Geology of the Negaunee Quadrangle, Marquette County, Michigan

GEOLOGICAL SURVEY PROFESSIONAL PAPER 788

Prepared in cooperation with the Geological Survey Division of the Michigan Department of Natural Resources

U. S. DEPARTMENT OF THE INTERIOR

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By WILLARD P. PUFFETT

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Description of an area underlain by Precambrian rocks that contain important sedimentary iron-ore deposits

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GEOLOGY OF THE NEGAUNEE QUADRANGLE, MARQUETTE COUNTY, MICHIGAN

By WILLARD P. PUFFETT

ABSTRACT

The Negaunee quadrangle covers about 52 square miles of the east-central part of Marquette County, Mich. Most of the area is of low relief, drainage is not integrated, and glacial deposits cover more than half the area.

Rocks of Precambrian age underlie the entire quadrangle. Lower Precambrian granitic and mafic metavolcanic rocks border two areas of downfolded middle Precambrian metasedimentary rocks of the Marquette Range Supergroup. The downfolded rocks form the Eagle Mills syncline on the north limb of the Marquette synclinorium in the southern part of the quadrangle and the eastern part of the Dead River basin in the west-central part of the quadrangle. The middle Precambrian rocks are unconformable against the older rocks, but faulting has juxtaposed rocks of different ages. Keweenawan diabase dikes cut most of the older Precambrian rocks.

Lower and middle Precambrian rocks are metamorphosed. Early metamorphism converted the volcanic rocks to amphibolite near the Compeau Creek Gneiss; later, lower grade metamorphism converted most of the other rocks to the chlorite grade. The Keweenawan diabase dikes are not metamorphosed.

Lower Precambrian rocks are mafic to intermediate metavolcanic rocks and felsic intrusive rocks. The metavolcanic rocks include the Kitchi Schist and the Mona Schist. The felsic rocks include the Compeau Creek Gneiss and Dead River pluton, which have intruded the Mona Schist.

The Kitchi Schist, the oldest formation in the quadrangle, is gray-green pyroclastic rock ranging from lapilli tuff to agglomerate with clasts as large as 5 inches. Chemically, the rocks range from dacite to rhyodacite but are dominantly dacitic. The formation is nearly equivalent in age to subaqueous pillow lavas in the lower member of the Mona Schist. Maximum thickness in the quadrangle is about 4,500 feet.

The Mona Schist consists mainly of metabasalt and layered amphibolite and is here divided into four members: lower member, Nealy Creek Member, sheared rhyolite tuff member, and Lighthouse Point Member. Undifferentiated greenstone is mapped in two areas. Total thickness of the formation is about 23,000 feet.

The lower member of the Mona Schist, about 10,000 feet thick, is dark-green fine-grained massive metabasalt characterized in many outcrops by large pillow structures. Layers of pillows dip steeply, and the top direction is to the north. Small, widely separated quartz and quartz-carbonate veins contain sparse copper minerals. Axinite occurs as large crystals in a quartz-calcite vein.

The Nealy Creek Member of the Mona Schist, 2,000–3,000 feet thick, is greenish gray quartz-sericite-chlorite schist, near rhyodacite in composition, and originally was an air-fall tuff. Cataclastic deformation is common.

The sheared rhyolite tuff member, 1,300–3,000 feet thick, is pink to greenish gray, felsic and quartz rich, and contains tabular fragments 0.5–5 inches thick. It is bounded on the north and south by faults of large displacement.

The Lighthouse Point Member of the Mona Schist, at least 8,500 feet thick, is principally dark-green fine-grained amphibolite—originally basaltic tuff—in layers 1–6 inches thick. A zone of felsic augen, saussuritized feldspar porphyroblasts, 700–1,000 feet wide is parallel to and 700–3,000 feet from the contact of the member with the Compeau Creek Gneiss.

The Compeau Creek Gneiss, light-colored foliated medium-grained gneiss of granodioritic composition, has intruded Mona Schist in the northwestern part of the quadrangle and locally reversed the dip of layering in the Lighthouse Point Member of the Mona Schist.

The Dead River pluton, nonfoliated porphyritic felsic rock, has intruded the Nealy Creek and lower members of the Mona Schist in the central part of the quadrangle. Rock adjacent to the lower member is a border phase of hornblende diorite. Broad bands of coarsely porphyritic hornblende-biotite syenite cross the pluton. The main body of the pluton has a composition near that of granodiorite.

Felsic metavolcanic rocks, cataclastically deformed and in part mylonitized and commonly containing glassy quartz phenocrysts, form thin tabular bodies and irregular-shaped masses, probably early Precambrian in age. Some are metatuffs and some possibly are intrusive.

