
10. Massive amygdaloidal greenstone. North side of railroad track in center of sec. 23, T. 42 N., R. 34 W.
11. Diabase. Fortune Lakes area; Bristol location, Iron County, Mich.; SW¼SW¼ sec. 24, T. 43 N., R. 33 W.
12. Greenstone. Outcrop in the NW¼SE¼ sec. 17, T. 42 N., R. 35 W.
13. Greenstone (from pillow flow). Pentoga area, Iron County, Mich.; sec. 29, T. 42 N., R. 33 W.
14. Fine-grained greenstone. Outcrops in the NE¼SW¼ sec. 17, T. 43 N., R. 35 W.
15. Medium-grained greenstone. Outcrops in the NW¼SE¼ sec. 17, T. 43 N., R. 35 W.
16. Porphyritic greenstone. Outcrop at old U. S. Highway 2, crossing of Chicagoan Creek, Iron County, Mich.; SE¼NW¼ sec. 25, T. 43 N., R. 34 W.
17. Porphyritic greenstone. Outcrop in the SW¼SW¼ sec. 20, T. 43 N., R. 33 W.
18. Greenstone. Sheridan Hill, Iron County, Mich.; outcrop at east quarter corner, sec. 20, T. 42 N., R. 35 W.
19. Agglomeratic greenstone. Outcrop in the NW¼SE¼ sec. 21, T. 42 N., R. 35 W.
20. Greenstone (from pillow). Chicagoan Creek area, Iron County, Mich.; sec. 8, T. 43 N., R. 33 W. (collected by J. Bokman).
21. Amygdaloidal greenstone. West end of Calumet district, Michigan; 4,050 feet north and 130 feet east of the southwest corner, sec. 32, T. 41 N., R. 30 W.
22. Altered gabbro porphyry. West end of Calumet district, Michigan; 1,400 feet north and 2,700 feet east of the southwest corner, sec. 32, T. 41 N., R. 30 W.
23. Medium-grained greenstone. West end of Calumet district, Michigan; 870 feet north and 5,200 feet east of the southwest corner, sec. 32, T. 41 N., R. 30 W.

Original pyroxene has been altered to hornblende or chlorite. In places biotite and chlorite appear to have formed from hornblende. Some chlorite is probably retrograde after biotite. Many grains of hornblende and aggregates of chlorite look vaguely pseudomorphous after pyroxene, particularly where they have an ophitic relationship with plagioclase. The hornblende is mainly pale green or olive green and of moderate birefringence. Pleochroism is generally weak. The maximum extinction angle ($Z \wedge c$) is generally 20°. The mineral is probably a low-alumina hornblende and therefore of the type common to the greenschist metamorphic facies.

Greenstones in a few places, including a possible meta-andesite, 1,100 feet north and 100 feet west of the southeast corner of sec. 6, T. 43 N., R. 31 W., have well-alined hornblende laths and microlitic plagioclases set in an original glassy base. Amygdaloidal metabasalts are found in the NE¼NW¼ sec. 17 and in the north-central part of sec. 18, T. 43 N., R. 31 W. An interesting amygdaloidal metabasalt (fig. 14) located near the middle of the north border of sec. 18 is an altered glass. The rock shows no evidence of deformation.

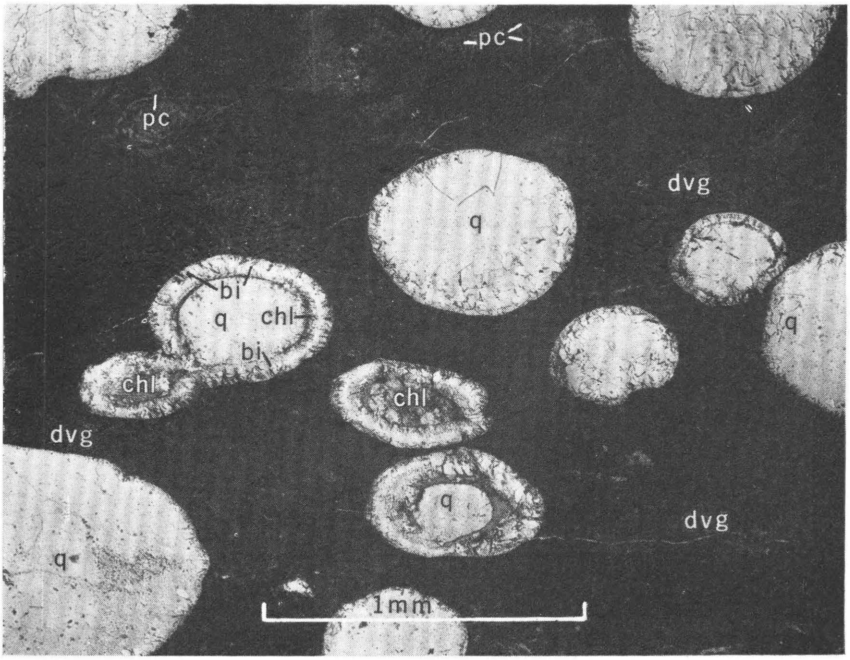

FIGURE 14.—Photomicrograph of amygdaloidal flow rock from Hemlock formation, 100 feet south and 2,500 feet west of the northeast corner, sec. 18, T. 43 N., R. 31 W. Amygdules and perlitic cracks undeformed. Original glassy groundmass devitrified to fine-grained aggregate of epidote, iron oxide, and quartz (?). Amygdules consist of quartz with some chlorite and minor shreds of biotite or stilpnomelane near rims. Plane light. (*dvg*) devitrified glass, (*q*) quartz, (*chl*) chlorite, (*bi*) biotite (or stilpnomelane), (*pc*) perlitic cracks.

The parent rocks of these greenstones, as indicated by mineralogy, relict textures, and chemical analyses, were mainly basaltic in composition.

METAMORPHOSED BASIC PYROCLASTIC ROCKS

Altered basic tuff and agglomerate are widespread in the Hemlock formation (pl. 1). Good exposures are found in the SW¼ sec. 5 and in the NE¼ sec. 8, T. 43 N., R. 31 W. Basic meta-agglomerate is exposed in several places on the northeast side of Michigamme Mountain. Much of the Hemlock along the east flank of the oval in sec. 10, T. 44 N., R. 31 W., may be highly altered basic and intermediate tuff.

The basic metatuff and meta-agglomerate form schistose and slaty greenstones. The weathered surfaces of many outcrops are checked, pitted, and broken by a hackly fracture. In places the rock contains discernible fragments, which suggests that such hackly greenstones are altered pyroclastic rock. In places, tuffaceous greenstone appears

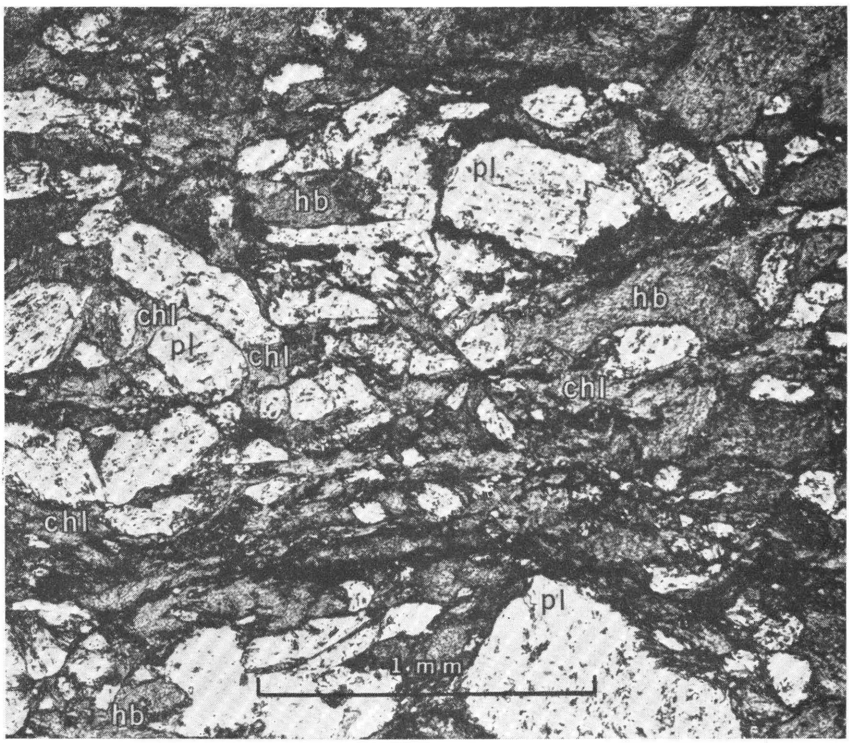

FIGURE 15.—Photomicrograph of crystal tuff from Hemlock formation, 2,100 feet north and 1,700 feet west of the southeast corner, sec. 6, T. 43 N., R. 31 W. Fragments of present hornblende and sodic plagioclase probably derived from original pyroxene and calcic plagioclase. Small particles within plagioclase are mainly chlorite. Plane light. (*pl*) plagioclase, (*hb*) hornblende, (*chl*) chlorite.

to grade into flow greenstone. Commonly, however, fragments can be seen only in thin section, so that field distinction between pyroclastic and flow rock generally cannot be made. Because of this and the scarceness of outcrops in parts of the Hemlock formation, pyroclastic and flow rocks are distinguished on the map only by letter symbol where identification is certain or probable.

In the metatuff, relict pseudomorphs of original feldspars are generally sparsely distributed in a matrix mainly of chlorite and quartz. (See table 6.) Most of these rocks probably had no more than 10 percent original crystalline material. About 90 percent of one crystal tuff (fig. 15), however, was made up of original crystal fragments. The glassy base of most of the poorly crystalline pyroclastic rock has altered mainly to chlorite. The original feldspar fragments now generally form poorly defined aggregates consisting largely of sericite. Commonly, the platy minerals are well alined, and sericite aggregates are elongated. Lensoid quartz mosaics occur in some of this rock and may be stretched amygdules.

A sample collected low on the northeast slope of Michigamme Mountain differs somewhat from the typical metatuff in that it contains fragments, probably of an original vitrophyre, in a matrix rich in chlorite and epidote. The altered vitrophyre contains pseudomorphs of feldspar (now sericite, clinozoisite, carbonate) in a groundmass of clinozoisite and epidote.

BIOTITE-, HORNBLENDE-, AND EPIDOTE-BEARING SCHISTS

Basic schists of varying composition are found in the belt of the Hemlock formation northward from the north shore of Michigamme Reservoir in sec. 22, T. 44 N., R. 31 W. Outcrops are especially abundant in sec. 10.

In outcrop the basic schists are dark green to gray green. They represent metamorphism of a higher grade than the metabasalts and altered pyroclastic rocks to the south and southwest. Primary textures are completely or almost completely absent in most places, particularly in the more strongly foliated schists. Some of the schists are only weakly foliated. Many of these have relict volcanic textures (intergranular, intersertal, pilotaxitic).

Biotite, hornblende, epidote, and chlorite, commonly in different combinations, are the principal minerals in the basic schists. These minerals and combinations are as follows:

biotite
biotite-hornblende
biotite-hornblende-epidote
biotite-hornblende-chlorite
biotite-epidote
biotite-chlorite

hornblende
hornblende-epidote
hornblende-chlorite
epidote-chlorite

Minor or subordinate amounts of quartz also occur in most of the basic schists. It has not been possible to delineate the different schists in the field.

The schists are both equigranular and inequigranular. The latter varieties are mainly the result of porphyroblastic growth although in some the larger crystals are relict feldspar phenocrysts. Most of the equigranular schists and the groundmass of most inequigranular types consist of aggregates of fine-grained biotite and quartz, commonly with some chlorite. In several places aggregates of fine-grained blue-green hornblende and quartz are found. The minerals are generally well alined and emphasize the schistosity of the rock. Porphyroblasts of biotite or blue-green hornblende are common in the inequigranular schists. Biotite porphyroblasts, as much as 1.5 millimeters in size, typically are elongated parallel to schistosity. Porphyroblasts of hornblende lie parallel to or across schistosity, indicating either that schistosity is palimpsest bedding along which recrystallization occurred with no shearing or that porphyroblasts grew under thermal influence after the shearing had ended.

The hornblende is rather strongly pleochroic (blue green to green to straw yellow), has maximum extinction ($Z \wedge c$) of 20 to 23°, and in porphyroblasts, ranges from a few tenths of a millimeter to 1.25 centimeters in maximum dimension. This hornblende is the principal indicator of the metamorphic grade of the basic schists.

The association of chlorite both with biotite and blue-green hornblende in many of the schists in sec. 10, T. 44 N., R. 31 W., probably represents an unstable metamorphic assemblage. The chlorite therefore probably formed by the retrogressive metamorphism of biotite. Just north of the reservoir in sec. 22, T. 44 N., R. 31 W., the intensity of metamorphism was lower than in sec. 10. Biotite and chlorite there are not associated with hornblende, and the paragenetic relationships of biotite and chlorite are not known.

Epidote occurs in the basic schists as granular and mosaic aggregates, as fillings in cracks and vesicles, and as partial replacements of original calcic plagioclase phenocrysts.