The middle Precambrian metasedimentary rocks underlie two widely separated areas in the northern and west-central parts of the quadrangle and are assigned to the Marquette Range Supergroup, which includes the Chocolay, Menominee, and Baraga Groups. In the southern part of the quadrangle, they include, from the base upward, the Enchantment Lake Formation, Mesnard Quartzite, Kona Dolomite, Wewe Slate, Ajibik Quartzite, Siamo Slate, and Negaunee Iron-Formation. In the west-central part of the quadrangle, they include the Michigamme Slate south of Dead River and the Reany Creek Formation north of Dead River.

The Enchantment Lake Formation, a lenticular unit less than 150 feet thick, consists of basal arkosic conglomerate with vein quartz pebbles overlain by sericitic slate, sericitic quartzite, and arkose.

The Reany Creek Formation, 1,500–3,500 feet thick, deposited in a glacial environment, is divided into three units: (1) coarse basal conglomerate, (2) a medial unit of chloritic slate containing widely scattered granitic boulders and arkose intraclasts, and (3) an upper unit of interbedded conglomerate, slaty graywacke, and arkose and quartzite lenses. It may be a time equivalent of the Enchantment Lake Formation, but could be older.

The Mesnard Quartzite is massive or thick-bedded, ripple-marked, and crossbedded quartzite truncated by younger metasedimentary rocks near the west edge of the quadrangle. Maximum thickness is 200 feet.

The Kona Dolomite crops out in widely separated eastern and western areas on the north limb of the Eagle Mills syncline. The eastern area consists of fine- to medium-grained pinkish-gray crystalline dolomite and thin beds of purplish-pink dolomite and slate. Chert is conspicuous and algal structures are abundant. The western area consists of sericitic quartzite, purple ferruginous slate, vitreous quartzite overlain by chert breccia and algal structures, and silty and ferruginous slate with thin quartzite beds, truncated by younger metasedimentary rocks. Thickness in the eastern area is 900–1,200 feet; maximum thickness in the western area, 800–900 feet.

Wewe Slate is not exposed but probably underlies an area near the east edge of the quadrangle and is truncated by an unconformity at the base of the Ajibik Quartzite. In the adjacent Marquette quadrangle, the Wewe consists of gray and thick-bedded and green and white thinly laminated slate.

The Ajibik Quartzite, averaging 150 feet thick, consists of white to purplish-gray, ripple-marked, and crossbedded quartzite underlain by sericitic slate. An important marker zone in the lower part of the formation is a chert granule bed overlain by uniquely crossbedded quartzite. The formation truncates older metasedimentary rocks and rests on lower Precambrian rocks at the west edge of the quadrangle.

Siamo Slate, 1,500–2,000 feet thick, consists of dark-gray sericitic and chloritic slate with thin to thick beds of graywacke and, rarely, conglomerate. Carbonate cement is common in some beds. Clastic dikes subparallel to slaty cleavage are conspicuous locally. The Goose Lake Member, as shown by magnetic surveys, is 500–1,000 feet above the base of the slate but does not crop out.

Negaunee Iron-Formation, 2,000–3,000 feet thick, consists of chert and iron-rich beds. The iron minerals, originally siderite, are hematite, goethite, and magnetite. Chert and chert-rich layers are paper thin to 12 millimeters thick; iron-rich beds range from discontinuous wisps to layers 10 mm thick. Jaspilite is common in the upper part of the formation. Important iron deposits formed by redistribution of the iron minerals and leaching of chert by downward circulating waters.

Michigamme Slate consists of basal quartzite, thin-bedded graywacke with magnetite-rich and carbon-rich beds, chert-goethite-hematite iron-formation, conglomerate with large chert clasts, and pyritic and carbonaceous slate and metasiltite. It crops out in the southern part of the Dead River basin and is unconformable against the Nealy Creek Member of the Mona Schist and the Dead River pluton. Estimated thickness is 5,000–7,000 feet. The top of formation is not determinable within the quadrangle; the upper limit is in part a fault.

Mafic intrusive rocks include metadiabase, metagabbro, and diabase. Metadiabase dikes trend eastward, cut all lower Precambrian rocks and the Negaunee Iron-Formation, are as much as 100 feet thick, and are probably of more than one age. Metadiabase sills, as much as 1,500 feet thick, parallel foliation in the Lighthouse Point Member of the Mona Schist. Two small masses of metagabbro in the Lighthouse Point Member probably are of early Precambrian age. Diabase dikes trend eastward to northward, are as much as 100 feet thick, and cut nearly all units.

Large folds include the west-plunging Eagle Mills syncline in the southern part of the quadrangle, a part of the Marquette synclinorium; a west- to northwest-plunging syncline in Dead River basin; and a southeast plunging syncline adjacent to the Compeau Creek Gneiss in the northeastern part of the area. Smaller southeast-plunging folds are on the north limb of the Eagle Mills syncline.