Plagioclase, rare in most of the schists, is found mainly as pseudomorphs of original plagioclase phenocrysts in a groundmass rich in biotite or hornblende. Slightly schistose rocks with some relict volcanic texture may also contain pseudomorphs of groundmass plagioclase. In such rocks, relict phenocrysts (now oligoclase—about An_{11}) typically occur in a groundmass containing much criss-crossing or well-alined albite (about An_5), as well as some biotite, chlorite, and blue-green hornblende.

The lime of the epidote evidently was extracted from the original calcic plagioclase during the change to the present sodic plagioclase. In one specimen original plagioclase phenocrysts have been completely replaced by carbonate. Carbonate and epidote appear to be almost mutually exclusive in the basic schists.

Leucoxene and magnetite are present in amounts ranging from a few percent or less to about 15 percent, and in places the rock causes strong magnetic anomalies. Finely granular and dusty magnetite forms ill-defined streaky zones parallel to schistosity. Other secondary magnetite octahedra or lath-shaped replacements of plagioclase or hornblende are widespread.

METARHYOLITE

Outcrops of the metarhyolite member of the Hemlock formation are found along the west side of the hill in the SW¼ sec. 27 and the NW¼ sec. 34, T. 44 N., R. 31 W. Outcrops of entirely similar metarhyolite are exposed about 1 mile to the southwest, on the north slope of Michigamme Mountain. Three-quarters of a mile south of the mountain, in the SE¼ sec. 4, two small exposures of metarhyolite occur within a few feet of Randville dolomite, and several outcrops lie within 100 to 200 feet of the Randville. The latter exposures of metarhyolite are on the structural nose where the regional strike of the Hemlock changes from south to northwest. Farther northwest felsite forms two small outcrops in the SW¼ sec. 5, T. 43 N., R. 31 W., and a cluster of outcrops in the SE¼ sec. 36, T. 44 N., R. 32 W. Sericite slate drilled in sec. 3, T. 43 N., R. 31 W., is correlated with the acid volcanic rock of the Hemlock. Acid volcanic rocks of the Hemlock formation are exposed west of the Kiernan quadrangle in secs. 4 and 32, T. 44 N., R. 32 W., and north of the quadrangle near the Sholdeis exploration in sec. 21, T. 45 N., R. 31 W.[13] (Clements and Smyth, 1899b, p. 91–95, 446).

The weathered metarhyolite is commonly light buff, light gray, or pinkish; the fresh rock is generally gray or dark gray. The rock is characterized by "eyes" of opalescent blue quartz in a quartz-sericite matrix (figs. 16, 17). Some of the felsite in the western part of the quadrangle and the sericite slate drilled in sec. 3, T. 43 N., R. 31 W., have "eyes" mainly of colorless glassy quartz.

The metarhyolite on the north slopes of Michigamme Mountain and a mile northeast of there was probably a crystal tuff originally containing abundant feldspar fragments. The feldspar is completely altered to quartz and sericite in many places. The alteration is

[13] Wier, K. L., and Kennedy, B. E., 1951, Geologic and magnetic data of the Sholdeis-Doane and Red Rock explorations, Iron County, Mich.: U. S. Geol. Survey, open file report.

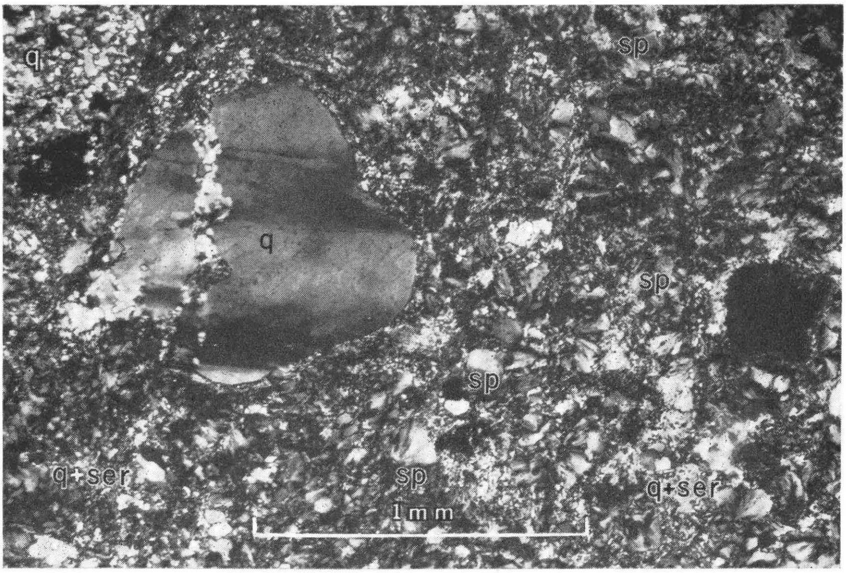

FIGURE 16.—Photomicrograph of metarhyolite from Hemlock formation, 550 feet north and 1,650 feet west of the southeast corner, sec. 33, T. 44 N., R. 31 W. Embayed quartz "eye" phenocryst has strain shadows. Groundmass contains fine-grained quartz and sericite and abundant spherulites, probably of feldspar. Crossed nicols. (*q*) quartz, (*ser*) sericite, (*sp*) spherulite.

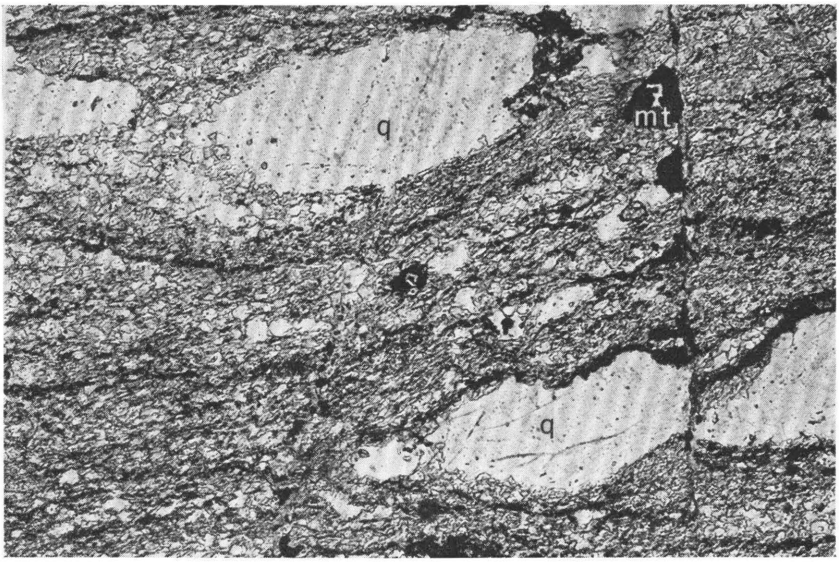

FIGURE 17.—Photomicrograph of metarhyolite from Hemlock formation, 1,900 feet north and 500 feet west of the southeast corner, sec. 4, T. 43 N., R. 31 W. Quartz "eyes" in groundmass of fine-grained quartz sericite, feldspar and hematite. Magnetite along margins of elongated quartz "eyes" and along crack indicates that in its present form it is postdeformational. Plane light. (*q*) quartz, (*mt*) magnetite.

unusual in that quartz, with much included sericite, appears to be pseudomorphous after feldspar. Furthermore, in each pseudomorph the quartz is not in mosaics or grandular aggregates but in single crystals corresponding to individual feldspars. The quartz of each pseudomorph extinguishes evenly under crossed nicols. Elongated sericite-rich patches occur in places and may be stretched feldspar pseudomorphs. The matrix originally was finely crystalline or glassy. It has been much sheared and now consists mostly of quartz and sericite. Embayed beta-quartz typical of acid volcanic rocks (fig. 16) and lenticular quartz mosaics (fig. 17) constitute as much as 10 percent of the volume of these rocks. The lenticular mosaics may be recrystallized quartz fragments or amygdules, or both.

In some of the metarhyolite on the north slope of the mountain, partly altered orthoclase, microcline, and albite lie in a matrix of sericite, quartz, kaolinite, and a nearly colorless or pale-brown material of unknown composition. The albite is mottled or has vague grid structure and evidently is mostly albitized microcline. In some of the metarhyolite a possible potash feldspar forms abundant spherulites in the matrix (fig. 16). The mineral forming the spherulites has a large optic angle, is biaxially positive, has low birefringence, indices of refraction close to 1.520, and parallel or nearly parallel extinction. South of the mountain in the SE¼ sec. 4, T. 43 N., R. 31 W., the metarhyolite contains abundant quartz and some fine-grained feldspar (fig. 17).

During the present investigation chemical analyses of the acid volcanic rock from four localities were obtained. (See table 8.) They show that these highly altered rocks are rhyolitic in composition. The only departures from the "average" rhyolites of Daly (1933) or from the rhyolites of Clarke (1924, p. 439) are in the relatively high potash and low soda contents and in the relatively high percentage of water. The analyses are strikingly like some of those listed by Washington (1917, p. 54–55).

The acid volcanic rock in the western part of the quadrangle (sec. 36, T. 44 N., R. 32 W.; sec. 5, T. 43 N., R. 31 W.) is much fresher, and poorer in feldspar, than the rock in the vicinity of Michigamme Mountain. It is not definitely known to be rhyolitic, but it is described here because of its felsitic appearance. It consists mainly of quartz and biotite forming a mosaiclike groundmass. Larger crystals of albite-oligoclase and mosaic quartz pods are subordinate or minor in amount. The rock has only small amounts of sericite. Reasons for the difference in intensity of alteration of this rock and the metarhyolite at the mountain are not known.

The metarhyolite apparently lies in the lower part of the Hemlock formation, as it crops out within a few feet of underlying Randville dolomite or Goodrich quartzite in the vicinity of Michigamme Mountain. Drilling in sec. 3 southeast of the mountain reveals sericite slate, believed to be equivalent to the metarhyolite, also immediately above the dolomite and quartzite.

TABLE 8.—*Chemical analyses of metarhyolite and rhyolite*

[Analyst (analyses nos. 1 to 4): Lucille M. Kehl, U. S. Geological Survey]

	1	2	3	4	Average of Clarke's 8 rhyolites (U. S. G. S. Bull. 770)
SiO_2	73. 53	72. 06	75. 86	75. 35	74. 46
Al_2O_3	12. 19	12. 04	12. 21	12. 86	13. 43
Fe_2O_3	2. 32	1. 27	. 33	. 69	. 99
FeO	. 22	3. 60	. 26	3. 17	. 79
MgO	. 31	. 95	. 12	1. 17	. 31
CaO	. 21	. 80	. 25	. 26	. 73
Na_2O	. 23	. 57	. 34	. 13	3. 44
K_2O	9. 85	5. 15	9. 34	2. 95	3. 99
H_2O-	. 05	. 05	. 06	. 06	1. 54 (H₂O− and H₂O+)
H_2O+	. 25	1. 71	. 26	2. 26	
TiO_2	. 49	. 68	. 67	. 76	. 13
CO_2	. 13	. 83	. 03	. 01	----------
P_2O_5	. 08	. 17	. 18	. 19	. 04
MnO	. 01	. 06	. 00	. 01	----------
Total	99. 87	99. 94	99. 91	99. 87	99. 85

1. Deep pink metarhyolite with lenticles and phenocrysts of opalescent quartz set in groundmass of fine-grained quartz, feldspar, sericite, and hematite. Lenticles of large quartz crystals or of fine-grained quartz in mosaic-textured aggregates. Sericite of groundmass stained by hematite. Quartz lenticles and phenocrysts, 5 to 10 percent; groundmass quartz and feldspar, about 75 percent; sericite and hematite, 10 to 20 percent. Minor amounts of magnetite, leucoxene, carbonate. See fig. 17 for photomicrograph of rock from this locality. Kiernan quadrangle, from outcrop 1,900 feet north and 500 feet west of the southeast corner of sec. 4, T. 43 N., R. 31 W.
2. Pink to gray metarhyolite with phenocrysts of opalescent quartz. Bulk of rock originally crystals or fragments of probable potash feldspar. Original feldspar now largely quartz-sericite pseudomorphs grading into aggregates of fine-grained sericite and chlorite in groundmass. Quartz phenocrysts, 1 to 5 percent; quartz-sericite pseudomorphs of feldspar, about 70 percent; groundmass sericite, about 15 percent; groundmass chlorite, about 10 percent. Minor amounts of magnetite, leucoxene, and relict feldspar. Kiernan quadrangle, from outcrop 200 feet north and 1,600 feet west of southeast corner of sec. 33, T. 44 N., R. 31 W.
3. Pink and gray mottled schistose metarhyolite with phenocrysts of blue opalescent quartz. Much original medium-grained feldspar altered to quartz-sericite pseudomorphs. Groundmass largely sericite and spherulites of probable feldspar. Quartz phenocrysts, 5 percent; quartz-sericite pseudomorphs of original feldspar, about 30 percent, relicts of alkali feldspar, 5 to 10 percent; groundmass sericite, 5 to 10 percent; spherulites, about 50 percent. Minor leucoxene. See fig. 16 for photomicrograph of rock from this locality. Kiernan quadrangle, from outcrop 550 feet north and 1,650 feet west of southeast corner of sec. 33, T. 44 N., R. 31 W.
4. Gray metarhyolite with phenocrysts of blue opalescent quartz. Original medium-grained feldspar crystals or fragments formed large part of rock. Feldspar now entirely altered to quartz-sericite pseudomorphs of original feldspar. Groundmass of fine-grained sericite, chlorite, biotite, and cherty quartz. Quartz phenocrysts, about 2 percent; quartz-sericite pesudomorphs of original feldspar, 75 to 85 percent; groundmass sericite about 10 percent; biotite and chlorite, about 5 percent. Minor leucoxene and apatite. Kiernan quadrangle, from outcrop 4,500 feet north and 4,200 feet west of southeast corner of sec. 34, T. 44 N., R. 31 W.

The disappearance of magnetic anomalies in the belt of Hemlock formation between sec. 22, T. 44 N., R. 31 W., and secs. 27 and 34 (pls. 2, 4) may be due in part to the wedging of metarhyolite into the stratigraphic section in place of magnetic greenstone.

SLATE

Slate in narrow belts from a few feet to about 100 feet wide is interbedded with greenstone of the Hemlock formation mainly in the S½ sec. 7 and in the N½ sec. 17, T. 43 N., R. 31 W. The zone of slate extends south into the Lake Mary quadrangle. It evidently grades southward into the locally iron-rich slate (the "Mansfield slate") that was formerly mined for iron at Mansfield on the Michigamme River (Van Hise and Leith, 1911, p. 295). The iron-rich part of the slate probably thins northward toward the Kiernan quadrangle. Iron-rich rock has been found by Bayley [14] in test pits, 100 to 200 feet west of the road in the west-central part of sec. 17, T. 43 N., R. 31 W., in the adjacent Lake Mary quadrangle, but has not been observed within the Kiernan quadrangle.

The slate is gray to gray green, thinly bedded, and characterized by narrow striped marking in outcrop. The well-defined layers generally are alternately rich in chlorite, sericite, biotite, and detrital or cherty quartz, and range from about ¼ to 1 inch in thickness. Layers rich in chlorite, sericite, or biotite typically have small amounts of the other two platy minerals, as well as leucoxene. The platy minerals are well alined parallel to compositional layering. The rock may be tuffaceous in part, with some of the platy minerals and leucoxene having been derived by the alteration of volcanic ash.

GRAYWACKE

A cherty graywacke is exposed on the south side of Michigamme Mountain in the NE¼ sec. 4, T. 43 N., R. 31 W., and graywacke is interbedded with sericite-chlorite slate in drill holes in sec. 3, T. 43 N., R. 31 W. The rocks appear to lie at or near the base of the Hemlock formation.

The rock forms low-lying outcrops, is dark gray green, and is thinly layered. The exposed graywacke consists mainly of fragments of recrystallized chert, clastic quartz, and feldspar in a matrix containing sericite, biotite, chlorite, and recrystallized chert. (See table 6.) The layering is caused by alterations of clastic chert and quartz with platy minerals and recrystallized chert (possibly original silica cement). Some of the finer-grained material may be of volcanic origin.

The graywacke drilled in sec. 3 is a fine-grained chlorite-rich rock with considerable clastic quartz, which is visible with a hand lens.

AGE RELATIONS

The metavolcanic rocks in the southwestern part of the quadrangle lie on the west side of the major uplifts of the Amasa oval and the

[14] Bayley, R. W., op. cit.

Lower Precambrian magnetic green schist. They are correlated with the Hemlock formation both because of lithologic similarities and because they strike northwestward directly into the type area of the Hemlock northeast of Amasa.

The metavolcanic rocks in the immediate vicinity of Michigamme Mountain are also correlated with the Hemlock formation although their correlation is less obvious. Altered volcanic rocks on the north side of the mountain can be traced northward along the east side of the oval and thence around the north end of the oval into the Hemlock formation at the type locality. The tracing of these rocks northward from the mountain to the SW¼ sec. 27, and from there northward across secs. 22, 15, 10, and 3, T. 44 N., R. 31 W. to the north edge of the quadrangle, has been done by means of scattered outcrops and magnetic data. From the north edge of the quadrangle, this belt of metavolcanic rocks continues northward to the area of the Sholdeis and Doane explorations in secs. 21, and 16, T. 45 N., R. 31 W. The outcrops of metarhyolite in secs. 27 and 34, T. 44 N., R. 31 W., are of particular significance in correlating the metavolcanic rocks on the north side of Michigamme Mountain with those of the Sholdeis-Doane area. The metarhyolite in secs. 27 and 34 lies between the magnetic anomaly extending north from the mountain and the magnetic anomaly extending south from the Sholdeis-Doane area. The identical appearance of the metarhyolite in secs. 27 and 34 and the metarhyolite at the mountain, and the position of both metarhyolites immediately east of the anomaly that extends northward from the mountain,[15] show that the metarhyolites are correlative. The metarhyolite in secs. 27 and 34, however, is also correlative with metavolcanic rocks in the Sholdeis-Doane area because both lie west of the magnetic crest that extends southward from the Sholdeis exploration. The metavolcanic rocks of the Sholdeis-Doane area, although mainly basic, do contain some quartz-bearing acid volcanic rock.[16] Lithologic differences between the metarhyolite in secs. 27 and 34 and the metavolcanic rocks to the north are attributed to a combination of lithologic facies change and difference in metamorphic grade. Clements and Smyth (1899b, pl. 3) extended the belt of metavolcanic rocks of the Sholdeis-Doane area north and west around the oval into the Hemlock formation of the type locality.

Metarhyolite south of the mountain in sec. 4, T. 43 N., R. 31 W., is correlated with the Hemlock because it strikes northwestward toward acid volcanic rock of the Hemlock formation. Some of the sericite slate drilled in sec. 3, T. 43 N., R. 31 W., is interbedded with

[15] The metarhyolite at the mountain lies both east and north of the magnetic anomaly, presumably because of a fold in the Goodrich quartzite at the mountain.

[16] Wier, K. L., and Kennedy, B. E., 1951, Geologic and magnetic data of the Shoeldeis-Doane and Red Rock explorations, Iron County, Mich., U. S. Geol. Survey, open file report.

greenstone. Similar sericite slate has been drilled in the eastern part of sec. 9 and across sec. 10, T. 43 N., R. 31 W. These slates are correlated with the Hemlock formation because of the greenstone interbedded with slate in sec. 3, and also because the slate has been drilled close to greenstone of the Hemlock formation in the northeast quarter of sec. 9.

The equivalence of the metavolcanic rocks north and south of Michigamme Mountain is established by the independent correlation of each with the Hemlock as outlined above and their similar stratigraphic position above the Goodrich quartzite. The position of the metavolcanic rock above the Goodrich is clearly shown north of the mountain by the upward sequence, mapped from west to east, of Randville dolomite—magnetic rock (Goodrich)—metarhyolite. In drill holes, south and east of the mountain, the metavolcanic rocks have been found above the Goodrich.

The Hemlock formation was formerly considered to be of "Middle Huronian" age because of its position on the east side of the oval between Randville dolomite and an iron-formation previously correlated with the "Middle Huronian" Negaunee iron-formation (Clements and Smyth, 1899b, p. 453–456; Van Hise and Leith, 1911, p. 296–297). In the present report, because the metavolcanic rocks near Michigamme Mountain overlie the "Upper Huronian" Goodrich quartzite, the Hemlock is considered to be "Upper Huronian"; that is, of late Middle Precambrian age. Inasmuch as these metavolcanic rocks have been shown to be correlative with the Hemlock formation of the type locality, the Hemlock is an "Upper Huronian" formation.

FENCE RIVER FORMATION

DISTRIBUTION AND NAME

A narrow positive magnetic anomaly extends northward from the SE¼ sec. 27, T. 44 N., R. 31 W., to the north edge of the quadrangle in sec. 34, T. 45 N., R. 31 W. (pls. 1 and 2). From there, the magnetic belt has been traced north to the Sholdeis exploration in the SE¼NE¼ sec. 21, T. 45 N., R. 31 W., where the only known exposure along the belt on the east side of the Amasa oval is found (Clements and Smyth, 1899b, p. 447). The magnetic rock exposed at the Sholdeis exploration is here named the Fence River formation, after the Fence River, which crosses the magnetic belt 1,100 feet south of the Sholdeis exploration.

DESCRIPTION

In its only known exposure, the Fence River formation is "mostly a dark, fine-grained, thin-banded rock consisting chiefly of quartz, magnetite, hornblende, and epidote . . ." that grades "stratigraphically upward into massive garnet and grunerite schist."[17] Test pits immediately west of the outcrop and at the Doane exploration in the SE¼ sec. 16 explore a stratigraphically lower part of the formation, which is a magnetite-specularite-quartz rock. At least some of the quartz, possibly much of it, is of clastic origin. This quartzitic rock is similar in appearance to some of the Goodrich quartzite at Michigamme Mountain.

The termination of the magnetic anomaly in sec. 27, T. 44 N., R. 31 W., is believed by the writers to be caused by the removal of the Fence River formation south of sec. 27 by erosion prior to the deposition of the overlying strata. An iron-formation on the west side of the oval has been partly truncated by an unconformity near Amasa (Allen and Barrett, 1915, p. 26). This iron-formation may be traced by means of an almost continuous magnetic line around the northern end of the oval into the Fence River formation. The iron-formations on both sides of the oval are probably correlative, and the unconformity near Amasa is believed to cross the Fence River formation in sec. 27.

AGE RELATIONS

The Fence River formation lies immediately east of and above the eastward-dipping Hemlock formation and appears to be structurally conformable with it at the Sholdeis exploration. The relationship of the Fence River formation to the Hemlock formation, and the decrease in the strength of the magnetic anomaly on the Fence River formation, southward from the Sholdeis exploration, are shown in plate 4.

Biotite-quartz schist overlies the Fence River formation and is exposed in one place in the E½ sec. 15, T. 44 N., R. 31 W. The rock is of volcanic origin and is similar to some of the schists of the Hemlock west of the iron-formation in sec. 10, T. 44 N., R. 31 W. If the schist were considered to be part of the Hemlock formation, the Fence River formation would be an upper member of the Hemlock formation. On the other hand, if the biotite-quartz schist is considered to be a basal member of the Michigamme slate, the Fence River is a distinct formation between the Hemlock and the Michigamme. The latter view is adopted in the present report for reasons given below in the section on the Michigamme slate.

The Fence River formation, therefore, overlies the "Upper Huronian" Hemlock formation. It is an "Upper Huronian" formation and is not correlative with the "Middle Huronian" Negaunee iron-formation.

[17] Wier, K. L., and Kennedy, B. E., op. cit., p. 8.

MICHIGAMME SLATE

The name "Michigamme formation" was first used in the 15th Annual Report of the U. S. Geological Survey (Van Hise and Bayley, 1895, p. 598) for outcrops on islands in Lake Michigamme at the west end of the Marquette Range. The formation was called Michigamme slate by Van Hise and Leith (1911).

The Michigamme slate is inferred to underlie much of the belt of glacial deposits in the eastern third of the quadrangle. Outcrops reported along the Michigamme River in the eastern part of the quadrangle may have been of Michigamme slate, but evidently they are now flooded by the backwaters of Michigamme Reservoir.

Descriptions of the formation are given by Van Hise and Bayley (1897, ch. 4), Clements and Smyth (1899b, p. 165–174), and Van Hise and Leith (1911, p. 267–268; 298–299). The formation is mainly a pelitic rock that originally consisted largely of argillaceous and graywackelike materials. It has been metamorphosed in varying degrees to form slates, mica and garnet schists, and impure quartzites. In places it contains metavolcanic members, particularly at the base of the formation in the western part of the Marquette Range.

The quartz-biotite schist east of the Fence River formation in the E½ sec. 15, T. 44 N., R. 31 W. (see fig. 18) is here considered to be a member of the Michigamme. It contains widely scattered relict plagioclase laths indicating that the rock is at least partly volcanic in origin. Most of the rock consists of fine- to medium-grained quartz and biotite, with subordinate amounts of carbonate and leucoxene and traces of chlorite. Most of the biotite forms small porphyroblasts in the well-foliated groundmass. The assignment of the schist to the Michigamme slate is based on two things: (1) similar metavolcanic rocks are known at the base of the Michigamme, 20 miles to the north in the western part of the Marquette Range, and (2) the Fence River formation is a suitable and convenient marker for separating the Hemlock from the Michigamme. The upward sequence of Hemlock formation—Fence River formation—Michigamme slate is quite similar to the upward sequence of Clarksburg formation—Bijiki iron-formation member—Michigamme slate in the western part of the Marquette Range. However, specific correlation of these two sequences cannot be made on the basis of available information.

The Michigamme is in general structural and metamorphic conformity with the underlying Fence River and Hemlock rocks and is therefore an upper Middle Precambrian unit.