Broad shear zones that might, in part, control location of the downfolded areas trend west to northwest across the quadrangle. The Carp River Falls shear zone, in the southern part of the map area, in part forms the boundary between lower and middle Precambrian rocks. The Dead River shear zone crosses the central part of the area and includes a horst of lower Precambrian rocks bounded by faults along which middle Precambrian rocks have been downfaulted for hundreds to thousands of feet.

Horizontal displacement along several northwestward-trending high-angle faults is as much as 300 feet. Displacements along the two high-angle reverse faults have repeated, in outcrop, parts of middle Precambrian formations.

Magnetic anomalies are caused by the Goose Lake Member of the Siamo Slate, a magnetite-rich argillite in the Michigamme Slate, and a chert-magnetite zone in lower Precambrian rocks north of Dead River. Magnetic values are relatively low over the hematite-goethite ore bodies and the oxidized Negaunee Iron-Formation.

More than 62 million tons of "soft" iron ore has been produced from the lower part of the Negaunee Iron-Formation. The ore is localized near the contact with Siamo Slate and is thicker in synclinal folds or where the contact flattens. Iron content of "soft" ore is 50–55 percent. Production in 1968 was only from the Mather mine B.

Widely separated, narrow quartz and quartz-carbonate veins contain sparse amounts of chalcopyrite and, rarely, tetrahedrite but no gold. No mines have been developed on these veins.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Negaunee 7½-minute quadrangle[1] occupies an area of about 52 square miles between lat 46°30′N. and 46°37′30″N. and long 87°30′W. and 87°37′30″W. in east-central Marquette County, Mich. (fig. 1; pl. 1).

It includes all but the easternmost half-mile of T. 48 N., R. 26 W., the southern part of T. 49 N., R. 26 W., and narrow strips of adjoining townships on the west and on the south. The northeastern part of the city of Negaunee is in the southwest corner of the quadrangle; the Marquette city limits are about 5 miles east of the quadrangle.

The main industry in the quadrangle is mining and processing of iron ore by the Cleveland-Cliffs Iron Co., which employed about 1,220 men in the spring of 1968. The Mather mine B, in the southwest corner of the quadrangle, is reportedly the world's largest and deepest underground iron mine.Ore from this mine is processed at the Pioneer ore improvement plant and pellet plant in the southeastern part of the quadrangle. Ore from the Republic mine, now inactive, about 9 miles southwest of the quadrangle, was pelletized at the Eagle Mills plant in the NE¼ sec. 36, T. 48 N., R. 26 W.

[1] As distinguished from Negaunee 15-minute quadrangle, the southeast quarter of which is the Negaunee 7½-minute quadrangle.

WORK METHODS AND ACKNOWLEDGMENTS

The Negaunee quadrangle was mapped as part of the restudy by the U.S. Geological Survey, made in cooperation with the Geological Survey Division of the Michigan Department of Natural Resources, of a much larger area that includes the Marquette synclinorium. C. E. Fritts mapped the southern part of the quadrangle in 1962 and 1963 and identified the Carp River Falls shear zone. Jack Hallberg mapped part of sec. 19, T. 48 N., R. 26 W., in July 1965.

The data were plotted directly on an enlargement of the topographic sheet. Pace and compass traverses were on north and south bearings at 300-foot intervals. A sun compass was used in areas of large magnetic declination. Areas between traverses were searched systematically for outcrops. Ground surveys with a magnetometer delineated magnetic anomalies.

All outcrops are shown on the geologic map (pl. 1); in some places small, closely spaced outcrops are shown as a single exposure. At map scale, small, isolated outcrops are necessarily shown larger than they actually are. All diabase and metadiabase dikes are shown in their true orientation, but as many of them are less than 100 feet thick, their mapped thickness is not to scale.

Rocks were identified megascopically and in thin section. Rapid-rock chemical analyses were made by the U.S. Geological Survey. Many of the photomicrographs were prepared by J. A. Denson, U.S. Geological Survey.

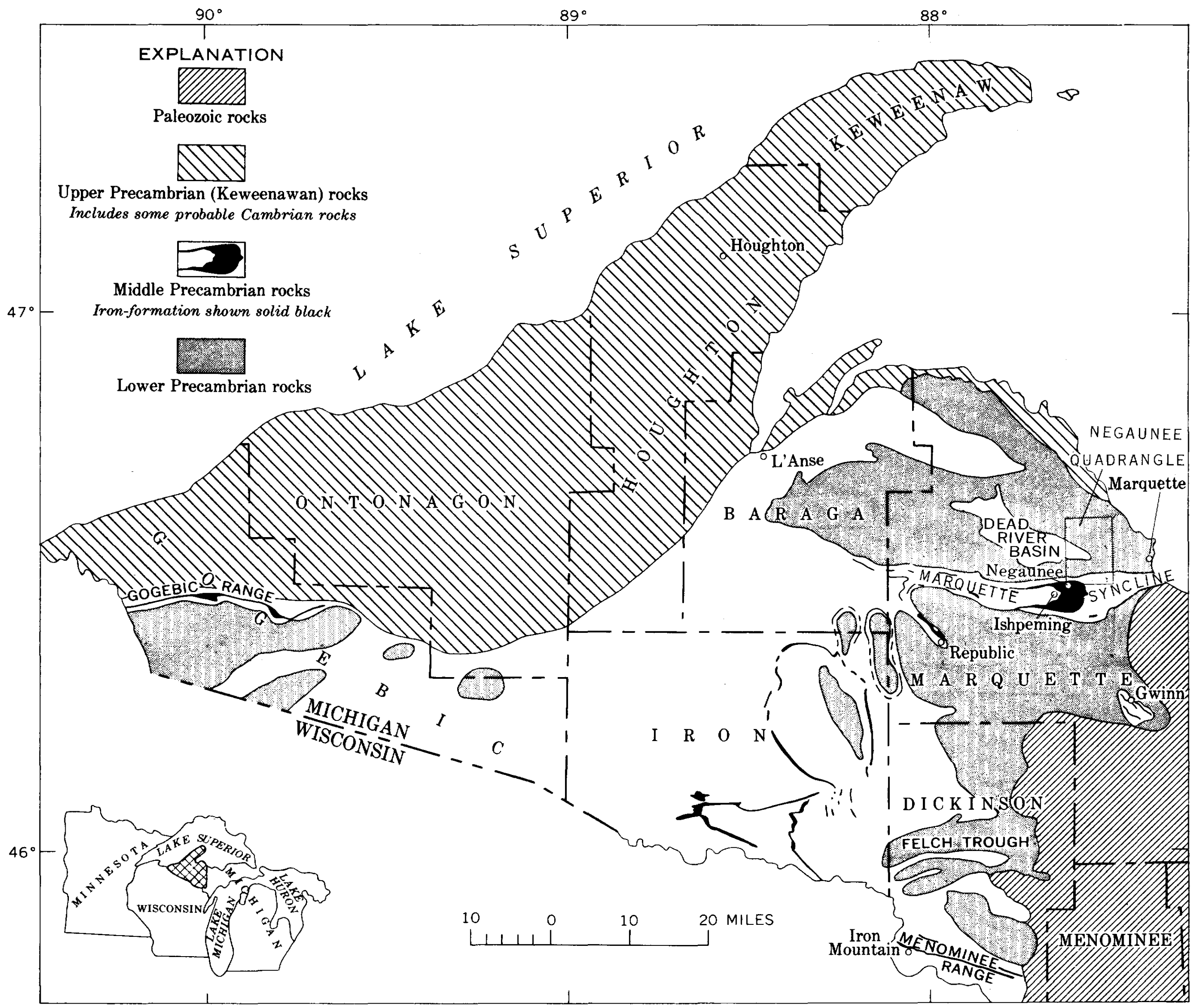

FIGURE 1.—Geology of western Upper Peninsula of Michigan and location of the Negaunee quadrangle.

The Cleveland-Cliffs Iron Co. freely permitted use of company mine maps and diamond-drill logs and inspection of diamond-drill cores.

GLACIAL FEATURES

Striated bedrock surfaces are common and glacial deposits are widespread. Glacial striae show that the glaciers moved toward the southwest, probably modifying existing east-west topographic elongation by deposits that were left. Outwash aprons, kame terraces, and ground moraine cover much of the bedrock and have disrupted preexisting drainage.

Outwash aprons and kame terraces form relatively conspicuous flat areas which decrease in altitude from southwest to northeast and commonly have a steep slope along their northeast margins. In the southeastern part of the quadrangle, however, in the N½ sec. 34, T. 48 N., R. 26 W., a lobate outwash apron has steep south slopes. An outwash terrace extending northwestward from the east boundary of the quadrangle in sec. 24 to sec. 4, T. 48 N., R. 26 W., is pitted with kettlelike depressions 150–700 feet in diameter and 40–80 feet deep. Outwash material in a borrow pit in the N½ sec. 34, T. 48 N., R. 26 W., is fairly well sorted crossbedded sand.

Ground moraine mantles much of the area, in many places only as a thin veneer. Areas of outcrop shown on the map (pl. 1) commonly include patches of thin ground moraine. The moraine is a source of gravel—the largest pit is south of county road 510 in sec. 15, T. 48 N., R. 26 W.—and contains blocks as much as 10 feet across, predominately of igneous or metamorphic rock; in the hills north of Dead River are large blocks of friable red sandstone and rounded boulders of fossiliferous limestone. A block of friable sandstone greater than 10 feet in diameter was found at an altitude of about 1,450 feet on the divide between the branches of Reany Creek near the east boundary of sec. 5, T. 48 N., R. 26 W. The sandstone probably is Jacobsville of Early Cambrian age that crops out along Lake Superior about 2 miles northeast of the quadrangle. The limestone contains corals of Paleozoic age that must have originated either in Michigan east of the quadrangle or near Hudson Bay.