371023—56——5

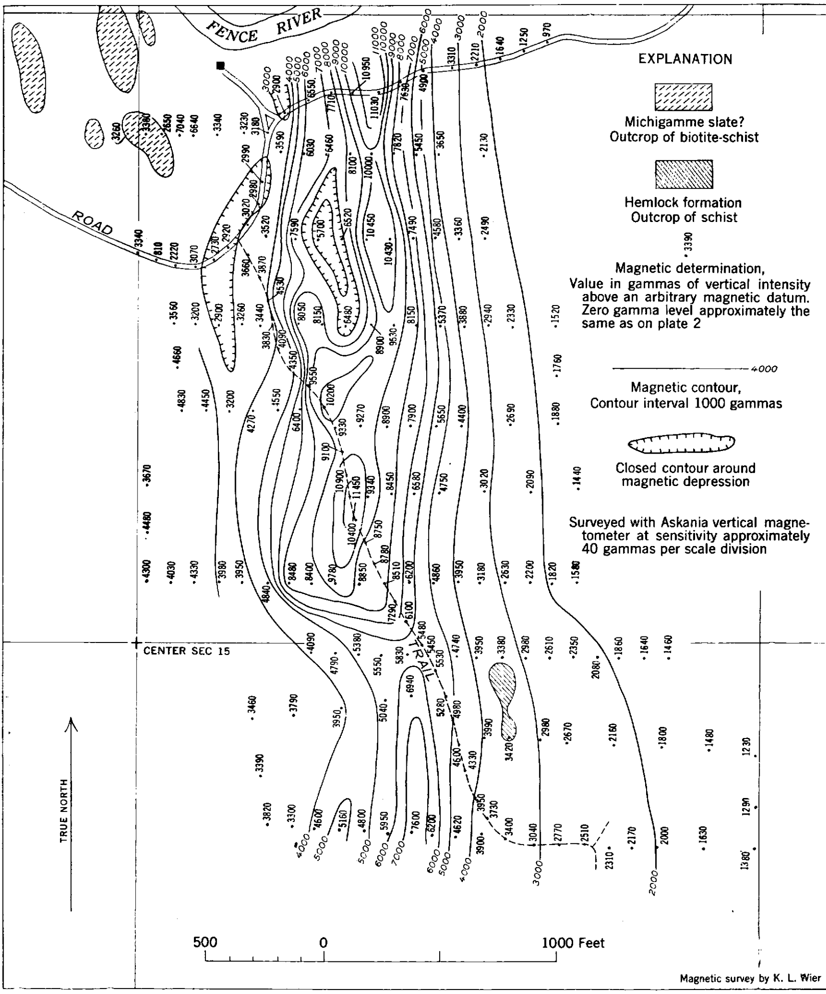

FIGURE 18.—Sketch map showing relationship of magnetic anomaly caused by the Fence River formation to outcrops of Hemlock formation and quartz-biotite schist (probable Michigamme slate) in sec. 15, T. 44 N., R. 31 W.

INTRUSIVE ROCKS

METAMORPHOSED BASIC INTRUSIVE ROCKS

KIERNAN SILLS

The bulk of the intrusive rock is metagabbro and metadiabase found in two contiguous sills in the Hemlock formation in the southwestern part of the quadrangle (pl. 1). These sills are here named the West Kiernan sill and the East Kiernan sill. Although Kiernan junction is located ⅓ to 1 mile from the sills, it is the nearest named geographic point of sufficient importance to be used for naming the bodies. The sills follow the southeast to south trend of the Hemlock across the area and into the Lake Mary quadrangle to the south. The West Kiernan sill is the larger and better defined of the two. It occurs in much of secs. 6, 7, 8, 16, and 17, T. 43 N., R. 31 W. The East Kiernan sill lies to the northeast in parts of secs. 5, 8, 9, 15, and 16.

The contacts of the West Kiernan sill with the Hemlock formation have not been seen in the area, although in places the upper contact is located within a few feet. An inclusion or residual layer of greenstone of the Hemlock formation is seen in contact with sill rock at one place, in the NE¼NE¼ sec. 17. In places in secs. 5 and 6, the northeastern contact is poorly defined owing to intermixing of the intrusion with volcanic rock of the Hemlock formation. The upper contact of the East Kiernan sill is exposed on a knob in the S½ sec. 9. In general, the sills appear to be concordant with beds of the Hemlock formation. However, in the SE¼ sec. 7, in the S½ sec. 8, and in the N½ sec. 17, the West Kiernan sill is discordant with slate of the Hemlock formation that strikes directly toward the contact from as little as 100 to 200 feet away. Probably these discordances are the result of minor faults.

The mapped width of the West Kiernan sill in the quadrangle ranges from about 2,000 to 5,000 feet. The dip is probably between 80° SW and vertical, so that the mapped width represents virtually the true thickness. The maximum thickness of the East Kiernan sill is about 3,000 feet.

The West Kiernan sill consists mainly of metagabbro and metadiabase, but, in addition the upper (southwestern) part of the sill contains relatively small amounts of basic pegmatite (coarse metagabbro and metapyroxenite) and granophyre. So far as is known, the East Kiernan sill contains only metagabbro and metadiabase.

Metagabbro and metadiabase.—The altered gabbro and diabase commonly form abrupt knobs or ridges. The rocks are deep green to greenish black on weathered surfacesand green to gray-green on fresh breaks. Relict igneous textures as well as mosaic and crystalloblastic arrangements of secondary minerals are found in the rocks. (See table 9.)

The mineralogy of the metagabbro and metadiabase, and of the metabasalt of the Hemlock formation, is very similar. The dominant minerals in the rock before alteration were calcic plagioclase and pyroxene. Minor primary minerals were ilmenite, magnetite, and apatite. During the late Middle Precambrian metamorphism, the dominant minerals were changed mainly to sodic plagioclase, epidote or clinozoisite, hornblende, and chlorite. Pyroxene has been seen only in a few thin sections of the metagabbro, generally as relicts surrounded by hornblende.

As in the greenstones of the Hemlock formation, the relatively low Na:Ca ratios (see table 7) are interpreted to be indicative of essentially isochemical change of original calcic plagioclase to albite-oligoclase during regional metamorphism. There is no evidence that these rocks originally had a high soda content or that they are the result of an addition of soda to the original material.

Pegmatitic metagabbro and metapyroxenite.—Very coarse-grained dark-green basic rocks occur in several outcrops within the West Kiernan sill between 200 and 900 feet from the southwestern edge of the intrusive body in the NE ¼ sec. 17, T. 43 N., R. 31 W. Most of the rocks now consist of large intergrown hornblende crystals. (See table 9.) Small patchy relicts of pyroxene within the hornblende of the metapyroxenite prove the derivation of the hornblende from pyroxene. Plagioclase forms about 2 percent of the only available thin section of metapyroxenite and about 10 percent of the only available thin section of pegmatitic metagabbro. Judging by six measurements of symmetrical extinction angles against albite twinning, the plagioclase of the pegmatitic metagabbro is calcic (A_{60}). These rocks evidently are not as severely metamorphosed as their finer grained metagabbro counterparts.

Granophyre.—Outcrops of granophyre occur near the southwest edge of the West Kiernan sill, a short distance north of the Michigamme River in sec. 7, T. 43 N., R. 31 W. The granophyre is a gray to mottled-gray and pink rock. The dominant minerals are albite-oligoclase, orthoclase, perthite, and quartz. (See table 9.) Graphic and myrmekitic intergrowths of quartz and feldspar are a characteristic feature. Biotite is aggregated between feldspar crystals and along cracks in the feldspar, and therefore is at least partly secondary. Some of the darker granophyre has considerable hornblende and grades into metagabbro in which wormy intergrowths of quartz and feldspar are interstitial to feldspar and hornblende.

Interpretation.—Granophyric and pegmatitic rocks derived by differentiation of gabbroic magmas that were intruded as flat-lying sills are commonly concentrated in the upper parts of such bodies (Walker, 1940; Hotz, 1953). The differentiating mechanism evidently is fractional crystallization under the influence of gravity. If such differentiation occurred in the West Kiernan sill, the granophyre must have formed essentially in a flat-lying zone in the upper part of the parent body. The present localization of the granophyric rocks along the southwest side of the intrusive body indicates that the intrusion has been steeply tilted to the southwest and is now exposed in cross section. This conclusion is supported by top directions to the southwest in ellipsoidal structures in nearby basalts of the Hemlock formation. The intrusive body is designated a sill because of its apparent structural conformity with the Hemlock formation and because of the evidence that it was originally flat-lying and roughly tabular in shape.

OTHER BASIC INTRUSIVE BODIES

Metagabbro and metadiabase.—Metagabbro and metadiabase also occur in small, isolated, ill-defined masses grading in places into surrounding fine-grained greenstones of the Hemlock formation in the SW ¼ sec. 5, in the SE ¼ sec. 6, and in the S ½ sec. 9, T. 43 N., R. 31 W. The description of the metagabbro and metadiabase in the Kiernan sills, as given above, suffices for similar rock in other intrusive bodies in the area.

Metadiabase found on a test-pit dump immediately northwest of Michigamme Mountain is assumed to represent a dike intruded into the Randville dolomite and the Goodrich quartzite.

Carbonate-rich metagabbro.—Carbonate-rich metagabbro is found south of the road in the NW¼NE¼ sec. 4, T. 43 N., R. 31 W., and on a hill in the NW¼SW¼ sec. 32, T. 44 N., R. 31 W. It is probably completely surrounded by Randville dolomite.

The rock forms knobby outcrops like those of the Kiernan sills. It is similar to the metagabbro with the exception that crystals or aggregates of fine- to medium-grained carbonate (probably calcite or dolomite) form 10 to 15 percent of the rock. Much of the carbonate in the metagabbro may have been derived from the nearby Randville at the time of intrusion.

Fine-grained greenstone.—Outcrops of fine-grained greenstone dike rock are found along many gullies in the southern part of the Margeson Creek gneiss, in the S½ sec. 17, and in the N½ sec. 20, T. 44 N., R. 31 W. Greenstone dikes are also widely scattered in the NE¼ sec. 6, in the SW¼ sec. 9, in the N½ sec. 17, and in the NW¼ sec. 21, T. 44 N., R. 31 W. Their locations are shown on the map by letter symbol.

The greenstone dikes commonly have slaty structure that is parallel to the gullies and, in many places, at an angle to foliation in adjacent granitic rocks. The greenstone generally becomes more slaty toward the margins of the gullies, and in at least one place in the NE¼NW¼ sec. 20, the greenstone becomes finer grained toward the edge of the dike.

The dominant minerals in the greenstone are chlorite or green-brown biotite, quartz, and carbonate. (See table 9.) Chlorite commonly is in aggregates roughly pseudomorphous after original hornblende or pyroxene. Otherwise, chlorite and other platy minerals have a pronounced alinement parallel to foliation (slaty parting). Carbonate evidently was derived by the alteration of original calcic plagioclase, and commonly forms porphyroblasts that lie astride

TABLE 9.—*Petrographic data for intrusive rocks in the Kiernan quardangle*

[Some minerals fall in more than one of the three percentage columns. Mineral name is in parentheses if that mineral belongs in indicated column in only few specimens.]

Rock	Dominant minerals >20 percent	Subordinate minerals 5–20 percent	Minor minerals <5 percent	Predominant grain sizes of dominant minerals, F–<0.1mm, M–0.1 to 2.0mm, C–>2.0mm	Remarks
Metagabbro and metadiabase.	Clinozoisite, hornblende, (chlorite).	Albite-oligoclase An_{8-15}, chlorite, (hornblende), (carbonate), (leucoxene).	Sericite, biotite, quartz, epidote, carbonate, apatite, leucoxene, magnetite, pyrite.	M and C, individual grains of clinozoisite are generally F.	Original textures hypidiomorphic granular, ophitic, diabasic. Hornblende pale olive green and moderately pleochroic—probably low in alumina. Clinozoisite in granular aggregates. Some aggregates of sericite, carbonate, and quartz pseudomorphous after plagioclase.
Carbonate-rich metagabbro.	Chlorite	Clinozoisite, carbonate, (chlorite), plagioclase, (sericite), (quartz).	Quartz, sericite, biotite, Ilmenite, leucoxene (plagioclase).	M and C	Most of original plagioclase altered to sericite, clinozoisite, quartz, and carbonate. Remaining plagioclase indeterminate. Original ferromagnesian mineral to chlorite. Possible assimilated carbonate forms relatively large clusters.
Pegmatitic metagabbro.	Hornblende	Labradorite An_{60}	Chlorite, sericite, fibrous amphibole, clinozoisite, carbonate, epidote.	C	Texture allotriomorphic to hypidiomorphic granular. Plagioclase altered in part to epidote, clinozoisite, carbonate, sericite, and a fibrous amphibole.
Pegmatitic metapyroxenite.	Hornblende		Plagioclase, pyroxene, chlorite, carbonate, epidote.	C	Texture allotriomorphic granular. Pyroxene relicts in hornblende. Some of chlorite, carbonate, and epidote are alteration products of pyroxene or hornblende.
Granophyre	Feldspar—albite-oligoclase, perthite, orthoclase, quartz.	(Quartz), (biotite), (hornblende).	Hornblende, biotite, chlorite, sericite, carbonate, apatite, magnetite.	Feldspar: M and C; Quartz: F and M.	Texture allotriomorphic granular and granophyric. Quartz in granophyric and myrmekitic intergrowths.
Fine-grained greenstone.	Chlorite or biotite, quartz, (carbonate).	Albite-oligoclase, (sericite), carbonate, (quartz), (epidote), (leucoxene).	Kaolinite, sericite, muscovite, epidote (chlorite or biotite), leucoxene, ilmenite, magnetite.	F	Biotite is minor mineral in chlorite-rich rocks. Where biotite common, it is generally interspersed evenly with quartz, sericite, and minor chlorite. Carbonate, epidote, sericite, and quartz probably derived by alteration of original calcic plagioclase.