Lacustrine-type sediments were not seen but have been reported in drill holes. Stuart, Brown, and Rhodehamel (1954, table 10) reported the following section of unconsolidated material in the Maas mine area in sec. 31, T. 48 N., R. 26 W:

	Thickness (feet)
Outwash—sand and gravel	60–130
Lacustrine deposits—red clay, gravel, and hardpan layers; finer grained than the usual till	70–120
Till—red clay, sand and gravel, boulders, and hardpan	10–40

PREVIOUS WORK

The geology in and adjacent to the Negaunee quadrangle has been the subject of many reports since the discovery of iron ore near Negaunee in 1844. Van Hise and Bayley (1897) summarized the reports published prior to 1895, and Gair and Thaden (1968) the changes in stratigraphy, nomenclature, and concepts of geology published since 1895. No detailed geologic map of the entire quadrangle has been published; but detailed geologic maps of parts of the quadrangle are included in reports by Rominger (1881), Irving (in Williams, 1890), Van Hise and Bayley (1897), and Seaman (in Van Hise and Leith, 1911, pls. XIX, XX). Descriptions of early exploration for iron ore and development of the early iron mines and other resources are detailed by Brooks (1873). The development of stratigraphic nomenclature in the quadrangle is shown in figure 2.

GEOLOGIC SETTING

Parts of several large-scale structures extend into the quadrangle from adjacent areas. The north limb of the Marquette syncline and the subsidiary Eagle Mills syncline cross the southern part of the quadrangle. The east end of the Dead River basin, an area filled with metasedimentary rocks, is in the central part of the quadrangle; only a small part of the much larger mass of the Compeau Creek Gneiss is in the northeastern part of the area. A broad shear zone, subparallel to the course of Dead River, extends across the central part of the quadrangle but was not mapped in the Marquette quadrangle to the east.

STRATIGRAPHY

All the bedrock units in the Negaunee quadrangle are of Precambrian age. Lower Precambrian rocks include the Kitchi and Mona Schists, Compeau Creek Gneiss, and Dead River pluton. The Kitchi Schist, a fragmental volcanic rock of latite to dacite composition, is approximately the same age as the lower member of the Mona Schist. The Mona Schist is a thick series of predominantly mafic extrusive volcanic rocks but includes a large body of sheared rhyolite tuff. The formation has been divided into four members: lower member, Nealy Creek Member, sheared rhyolite tuff member, and Lighthouse Point Member. Undifferentiated greenstone, a part of the Mona Schist, is mapped in two areas. Compeau Creek Gneiss is predominantly granodioritic and has intruded the Mona Schist in the northeastern part of the quadrangle. The Dead River pluton, a composite body of syenite, diorite, and granodiorite, has intruded the Mona Schist extensively south of and locally north of the Dead River.

Rocks of middle Precambrian age are unconformable against the Mona Schist on the north limb of the Eagle Mills syncline in the southern part of the quadrangle, the Dead River pluton on the south side of the Dead River basin, and the Mona Schist on the north side of the Dead River basin.

Middle Precambrian rocks are, from the base upward, the Enchantment Lake Formation, Mesnard Quartzite, Kona Dolomite, Wewe Slate (not exposed but believed to be present), Ajibik Quartzite, Siamo Slate, and Negaunee Iron-Formation, all on the north limb of the Eagle Mills syncline. These formations belong to the Marquette Range Supergroup as defined by Cannon and Gair (1970). The Michigamme Slate, the youngest formation in the area, unconformably overlies the Dead River pluton in the Dead River basin. The Reany Creek Formation is of uncertain age, but probably is stratigraphically at the base of the Marquette Range Supergroup north and northeast of the Dead River basin.

Metamorphosed mafic and felsic dikes are common in the Mona Schist and Compeau Creek Gneiss; the felsic dikes are probably all of early Precambrian age; the mafic dikes might be either early or middle Precambrian in age. Unmetamorphosed Keweenawan diabase dikes have intruded all rock units in the area.

METAMORPHISM

Metamorphism has affected all lower and middle Precambrian rocks in the quadrangle but is reflected mainly in the mineral assemblages of the mafic rocks. The quadrangle is entirely within the chlorite zone of the last regional metamorphism of pre-Keweenawan age (James, 1955, pl. 1). The characteristic mineral assemblage of the mafic rocks in this zone includes sodic plagioclase, epidote minerals, sericite, quartz, and pale-green actinolite-tremolite. Gair and Thaden (1968, p. 17) found evidence in the Lighthouse Point Member of the Mona Schist for an earlier, higher grade metamorphism. They concluded that well-alined blue-green hornblende developed prior to the intrusion of metadiabase, probably the result of igneous activity connected with the formation of the Compeau Creek Gneiss. The Lighthouse Point Member is of higher metamorphic grade than the rest of the Mona Schist in the quadrangle. It is fine- to medium-grained amphibolite and is coarser grained near the Compeau Creek Gneiss.

The sedimentary rocks in the quadrangle are only weakly metamorphosed; the main evidence for metamorphism is chlorite and sericite and the slaty cleavage in the finer grained rocks. The metamorphism has not obliterated primary sedimentary features except in the quartzites, where silicification locally has obscured the bedding.

LOWER PRECAMBRIAN ROCKS

Rocks of early Precambrian age underlie more than two-thirds of the Negaunee quadrangle. They are divided into two groups, mafic to intermediate volcanic rocks and felsic coarse-grained intrusive rocks. The volcanic rocks have been assigned to the Kitchi Schist and Mona Schist in earlier reports, and the names are retained in this report.

Felsic intrusive rocks are the Compeau Creek Gneiss, a foliated granodiorite in the northeastern part of the quadrangle, and the Dead River pluton, a nonfoliated, generally porphyritic syenite-diorite-granodiorite in the east-central part of the quadrangle. A few small intrusive bodies, similar to rocks of the pluton, crop out north of the Dead River along the south edge of sec. 5, T. 48 N., R. 26 W., and might be outliers of the Dead River pluton.

Felsic dikes intrude all lower Precambrian rocks and probably are of early Precambrian age. Some metamorphosed mafic dikes, particularly north of the Dead River basin, have been truncated by the unconformity between lower and middle Precambrian rocks and probably are of early Precambrian age.

KITCHI SCHIST

DEFINITION, DISTRIBUTION, THICKNESS, AND DESCRIPTION

The Kitchi Schist is foliated greenstone containing pebbles and boulders of pyroclastic rock named by Van Hise and Bayley (1895, p.496) for the Kitchi Hills in sec. 33, T. 48 N., R. 27 W., about 3 miles west of the Negaunee quadrangle, not named on modern topographic maps. The maximum mapped width of the formation is 4,800 feet, along the west edge of the quadrangle.

The Kitchi Schist is mainly a pyroclastic rock, ranging from coarse agglomerate with accessory lapilli tuff to relatively fine grained crystal tuff and crystal-lithic tuff. Fragments range from less than 1 inch to more than 5 inches in diameter. Van Hise and Bayley (1897, p. 167) reported boulders as much as 2 feet in diameter; none this large were seen in the Negaunee quadrangle. Some large fragments are well rounded, but many are angular. As a result, the rock in some outcrops resembles a conglomerate, and in others a breccia. The larger fragments are generally similar to the enclosing rock, whereas the smaller fragments are mainly single crystals or aggregates of crystals; some are small lithic fragments (fig. 3). Where fragments consist of pieces of single crystals, the rock resembles a porphyry, but its pyroclastic origin seems certain (fig. 4).

The fragmental character of the rock is apparent on weathered surfaces but generally obscure on smoothly

ROMINGER (1881)	VAN HISE AND BAYLEY (1895)				VAN HISE AND LEITH (1911)					
ARENACEOUS SLATE GROUP	PRECAMBRIAN	ALGONKIAN SYSTEM	UPPER MARQUETTE SERIES	MICHIGAMME FORMATION	PRECAMBRIAN	ALGONKIAN TYPE	HURONIAN SERIES	UPPER HURON-IAN	ANIMIKIE GROUP	MICHIGAMME FORMATION
IRON-FORMATION			LOWER MARQUETTE SERIES	NEGAUNEE FORMATION				MIDDLE HURON-IAN		NEGAUNEE FORMATION
ARENACEOUS SLATE GROUP				SIAMO SLATE						SIAMO SLATE
QUARTZITE GROUP				AJIBIK QUARTZITE						AJIBIK QUARTZITE
MARBLE SERIES				WEWE SLATE				LOWER HURON-IAN		WEWE SLATE
QUARTZITE GROUP				KONA DOLOMITE						KONA DOLOMITE
				MESNARD QUARTZITE						MESNARD QUARTZITE
GRANITE GROUP		ARCHEAN SYSTEM	BASEMENT COMPLEX	GRANITE		ARCHEAN TYPE	LAURENTIAN SERIES			GRANITE
				SYENITE						SYENITE
DIORITIC GROUP				KITCHI AND MONA SCHISTS			KEEWATIN SERIES			KITCHI SCHIST
										MONA SCHIST