Quartz porphyry	Quartz, biotite (sericite)	Sericite (biotite)	Feldspar, carbonate, leucoxene, magnetite.	F, quartz "eyes" are M.	Biotite and sericite well alined in groundmass. Foliation bends partly around quartz "eye" phenocrysts. Biotite blebs are aggregates of biotite flakes; they may be sheared out pseudomorphs of earlier dark mineral. Remnants of feldspar in midst of some sericite patches. In few places, carbonate in "shear shadows" of quartz "eyes."
Trachyte	Feldspar, sericite	(Carbonate), (leucoxene).	Carbonate, leucoxene, iron oxides.	F and M	A few quartz grains seen in one hand specimen, but none in thin sections.
Diabase	Labradorite An_{52}, pigeonitic pyroxene.	Magnetite, chlorite, biotite.	Sericite, muscovite, kaolinite, apatite, iron oxides.	M	

foliation planes but have little or no dimensional orientation. Kaolinized and albitized relicts of probable calcic plagioclase and crystals of secondary albite are subordinate constituents in some of the greenstone.

A thin greenstone dike cuts the northermost dolomite outcrop at the water's edge in the SW¼ sec. 28, T. 44 N., R. 31 W. The rock is now essentially a quartz-chlorite schist with a subordinate amount of leucoxene. The quartz is evenly interspersed with well-alined flakes of chlorite. Leucoxene aggregates are generally elongated parallel to foliation.

AGE OF ALTERED BASIC INTRUSIVE ROCKS

The sills and other less well-defined bodies of metagabbro, metadiabase, and associated rocks intruded into the Hemlock formation are clearly post-Hemlock in age. The carbonate-rich metagabbro must be post-Randville in age, and because of its general similarity to metagabbro of post-Hemlock age, it, too, may be post-Hemlock. The degree of alteration of these basic intrusive rocks shows that they were emplaced before the time of late Middle Precambrian regional metamorphism. The rocks intruded into the Hemlock are therefore rather late Middle Precambrian, and the carbonate-rich metagabbro is probably of the same age.

The fine-grained greenstone dikes in the Margeson Creek gneiss are clearly younger than the Lower Precambrian rocks in places where they transect the foliation of the complex. They also truncate and are younger than quartz veins in the adjacent granitic rock. The degree of metamorphism of the dikes indicates that they formed prior to the late Middle Precambrian, and it is entirely possible that they were associated either with the eruption of the volcanic rocks of the Hemlock formation or with later Middle Precambrian basic intrusive rocks.

QUARTZ PORPHYRY

Quartz porphyry is exposed in T. 44 N., R. 31 W., in the SE¼ sec. 5, in the NE¼NE¼ sec. 17, in the SE¼SE¼ sec. 17, in the NE¼NE¼ sec. 20, in a northeast-trending gully in the NW¼NW¼ sec. 20, and in relatively large outcrop in the SE¼SW¼ sec. 16. In several exposures the porphyry forms a thin comformable layer in the gneiss, and in one place it projects several feet above the surface in a small tabular outcrop. The quartz porphyry in the large outcrop in sec. 16 was described in Monograph 36 (Clements and Smyth, 1899b, p. 429),[18] although it was not thought to be intrusive rock. The similar-looking quartz porphyry in the other localities is here considered approximately correlative with the quartz porphyry in sec. 16.

[18] In Monograph 36 this outcrop was referred to sec. 21. This was probably because of an error of several hundred feet in field location.

The quartz porphyry is generally gray brown to tan. It is schistose to slaty and is characterized by "eyes" of blue opalescent quartz and, in places, by platy blebs of biotite or sericite. (See table 9.) Some of the quartz "eyes" are mosaic pods or lenses, and some are single strained and embayed crystals, clearly of volcanic or hypabyssal origin. The quartz "eyes" are set in a strongly alined groundmass of quartz, biotite, and sericite. Patchy aggregates of sericite are vaguely pseudomorphous after feldspar.

Fragments of pink coarse-grained inequigranular granitic rock as much as several feet in diameter are included in the quartz porphyry in sec. 16, T. 44 N., R. 31 W. They were noted by Smyth in Monograph 36.

The granitic inclusions in the porphyry in sec. 16 prove that the porphyry there is younger than the Margeson Creek gneiss. If the porphyry (forming layers in gneiss) at the other occurrences is correlative with the porphyry in sec. 16, the rock in the other occurrences must also be younger than the Margeson Creek gneiss. Accordingly, the thin conformable layers of quartz porphyry in the gneiss would be intrusive rock. The quartz porphyry in the gully in sec. 20 is apparently associated with a greenstone dike that transects the foliation of the gneiss and is clearly intrusive. The conclusion that the quartz porphyry of the other occurrences is intrusive at least suggests that the porphyry in sec. 16 is also intrusive, rather than a flow of post-granite, pre-Randville dolomite age, as suggested by Smyth (Clements and Smyth, 1899b, p. 429).

Foliation in a flow rock unconformably overlying foliated granitic rock should truncate the foliation in the granitic rock, and its trend should approximate that of the contact between granitic and flow rock. Foliation in the porphyry in sec. 16 strikes northward directly toward an outcrop of foliated granitic rock, 150 feet away. The foliation trend of the granitic rock is variable but, in general, parallels the trend in the quartz porphyry. The apparent structural concordance between porphyry and granitic rock at this place is similar to that where quartz porphyry is actually seen in contact with enclosing gneissic rock. This seems to disprove Smyth's suggestion that the porphyry is flow rock.

The degree of alteration of the quartz porphyry indicates that the porphyry antedated the late Middle Precambrian regional metamorphism. The intrusion of the quartz porphyry took place sometime after the formation of the Margeson Creek gneiss and before the end of Middle Precambrian time; it may be related to the acid rocks of the Hemlock formation.

TRACHYTE

Trachyte is interlayered with Randville dolomite in the east-central part of sec. 32, T. 44 N., R. 31 W., and is found in several small isolated outcrops in the NE¼ sec. 4, T. 43 N., R. 31 W.

The rock in sec. 32 is a layer of pink dense fine-grained material, not more than a few feet thick. It has a trachytic texture and consists mainly of feldspar laths and sericite in about equal amounts. Most of the feldspar shows faint gridlike twinning and is probably a potassium feldspar. The sericite and minor iron oxides may have formed from the alteration of a glassy base. The trachyte in sec. 4 is buff and similar to that in sec. 32, except that it contains considerable carbonate (probably dolomite or calcite). The texture of the rock is fairly trachytic, with well-alined sericite surrounding somewhat alined feldspar laths. The carbonate has no dimensional orientation.

The trachyte is either a volcanic flow rock emplaced during deposition of the Randville or a sill rock of uncertain age. In the general absence of other evidence of possible volcanism while the Randville was forming, the trachyte is considered an intrusive rock of post-Randville age.

DIABASE

Several outcrops of an eastward-trending diabasic dike are found across the belt of volcanic rock of the Hemlock formation in the SW¼ sec. 10, T. 44 N., R. 31 W.

The diabase is in contact with the Hemlock in several outcrops. Although only single steeply dipping contacts are seen at any one place, the thickness of the diabase dike does not exceed 100 feet. The rock is dark green or greenish black. On weathered surfaces it is rusty looking; where freshly broken the minerals appear to be largely unaltered. Feldspar laths, intergrown with ferromagnesian mineral to form a diabasic texture, are clearly visible to the naked eye. Magnetometer readings along a traverse from the Hemlock formation across the diabase show a strong negative anomaly, indicating that the dike rock is negatively polarized in a manner similar to that described for other diabase dikes in the region (Balsley, James, and Wier, 1949).

The essential primary minerals are sodic labradorite, 40 to 50 percent, and pigeonitic pyroxene, 20 to 25 percent. The labradorite forms laths and a few blocky grains, from 0.4 to 2 millimeters in size. A few feldspar laths as large as 1 centimeter in length have been seen in hand specimen. Some zoning of feldspar is evident. Minor amounts of sericite and kaolinite form small alteration patches in some feldspar crystals.

There is about 15 percent primary and secondary magnetite (?) that are not always distinguishable from one another. Combined muscovite-magnetite (?) mixtures have rather well-defined boundaries and may be replacements of an earlier mineral, possibly feldspar. The general freshness of the feldspar and the spotty distribution of the muscovite-magnetite (?) mixtures suggest the origin of these mixtures by deuteric processes.

The pigeonitic pyroxene is generally fresh. Aggregates of chlorite, biotite, and iron oxides border some of the pyroxene crystals and form about 10 percent of the rock. They are probably deuteric products.

The high percentage of primary minerals in the diabase and their small degree of marginal alteration indicate that the diabase is younger than the metamorphism of the Hemlock formation. The negative magnetization of the diabase as well as its general appearance make it entirely analogous to diabase of the Keweenawan of adjacent regions.

CAMBRIAN ROCKS

Boulders and smaller fragments of sandstone have been found in test-pit dumps in the NW¼ sec. 33, in the NW¼ sec. 34, and in the SW¼ sec. 27, T. 44 N., R. 31 W. The rock was not observed in place, but presumably it forms flat-lying or low-dipping erosional remnants comparable to many found in adjacent parts of the region.

The sandstone is massive, rather loosely cemented, and buff to red. It consists almost entirely of fairly well-rounded medium-size frosted quartz grains with some quartz and chert pebbles. The rock is considered to be Cambrian because of lithologic similarity to Cambrian rocks in adjacent areas and because its occurrence astride belts of two different Middle Precambrian formations indicates that it forms flat-lying erosional remnants.

STRUCTURE

The two major structural features in the quadrangle are the elongate anticlinal uplights of the Amasa oval in the northwest and the magnetic green schist in the southeast. Both lie along the same axis. Between them, the axis plunges into the saddle near Kiernan junction southeast of Michigamme Mountain. The simple structural pattern is disrupted in the vicinity of the mountain by cross folding. A relatively small north-trending anticline lies east of the main axis in secs. 27 and 34, T. 44 N., R. 31 W. The present form of the uplifts is related to the late Middle Precambrian orogeny.

AMASA OVAL

Most of the granitic rocks of the oval have a pronounced foliation, commonly accentuated by the alinement of large tabular crystals of feldspar. Banding in the gneiss is conformable with foliation of the associated granitic rocks. The strikes of foliation are mainly between N 30° W and N. Dips are generally eastward, are practically always steeper than 40°, and are commonly between 70° and 90°. A striking and significant feature of the foliation is the fact that at the southernmost end of the Margeson Creek gneiss it maintains the same north to north-northwest trends that it has farther north, with no deflection toward parallelism with the southern contact of the gneiss. The Randville dolomite, in passing across the nose of the uplift from one flank of the oval to the other, evidently truncates the foliation of the gneiss. This is proof of an unconformity between the Margeson Creek gneiss and the Randville dolomite. Furthermore, it shows that the foliation was a Lower Precambrian feature as does also the directional control exerted by foliation planes on the growth of feldspar metacrysts in gneiss during Lower Precambrian migmatization.

Foliation is the only internal structural element mapped. True linear arrangement of minerals was not noted in the Margeson Creek gneiss, except in the sparse amphibolite. The parallelism of the Lower Precambrian foliation and the long axis of the oval indicates some type of relationship between foliation trends and the uplift of the oval. Poles of foliation planes have been plotted on a Schmidt equal-area net held in a horizontal position. There is practically no difference between plots of foliation in the eastern and western parts of the oval (see fig. 19). Possibly, movements like those of shear folding along the Lower Precambrian foliation surfaces produced the late Middle Precambrian uplift without affecting the general attitudes of foliation surfaces.

The southern part of the gneiss, chiefly the part in secs. 17 and 20, is cut by numerous dikes of greenstone and minor associated siliceous rock. Most of the dikes are now marked by narrow gullylike valleys. The dikes converge northward toward the south-central part of sec. 17. The elongate swampy depression extending north for 2 miles from the SE¼ sec. 17 may represent the continuation of the converged dikes. Along and adjacent to this swampy depression, there are small isolated occurrences of basic rock. Some of this rock is thinly interlayered with gneiss and may be merely darker phases of the gneiss. The pattern of the dikes, the presence of zones of gash veins of quartz forming typical ladder structures immediately adjacent to the dikes in some places (see fig. 20), and the apparent off-sets in the border of the Margeson Creek gneiss in the NE¼ sec. 20 indicate that the dikes were intruded along faults. The maximum horizontal or apparent horizontal offset is on the order of 1,500 feet. The age of the faults is unknown, although their location and pattern on the nose of the uplift suggest a genetic relationship with the doming. Inasmuch as metamorphism of the dikes was approximately concomitant with the doming, the faults, if related to the doming, must have formed very early in the period of deformation.