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AJIBIK QUARTZITE</td><td rowspan="4">ANIMIKIE SERIES CHANGED TO MARQUETTE RANGE SUPERGROUP</td><td rowspan="3">MIDDLE PRECAMBRIAN</td><td rowspan="3">MARQUETTE RANGE SUPERGROUP</td><td>BARAGA GROUP</td><td>MICHIGAMME SLATE</td></tr>
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MONA SCHIST</td><td colspan="3">LOWER PRECAMBRIAN</td><td>DEAD RIVER PLUTON
COMPEAU CREEK GNEISS
MONA SCHIST
KITCHI SCHIST</td></tr>
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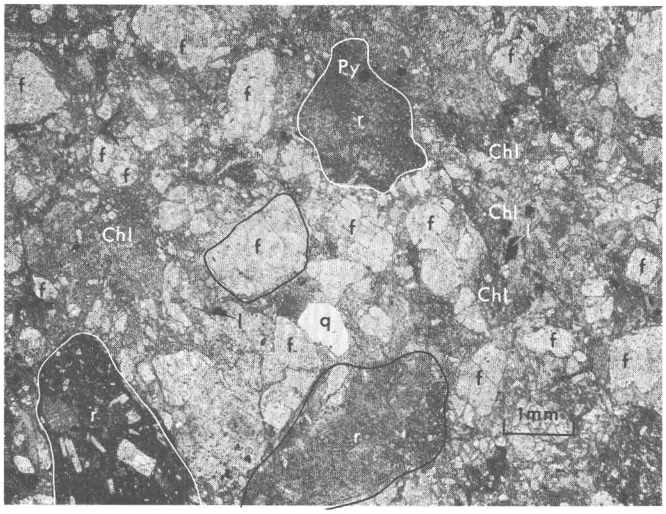
FIGURE 2.—Development of stratigraphic nomenclature in the Negaunee quadrangle.



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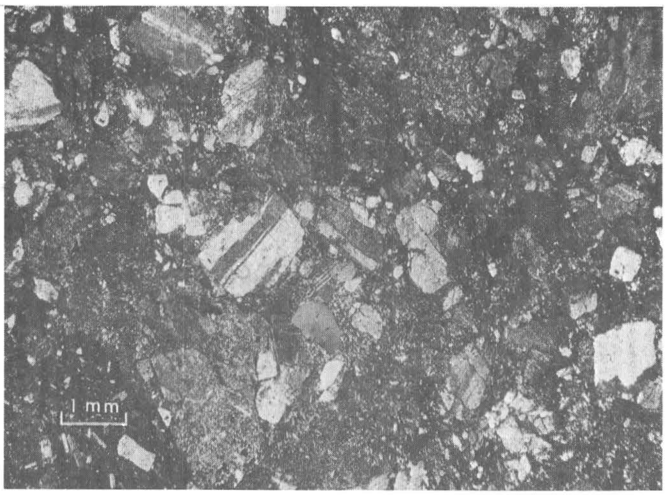

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FIGURE 3.—Photomicrographs of lithic crystal tuff in matrix of agglomerate shown in figure 5, Kitchi Schist. Sparse quartz and abundant subrounded fragments of volcanic rock and feldspar crystals, in sericitic and chloritic matrix. *A*, Plane-polarized light. *B*, Crossed polarizers. q, quartz; f, feldspar; Chl, chlorite; l, leucoxene; Py, pyrite; r, rock fragment.

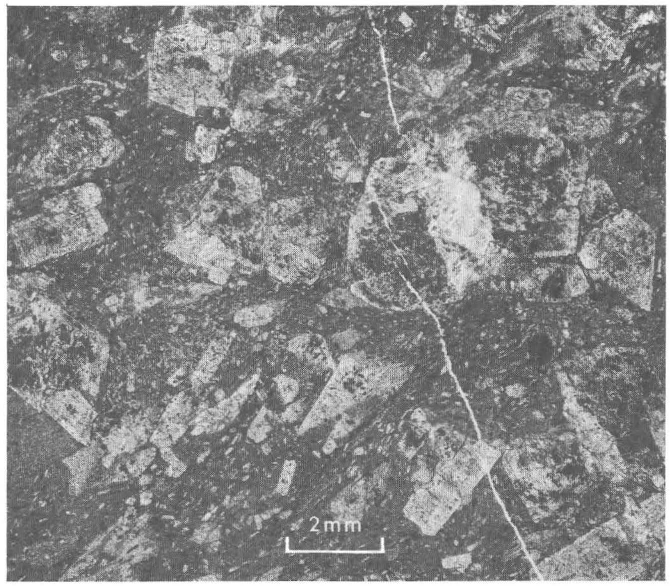


FIGURE 4.—Photomicrograph of felsic crystal tuff, Kitchi Schist. Feldspar crystals in chloritic and sericitic matrix. Plane-polarized light. For analysis see table 1, column 1.