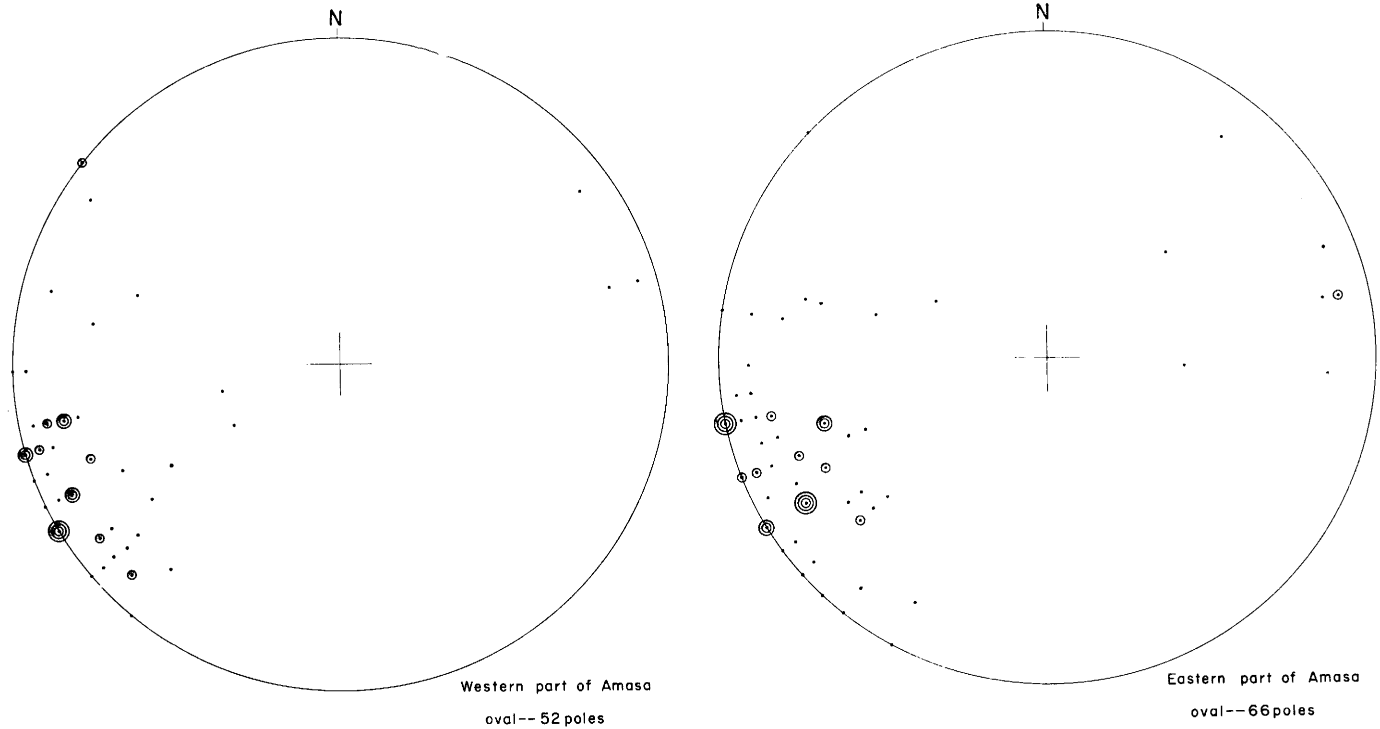

FIGURE 19.—Poles of foliation planes in Margeson Creek gneiss. Plotted on lower hemisphere of equal-area projection. Circles around points represent more than one pole at same point. Western part of Amasa oval—52 poles. Eastern part of Amasa oval—66 poles.

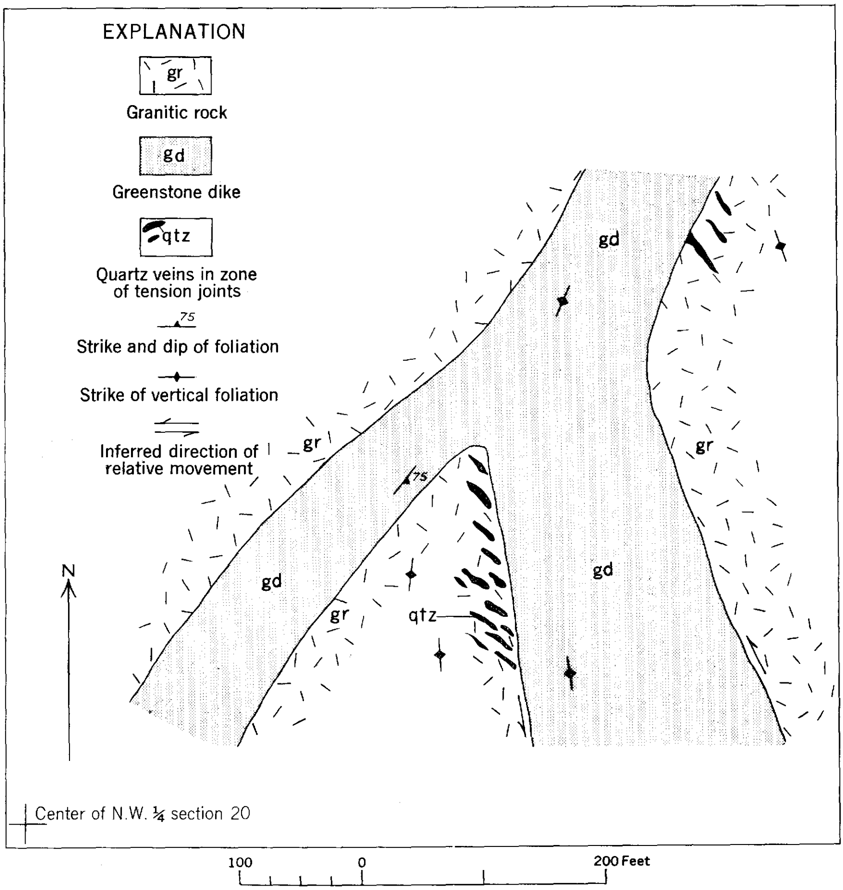

FIGURE 20.—Diagrammatic plan view showing relationships of granitic rock, basic dikes, quartz veins, and inferred fault in the southwestern part of the NE¼NW¼ sec. 20, T. 44 N., R. 31 W.

SOUTHEASTERN GREEN SCHIST UPLIFT

Because of the absence of exposures, structures within the green schist are practically unknown. Drilling reveals a crinkled highly schistose to slaty rock. Correlation of magnetic highs with green schist is based mainly on a drill hole in sec. 25, T. 43 N., R. 31 W., that disclosed strongly magnetic schist. The trend of the belt has been established by magnetometer surveys. The green schist occupies the core of an anticlinal uplift, as indicated by the following facts:

1. Dolomite and arkose of the Randville form a belt along the west side of the magnetic green schist anomaly. The belt has been drilled in the Lake Mary quadrangle in the W½ secs. 23 and 26, T. 43 N., R. 31 W.

2. West-dipping greenstone of the Hemlock formation is exposed immediately west of the belt of Randville dolomite in sec. 26.
3. Dolomite has been drilled east of the magnetic anomaly and just south of the Kiernan quadrangle in sec. 14, T. 43 N., R. 31 W.
4. Metatuff of probable Hemlock age has been drilled east of the dolomite in sec. 14, T. 43 N., R. 31 W.

In a line of shallow drill holes in the N½ sec. 10 sericite slate, here correlated with the Hemlock formation, is found both east and west of dolomite and arkose of the Randville. Rocks of the Randville are the oldest found in this drilling because the green schist anticline plunges northwestward toward Michigamme Mountain.

MICHIGAMME MOUNTAIN AND VICINITY

In the vicinity of Michigamme Mountain, east-trending structures lie across the main north-northwest structural axis (fig. 21, A_1 and A_2). There are at least two folds trending approximately east to northeast, one at Michigamme Mountain, and the other, southeast of the mountain (fig. 21, A_3, A_4; pls. 2 and 3, cross sections A–A' and B–B'). About 1½ miles northwest of the mountain, in the W½ sec. 32, at least three other east-trending or east-southeast-trending folds involve the Randville dolomite and its associated slate (fig. 21, S_1, S_2, A_5). The folds are probably due mainly to compressional forces developed in the saddle between the Amasa oval uplift and the uplift of green schist to the southeast.

The east-trending fold at Michigamme Mountain (fig. 21, A_3) is recognized by the following features:

1. The narrow magnetic crest extending north-northeast and south-southeast from the mountain has a pronounced bend or loop to the east at the mountain. Goodrich quartzite drilled in the NW¼ sec. 3, T. 43 N., R. 31 W., is on an anticline (fig. 21, A_6) that is in line with this bend (pls. 2 and 3, eastern half of cross section A–A').
2. The strike of foliation in the metarhyolite commonly approximates the strike of the formation; on the north side of the mountain foliation in the metarhyolite strikes about east.
3. Probable bedding in the Goodrich quartzite on the north side of the mountain strikes a little north of east.

A northeast-trending anticline lies some 2,000 feet southeast of the mountain (fig. 21, A_4; pls. 2 and 3, cross section D–D'). The magnetic crest trending southeast from the mountain turns northeast along the northwest limb of this anticline. Magnetic quartzite is exposed on the southeast limb. A northeast-trending magnetic trough lies along the axis of the anticline. Randville dolomite is exposed in two places near the southwest end of the magnetic trough in the eastern part of sec. 4 and probably also occupies the core of the anticline, inasmuch as the carbonate-rich trachyte exposed in the magnetic trough is believed to have intruded dolomites.

The northeast-trending anticline in the NE¼ sec. 4 (fig. 21, A_4) is also indicated by dolomite in diamond-drill holes L–111, L–112, and L–113 near the northwest shore of Butler Lake in sec. 3 (pls. 2 and 3, cross section *B–B′*) because the drilled dolomite lies nearly on the projection of the anticline and thus confirms the presence of a structural axis. Northwest and northeast of the dolomite in sec. 3, nonmagnetic to slightly magnetic Goodrich quartzite has been found at bedrock surface in drill holes L–117, L–118, L–202, L–203, and L–204.

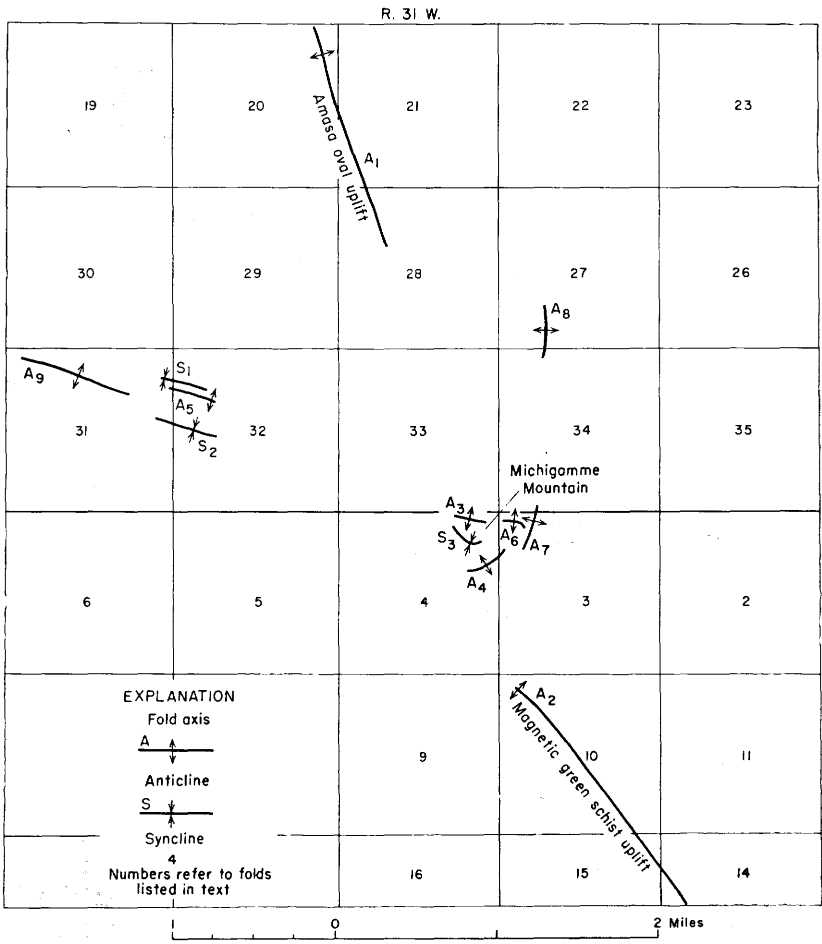

FIGURE 21.—Axial lines of principal folds at Michigamme Mountain and vicinity.

Between the dolomite drilled in sec. 3 and the northeast-trending anticline in sec. 4, metavolcanic rocks of the Hemlock formation overlie ferruginous cherty quartzite (pls. 2 and 3, drill holes F–3, F–4, F–5, L–108, L–109, L–201, L–209, L–211, L–213, L–301, and L–302). Some of the quartzite and metavolcanic rock is magnetic. The northeast-trending anticline in sec. 4 evidently plunges northeastward beneath rocks of the Hemlock formation and rises again in echelon northwest of Butler Lake (pl. 1; fig. 21, A_7), where the rocks are folded along north-northeastward (A_7) and west-northwestward (A_6) axes. If the north-northeast-trending and plunging axis bends somewhat westward, extends 1 mile north, and rises again toward the surface, it accounts for the probable Goodrich quartzite on test-pit dumps in the NW¼ sec. 34 and for probable silicified Randville dolomite a short distance north of the test pits (pl. 1; fig. 21, A_8).

The embayment of rocks of the Hemlock formation immediately east, southeast, and south of Michigamme Mountain is indicated by several outcrops of altered basic agglomeratic tuff on the east side of the mountain in the NE¼NE¼ sec. 4, by the outcrops of graywacke on the south side of the mountain, and by drilling in sericite slate and greenstone members of the Hemlock in the NW¼ sec. 3 (pls. 2 and 3, cross section *B–B′*, drill holes L–201, L–209, L–211, and L–301). The location of the contacts on the west and south sides of the embayment in the NE¼ sec. 4 is established rather accurately by the location of outcrops of greenstone, graywacke, and quartzite with respect to the magnetic data. The shape of this embayment appears to reflect a combination of east-trending and north-trending folds (fig. 21, S_3). To the east and northeast in sec. 3, magnetic lines have few or no definite trends and are difficult to interpret.

Attitudes of bedding in dolomite and slate along the shore of Michigamme Reservoir in the NW¼ of sec. 32 indicate at least three small east-southeast-trending folds. (See also Clements and Smyth, 1899b, p. 434.) Two of the three structures are adjoining tight folds in dolomite (fig. 21, S_1 and A_5). The fold axis of the anticline (A_5) plunges rather steeply westward. Several small drag folds are exposed on the south limb of the anticline. (See fig. 8.) The third fold, a syncline (fig. 21, S_2), is in dark-gray fissile slate cropping out on a small headland. The plunge of the syncline is interpreted to be westward. Other folds may lie between this syncline and the anticline (A_5) to the north. Slate exposed near the center of sec. 32 is either on the eastward extension of the syncline (S_2) or in another small fold north of the syncline. Slate and dolomite have been reported from test pits, about half way between the slate near the west quarter corner and the slate near the center of the section.

Slate is also exposed about 700 feet southeast of the west quarter corner of sec. 32; it may be on the south limb of syncline S_2, or it may represent another fold south of that syncline. Dolomite in the SE¼ of the section is south of the eastward projection of the slate. The slate in the W½ sec. 32 accordingly is in one or more tight folds and is bordered on the north and at least partly on the south by dolomite. The slate in the syncline (S_2) near the west quarter corner of the section evidently is underlain by dolomite and apparently has no dolomite above it in the core of the syncline. Therefore, the slate probably lies above the dolomitic part of the Randville, although the observed features could be caused by tightly folded slate and dolomite interbedded near the top of the formation.

As noted earlier, Smyth considered the slate in the W½ sec. 32, equivalent to the Mansfield, whereas Van Hise and Leith merely placed it above the Randville dolomite and beneath the "Negaunee," without attempting a specific correlation.

The westward plunges of fold axes in the NW¼ sec. 32, and the inferred trend of the Randville-Hemlock contact in secs. 30 and 31, indicate that the Randville dolomite is arched into a relatively large westward-trending and plunging anticline (fig. 21, A_9). This anticline possibly represents a major axis of cross folding to which the smaller cross folds of the area are related. If so, the distribution of the smaller cross folds suggests that the plunge of the main axis of cross folding may alternate from westward to eastward several times between sec. 31, T. 44 N., R. 31 W. and sec. 3, T. 43 N., R. 31 W. The small syncline (S_2) can be reconciled with the larger anticline (A_9) if it is assumed that the syncline, as well as the other small folds in sec. 32, are part of an anticlinorium-type structure in the Randville, one in which there is considerable down folding near the crest.

MAGNETIC SURVEYS

Magnetic data obtained from aeromagnetic and ground magnetic surveys were of considerable help in making geological interpretations in the Kiernan quadrangle. Definite magnetic units and trends are disclosed which make it possible to draw geologic contacts with reasonable confidence in areas where little or no other information is available.

AEROMAGNETIC SURVEY

The Kiernan quadrangle was included in an aeromagnetic survey of part of the northern peninsula of Michigan made in 1949 by the U. S. Geological Survey in cooperation with the Geological Survey Division of the Michigan Department of Conservation. J. R. Balsley directed the aeromagnetic survey, and J. Blanchett supervised the compilation of the magnetic data. Total-intensity measurements were made with an AN/ASQ–3A magnetometer installed in a DC–3 airplane. East and west trending flight traverses were flown at quarter mile intervals at about 500 feet above the ground. The aeromagnetic data in the Kiernan quadrangle are presented here as a series of total-intensity profiles (pl. 5). Crest positions of the anomalies are plotted on plates 1, 2, and 5 as dots sized in proportion to the intensity of the anomaly each represents. Errors in plotting the crest positions are believed to be less than 300 feet.

The dominant magnetic feature is the strong magnetic high that trends generally north across the eastern part of the quadrangle. Results of geologic mapping and ground magnetometer surveys indicate that this aeroanomaly is caused by several different magnetic rocks. The central part of the anomaly is caused mainly or entirely by magnetite-bearing Goodrich quartzite exposed in sec. 33, T. 44 N., R. 31 W., and in sec. 4, T. 43 N., R. 31 W. The northern part is evidently caused by the Fence River formation and the southern part by Lower Precambrian green schist. Correlation of the parts of this composite anomaly with specific formations is discussed in the following section on the ground magnetic survey.

Moderate to small anomalies occur throughout the Hemlock formation in the southwestern part of the quadrangle. These anomalies probably reflect original differences in lithology of the formation, but none was related to specific rocks. Some of the anomalies appear to cross geologic trends and perhaps are due to intrusions of magnetic rock.

The rest of the area is relatively free of anomalies, although a few scattered ones of unknown cause occur in the Lower Precambrian rocks of the Amasa oval and in the Middle Precambrian Randville dolomite.

GROUND MAGNETIC SURVEY

An area of about 11 square miles along the trend of the large aeroanomaly in the southeastern part of the quadrangle was surveyed in detail with vertical-intensity magnetometers (pl. 2). Two temperature-compensated magnetometers were used, one with a sensitivity of about 28 gammas per scale division and the other with a sensitivity that varied from 39 to 42 gammas per scale division during the course of the survey.

Fieldwork was done sporadically from February 1952 through June 1953, much of it during the winter months when traverses could be made across frozen swamps and lakes. Magnetic determinations were made at paced intervals of 100 feet or less on compass traverses spaced from 200 to 400 feet apart in that part of the area where the magnetic pattern was most complex. Elsewhere, readings were taken at intervals of from 100 to 200 feet on traverses spaced up to a quarter of a mile apart. A sundial compass was used to control the direction of traverses in places where the magnetic declination deviated greatly from normal. About 5,300 magnetic stations were occupied.

Traverses and individual stations were located with respect to all observable topographic features, land boundaries, roads and trails, and rock exposures. Most of the stations shown on plate 2 are probably located with an error of less than 50 feet, although a few may be mislocated by as much as 200 feet.

Magnetic values shown on plate 2 are in tens of gammas above an arbitrary zero base, and the isomagnetic contours are at 100 gamma intervals. The approximate absolute vertical-intensity gamma value of the abritrary zero base level is 57,500, as determined from magnetic base stations established in southeastern Iron County by the U. S. Bureau of Mines (Bath, 1951).

Corrections for diurnal variation were determined by checking at base stations several times a day, usually at about 2-hour intervals. Relative gamma values of adjacent stations on individual traverses are accurate to within several gammas, but values between widely spaced stations may be in error by larger amounts, chiefly because of magnetic storms that may have occurred between base station checks. Inasmuch as extreme magnetic storms are readily detected in the normal course of making a magnetometer survey and because surveying was discontinued during such periods, the average error is believed to be less than 25 gammas.

In addition to the magnetic survey in the vicinity of Michigamme Mountain, magnetometer traverses were made across the trend of the magnetic Hemlock formation and Fence River formation on the east side of the Amasa oval. The results of these traverses are shown on plate 4 as a series of vertical-intensity magnetic profiles with corresponding geologic cross sections. The profiles clearly illustrate the relative magnetic character of the Randville dolomite, the Hemlock formation, and the Fence River formation. The dolomite is essentially nonmagnetic, whereas the metavolcanic rocks and the iron-formation are strongly magnetic. Magnetic zones in the Hemlock formation are typically erratic and discontinuous in contrast to the strong narrow linear anomaly caused by the Fence River formation. Profile and cross section *A–A′* of plate 4 shows the relationships in the vicinity of the Sholdeis exploration in T. 45 N., R. 31 W., about 2 miles north of the quadrangle, where good exposures of the three rock units make possible definite correlation of magnetic data and geology. A local detailed survey was also made in sec. 15, T. 44 N., R. 31 W., (see fig. 18) which clearly revealed the position of the unexposed Fence River formation with respect to outcrops of Hemlock formation and an outcrop of biotite schist referred to the Michigamme slate.

MAGNETIC ANOMALIES

The ground magnetic data on plate 2 show that the magnetic belt in the southeastern part of the quadrangle consists essentially of a northern, a central, and a southern anomaly, each a rather distinct magnetic unit.

Northern anomaly.—The strong linear anomaly in the SE¼ sec. 27, T. 44 N., R. 31 W., is the southern end of a narrow magnetic belt that continues northward along the east side of the Amasa oval. This anomaly is caused by the southward extension of the Fence River formation, which is exposed in the SE¼NE¼ sec. 21, T. 45 N,. R. 31 W., about 2½ miles north of the Kiernan quadrangle. The Hemlock formation is also magnetic in places and may be responsible for the small irregular magnetic highs in the southeastern part of sec. 27 that trend southward and die out near the center of section 34, T. 44 N., R. 31 W.

Termination of the northern anomaly in secs. 27 and 34 is believed caused by erosion of the magnetic Fence River formation prior to deposition of the Michigamme slate. Although erosion may also have cut into and removed part of the Hemlock formation, the general decrease in the magnetic character of the Hemlock in this vicinity is probably caused mainly by the appearance and predominance of nonmagnetic metarhyolite in the unit.

Central anomaly.—The central anomaly is a series of somewhat erratic and discontinuous magnetic highs in the vicinity of Michigamme Mountain (pl. 2). Some of the individual magnetic highs can be related directly to outcrops of magnetite-bearing Goodrich quartzite in secs. 4 and 33. The other anomalies of this group are almost certainly caused by unexposed quartzite. The magnetic pattern suggests that the quartzite occurs in shallow semiconnected patches that have been folded and cross folded. The small anomaly in the NW¼ sec. 3 may, at least in part, be due to magnetic rocks of the Hemlock formation as drilling in that vicinity revealed some magnetic greenstone.

According to previous geologic interpretation in this area, based largely on dip-needle data, both the northern and central anomalies were caused by Negaunee iron-formation which was believed to be offset along an inferred northwest-trending fault in secs. 28 and 34, T. 44 N., R. 31 W. This concept appears untenable in view of the additional and more detailed geologic and magnetic information derived from the present study. The detailed magnetometer data disclose a considerable difference in the magnetic character of the two anomalies. The northern one is uniform and linear and obviously caused by a narrow continuous magnetic bed that extends downward to some depth, whereas the central anomaly consists of a group of magnetic highs that appear to be caused by shallow lenses of magnetic material. Furthermore, no offset or other complexity in the magnetic pattern, such as would be expected at a fault crossing a single magnetic bed, is disclosed by the magnetic data.

Geologic evidence that the two anomalies are separate has been presented earlier in this report. The Hemlock formation lies stratigraphically below the magnetic rocks causing the northern anomaly, but in the vicinity of Michigamme Mountain the Hemlock formation lies stratigraphically above rocks causing the central anomaly. This is clearly shown by the position of metarhyolite exposed west of the northern anomaly and east of the central anomaly in the SW¼ sec. 27 and the NW¼ sec. 34 and by the position of identical metarhyolite east of the central anomaly in sec. 33, T. 44 N., R. 31 W.

Erratic magnetic values in the SW¼SW¼ sec. 27, T. 44 N., R. 31 W., are believed to be caused by magnetic material in the glacial overburden.

Southern anomaly.—The southern anomaly consists of a broad fairly regular magnetic belt that extends southeastward from near the southern end of the central anomaly. It differs in character from the northern anomaly by being broader and not as uniform or well defined, and from the central group of magnetic highs by being more regular and continuous. The shape of the magnetic profiles indicate that the upper pole of the material causing the anomaly may range in depth from several hundred to one or two thousand feet and that the magnetic rocks may dip to the southwest.

Some of the local magnetic highs along the trend of the anomaly in sec. 10, T. 43 N., R. 31 W. (pl. 2) appear to be due to relatively shallow magnetic bodies and are probably caused by small remnants of Goodrich quartzite lying on Randville dolomite a short distance above the magnetic green schist. The magnetic pattern in sec. 10 possibly represents an overlap of the central and southern anomalies. (See magnetic crest lines on plate 1.)

The anomaly continues southeastward as a complex magnetic zone as far as T. 42 N., R. 30 W., in Dickinson County. A drill hole on the anomaly in the SE¼NE¼ sec. 25, T. 43 N., R. 31 W., disclosed magnetic green schist. The northwestward extension of this rock is believed to cause the southern anomaly in the Kiernan area, although shallow drilling in secs. 10, 14, and 23, T. 43 N., R. 31 W., disclosed no magnetic material.

No completely satisfactory explanation can be given for the northward termination of the southern anomaly at approximately the same place that the southern part of the central anomaly ends. The magnetic rock of the southern anomaly may lens out entirely to the northwest. However, it seems more likely that the termination of both anomalies in about the same place is at least partly related to the preservation of the magnetic Goodrich only in the structural depression created by the northwestward plunge of the green schist. To the northwest the green schist may plunge deeply beneath nonmagnetic Randville dolomite or Hemlock formation.

GEOLOGIC HISTORY

The earliest known geologic event in the quadrangle was the formation of the banded gneiss of the Margeson Creek gneiss. The magnetic green schist in the southeastern part of the quadrangle almost certainly signifies extrusion of basic flows or tuffs early in the Pre-Cambrian history of the area, but whether the volcanism antedated the banded gneiss is not known. The granitic rocks of the gneiss developed later than the banded gneiss. Although the granitic rocks probably formed by a combination of magmatic intrusion and granitization-migmatization of the gneiss, it is unknown which process produced most of the rock. Uplift and extensive erosion exposed the green schist and the rocks of the Margeson Creek gneiss.

The area was inundated, and carbonate deposits that now form the Randville dolomite were laid down. Beds of clay and of quartz and quartz-feldspar sand were interlayered with the carbonate. The clay and sand may have come from local projections of the granite-gneiss basement above the sea. There is no evidence that the Randville was eroded in the Kiernan area before the next formation was deposited, although this did occur in some adjacent areas. Following deposition of the present Randville dolomite, iron-rich sediment and silica (chert) of the Negaunee iron-formation were probably deposited in the Kiernan area. Erosion following gentle uplift then evidently stripped all or almost all of the Negaunee iron-formation from the Kiernan area.

Submergence, probably only of parts of the area, occurred again. Quartz sand and precipitated silica, mixed in places with rubble of the eroded Negaunee iron-formation, accumulated in the basin or basins resulting from this submergence. The material is now the Goodrich quartzite; probably it is magnetic only where it received iron oxide from the remains of the Negaunee and where appreciable magnetite formed during diagenesis.

A period of volcanism succeeded the deposition of the Goodrich. It is unknown to what extent the area had emerged from the sea prior to the eruptions of acid and basic lava or ash. Slate and graywacke associated with the volcanic rocks in the Hemlock formation indicate either continuing or recurring submergence in parts of the region.

Ellipsoidal structures in the greenstone in several places in the southwestern part of the area indicate submarine extrusion during at least part of the period of volcanism.

After the volcanism the area either again became submerged or continued in general submergence. The present Fence River formation was formed by deposits of iron-rich sediments mixed in small part with chemically precipitated silica, and with quartz sand near the bottom of the sequence. After gentle uplift, erosion removed the Fence River formation from the southern part of the quadrangle and may have cut into the Hemlock formation. Then widespread submergence occurred and the muds and sands of the Michigamme slate were laid down. Sometime between the emplacement of the Hemlock and prior to post-Michigamme uplift and metamorphism, gabbroic and more siliceous magmas intruded the area.

The deposition of the Michigamme was followed by a period of intense deformation accompanied by widespread metamorphism and local granite intrusion in the western part of the northern peninsula of Michigan. In the Kiernan area the Amasa oval and the southeastern green schist uplifts were formed.

After the period of regional deformation and metamorphism, diabase dikes were intruded into Lower and Middle Precambrian rocks over a large part of the western part of the northern peninsula of Michigan. They were evidently related to Upper Precambrian Keweenawan lavas.

During a vast period of time following the post-Michigamme orogeny, the deformed belts were eroded to their roots in a widespread peneplanation. During this time, iron-formations were oxidized, and bodies of oxidized (soft) iron ore formed. Later, during the Cambrian period, gentle submergence resulted in the accumulation of well-sorted quartz sand, in places mixed with carbonate, that now forms gently dipping sandstone and dolomitic sandstone. Silicification of favorable rocks, particularly dolomite, may have taken place on the Precambrian peneplain represented by the unconformity at the base of the Cambrian sandstone. Almost all of the Cambrian sandstone of the Kiernan area was eroded away during the Cambrian to Pleistocene interval. There is no evidence of deposition during the interval. Glacial drift and outwash of Pleistocene age were laid over much of the Kiernan area.

ECONOMIC GEOLOGY

Up to the present time iron-rich rock has been the only geologic material of economic interest in the Kiernan quadrangle, although in the future, glacial materials may be utilized for sand and gravel and Randville dolomite for road rock and building stone.

EXPLORATION

Exploration in the form of drilling, trenching, test pitting, and dip-needle surveys has been carried on sporadically in the past without proving iron ore in more than insignificant quantities. This activity has centered at Michigamme Mountain and vicinity.

Test pits and trenches, dug during the past 60 years or more, are located mainly in the SW¼ sec. 27, in the NW¼ sec. 33, in the SE¼ sec. 33 (north slope of Michigamme Mountain), in the NW¼ sec. 34, T. 44 N., R. 31 W., and in the NE¼ sec. 4, T. 43 N., R. 31 W. In the NW¼ sec. 34, test pits have revealed Goodrich quartzite, greenish chloritic schist, and Cambrian sandstone stained by iron oxides. In the SW¼ sec. 27, red to green probable metavolcanic schist has been found on test-pit dumps. Similar material occurs on dumps in the NW¼ sec. 33.

Between 1917 and 1919 the J. M. Longyear Company of Marquette, Mich., drilled in the SW¼ sec. 27, in the S½ sec. 33, in the NW¼ sec. 34, T. 44 N., R. 31 W., and in the W½ sec. 3, in sec. 9, and in sec. 10, T. 43 N., R. 31 W. Ten holes were drilled in the W½ sec. 3 and two in the NW¼ sec. 4 by the Ford Motor Company in 1922 and 1923.

No known exploration has been done in the northeastern part of the quadrangle, along the magnetic belt of the Fence River formation. The magnetic green schist in the southeastern part of the quadrangle has been drilled only in the Lake Mary quadrangle to the south.

GOODRICH QUARTZITE

The iron-rich rock explored by most of these operations is the Goodrich quartzite. The Goodrich of this area consists mainly of clastic quartz, recrystallized chert, magnetite, and hematite. Recrystallized chert and dusty hematite generally form the matrix around magnetite, clastic quartz, and clastic chert. The iron content of the Goodrich ranges from traces or minor amounts to about 60 percent very locally but generally is between 15 and 35 percent. Commonly magnetite forms 5 to 35 percent, and hematite forms 1 to 10 percent of the rock.

Clastic quartz grains range in size from 0.05 to 0.5 mm and are mostly between 0.1 and 0.4 mm. Individual chert grains are commonly less than 0.05 mm in diameter. Magnetite grains range from 0.05 to 1.0 mm but some crystals or aggregates are as much as 2 mm in diameter. Hematite particles are generally smaller than 0.02 mm. Although the Goodrich is dense and compact, microscopically much of it is seen to have a foliated texture.

Magnetic and geologic data (pls. 2 and 3, cross sections *A–A′*, *B–B′*) indicate that the magnetic Goodrich extends to the relatively shallow depth of 400 to 500 feet at Michigamme Mountain. Drilling southeast of the mountain, in the W½ sec. 3, disclosed magnetic and nonmagnetic (oxidized) Goodrich down to depths greater than 1,000 feet (pl. 3, cross sections *C–C′*, *D–D′*, *E–E′*, *F–F′*), but the actual extent of the formation is probably rather limited.

The Goodrich apparently contains very little "iron ore," but possibly is amenable in part to beneficiation. However, until more information is obtained regarding the volume of Goodrich quartzite that can be beneficiated, the possibility of development is unlikely.

FENCE RIVER FORMATION

The Fence River formation is not exposed within the quadrangle. At the Sholdeis exploration, north of the quadrangle in the SE¼NE¼ sec. 21, T. 45 N., R. 31 W., it consists of a thin-banded rock composed mainly of quartz, magnetite, hornblende, and epidote, with some massive garnet-grunerite schist. Test pits near the Sholdeis exploration and at the Doane exploration show that the lower part of the formation contains magnetite, specularite, and quartz. Grain sizes range from about 0.05 to 0.2 mm, although hornblende or garnet porphyroblasts range from about 1.0 mm to 1.0 cm in size. The favorable effect of metamorphism in increasing grain size may make the rock amenable to concentration. The consistent nature of the magnetic anomaly from the Sholdeis exploration southward into the Kiernan quadrangle (pl. 4) suggests little change in the Fence River formation, but a decrease in grain size is to be expected southward from the Sholdeis exploration because of decreasing metamorphic grade.

MAGNETIC GREEN SCHIST

Drilling in the Lake Mary quadrangle south of the Kiernan area has shown that the magnetic green schist is too low in iron content for economic consideration.

LITERATURE CITED

Allen, R. C., 1910, The Iron River iron-bearing district of Michigan: Mich. Geol. and Biol. Survey, Pub. 3, Geol. Ser. 2.

Allen, R. C., and Barrett, L. P., 1915, Contributions to the pre-Cambrian geology of northern Michigan and Wisconsin: Mich. Geol. and Biol. Survey, Pub. 18, Geol. Ser. 15, p. 15–164.

Bailey, E. B., 1923, The metamorphism of the south-west Highlands: Geol. Mag. v. 60, p. 317–331.[4]

Balsley, J. R., James, H. L., and Wier, K. L., 1949, Aeromagnetic survey of parts of Baraga, Iron, and Houghton Counties, Michigan, with preliminary geologic interpretation: U. S. Geol. Survey Geophys. Inv.

Barrett, L. P., Pardee, F., and Osgood, W., 1929, Geological map of Iron County: Geol. Survey Div., Mich. Dept. of Conservation.

Barrow, G., 1893, On an intrusion of muscovite-biotite gneiss in the south-east Highlands of Scotland: Geol. Soc. London Quart. Jour., v. 69, p. 330–358.

——— 1912, On the geology of lower Dee-side and the southern Highland border, Geol. Assoc., Proc., v. 23, p. 268–284.

Bath, G. D., 1951, Magnetic base stations in the Lake Superior iron districts: U. S. Bur. of Mines, Rept. Inv. 4804.

Bergquist, S. G., 1932, Glacial geology of Iron County, Michigan: Mich. Acad. Sci. Paper, v. 16.

——— 1935, Valley-train deposits in the northern peninsula of Michigan: Mich. Acad. Sci. Paper, v. 20.

Chayes, F., 1952, On the association of perthitic microcline with highly undulant or granular quartz in some calcalkaline granites: Am. Jour. Sci., v. 250, p. 281–296.

Clarke, F. W., 1924, The data of geochemistry (5th ed.): U. S. Geol. Survey, Bull. 770.

Clements, J. M., and Smyth, H. L., 1899a, The Crystal Falls iron-bearing district of Michigan: in U. S. Geol. Survey 19th Ann. Rept., pt. 3, p. 1–151.

Clements, J. M., and Smyth, H. L., 1899b, The Crystal Falls iron-bearing district of Michigan: U. S. Geol. Survey Mon. 36.

Daly, R. A., 1933, Igneous rocks and the depths of the earth: McGraw-Hill Book Co., New York.

Emmons, R. C., and others, 1953, Selected petrogenetic relationships of plagioclase: Geol. Soc. America Mem. 52.

Eskola, P., 1915, On the relation between chemical and mineralogical composition in rocks of the Orijarvi region: Comm. géol. Finlande Bull. 44.

——— 1920, The mineral facies of rocks: Norsk geol. tidsskr., v. 6, p. 143–194.

Hotz, P. E., 1953, Petrology of granophyre in diabase near Dillsburg, Pennsylvania: Geol. Soc. America Bull., v. 64, p. 675–704.

Hunt, T. S., 1861, On some points in American geology: Am. Jour. Sci., 2d ser., v. 31, p. 393–414.

Irving, R. D., 1885, Preliminary paper on an investigation of the Archean formations of the northwestern States: U. S. Geol. Survey 5th Ann. Rept., p. 175–242.

James, H. L., 1955, Zones of regional metamorphism in the Precambrian of northern Michigan: Geol. Soc. America Bull. v. 66, p. 1455–1487.

Kimball, J. P., 1865, On the iron ores of Marquette, Michigan: Am. Jour. Sci., 2d ser. v. 39, p. 290–303.

Leith, C. K., 1925, Silicification of erosion surfaces: Econ. Geol., v. 20, p. 513–523.

Leith, C. K., Lund, R. J., and Leith, A., 1935, Pre-Cambrian rocks of the Lake Superior region, a review of newly discovered geologic features with a revised geologic map: U. S. Geol. Survey Prof. Paper 184.

Martin, H. M., (Compiler), 1936, The centennial geological map of the northern peninsula of Michigan: Mich. Geol. and Biol. Survey Pub. 39, Geol. Ser. 33.

Turner, F. J., 1948, Evolution of the metamorphic rocks: Geol. Soc. America, Mem. 30.

Turner, F. J., and Verhoogen, J., 1951, Igneous and metamorphic petrology: McGraw-Hill Book Co., New York.

Van Hise, C. R., 1899, *in* Introduction to The Crystal Falls iron-bearing district of Michigan, by Clements, J. M., and Smyth, H. L.,: U. S. Geol. Survey 19th Ann. Rept., pt. 3, p. 1–151.

Van Hise, C. R., and Bayley, W. S., 1895, Preliminary report on the Marquette iron-bearing district of Michigan: U. S. Geol. Survey 15th Ann. Rept., p. 477–650.

Van Hise, C. R., and Bayley, W. S., 1897, The Marquette iron-bearing district of Michigan: U. S. Geol. Survey, Mon. 28.

Van Hise, C. R., and Leith, C. K., 1911, The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52.

Walker, F., 1940, Differentiation of the Palisades diabase, New Jersey: Geol. Soc. America Bull., v. 51, p. 1059–1106.

Washington, H. S., 1917, Chemical analyses of igneous rocks . . .: U. S. Geol. Survey Prof. Paper 99.

Wiseman, J. D. H., 1934, The central and south-west Highland epidiorites: Geol. Soc. London Quart. Jour., v. 90, p. 354–417.

INDEX

U. S. GOVERNMENT PRINTING OFFICE: 1956