FIGURE 5.—Kitchi Schist agglomerate exhumed in recent cut, east side of county road in SE¼SW¼ sec. 30, T. 48 N., R. 26 W. Large rounded clasts are similar in composition to the enclosing matrix. Matrix material shown in figure 3.

glaciated or freshly broken surfaces. The light color of some rounded clasts is conspicuous on smoothly glaciated outcrops that have been exhumed in new roadcuts (fig. 5). A pitted surface is often the only clue to the fragmental character of some of the finer grained rock. Where feldspar crystals have been altered to sericite, the rock has a knotty schistose aspect, and fragments are not evident.

The schists in the Kitchi are quartz-poor volcanic rocks of intermediate composition; regional metamorphism has largely erased original mineralogic variations. Phenocrysts and pyroclasts of quartz are rare. Although plagioclase feldspars are cloudy, multiple twinning is evident in some grains. Extinction angles indicate sodic andesine. Albite is present in some rocks, in particular those that are trachyte textured. Staining with sodium cobaltinitrite indicates that none of the phenocrysts or pyroclasts are potassium feldspar and that sericite is an alteration product of some of the plagioclase in the fine-grained groundmass. The original ferromagnesian minerals have been altered to chlorite, epidote, rare tremolite, carbonate, and clusters of opaque minerals.

A generally massive pinkish-gray porphyritic rock exposed in some outcrops contrasts with more common, foliated fragmental greenstone. A dike of this rock prospected in a shallow pit about 2,000 feet northwest of the SW. cor. sec. 25, T. 48 N., R. 27 W., contains abundant pyrite. Similar pinkish-gray rock forms rounded clasts, as much as 2 inches long, in greenstone near the west edge of the quadrangle about 1,800 feet north of the south edge of sec. 25. Van Hise and Bayley (1897, p. 164) described similar pebbles scattered through the Kitchi Schist.

The pinkish-gray rock is highly altered. The feldspar phenocrysts are now a cloudy mixture of sericite and chlorite. Original mafic minerals are represented by chlorite; a few coarse aggregates contain muscovite and calcite; biotite occurs with chlorite in one thin section. Pyrite and magnetite, plus ilmenite(?) now altered to leucoxene, constitute the opaque minerals. Quartz is rare and probably is an alteration product.

The pinkish-gray porphyritic rock contains more than twice the K_2O, two to five times the CO_2, and less than half the MgO of the fragmental rock (table 1). According to Rittman (1952, p. 93–102), the pinkish-gray porphyritic rock is latite or rhyodacite, the more common fragmental rocks represented by other analyses in table 1, dacites and pigeonite andesites. These rocks are less mafic than the greenstones of the Mona Schist (table 2).

Lenses of quartz porphyry, a few feet thick and less than 50 feet long, are in greenstone near the west border of the quadrangle, about 700 feet south of Carp River in sec. 25, T. 48 N., R. 27 W. The rock weathers pinkish-white, is massive, and contains conspicuous glassy quartz and milky white feldspar phenocrysts. The quartz phenocrysts are 0.15–1.8 millimeters across, constitute 5–10 percent of the rock, and have been embayed and corroded. The feldspar phenocrysts, 0.4–1.4 mm across and composed of variously oriented single crystals or clusters of crystals, are about three times as abundant as the quartz phenocrysts. The extinction angle and index of refraction indicate the feldspar is oligoclase. Some phenocrysts have rims of intergrown quartz and feldspar (fig. 6). Some feldspars have been corroded and in part replaced by sericite.

Dense, banded white to light-gray porcelaneous rock crops out on the northeast slope of the hill 1,300 feet north and about 2,500 feet west of the SE. cor. sec. 25, T. 48 N., R. 27 W. The color bands, 1⁄16–1 inch wide, strike northeastward and dip steeply northwest at a high angle to the foliation in the greenstone. The finest grained material is mainly sericite with sparse chert. The light-gray bands are coarser grained, containing dark-greenish-gray shredlike aggregates, 1–3 mm long,

TABLE 1.—*Chemical and semiquantitative spectrographic analyses of Kitchi Schist in the Negaunee quadrangle*

[Rapid-rock analyses by P. L. D. Elmore, S. D. Botts, Lowell Artis, Hezekiah Smith, Dennis Taylor, and J. L. Glenn, U.S. Geological Survey. Semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey. Results of semiquantitative spectrographic analyses are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, ..., which represent approximate midpoints of interval data on a geometric scale. The assigned interval for about 30 percent of the semiquantitative results will include the quantitative value. Elements looked for but not detected in the semiquantitative spectrographic analyses: As, Au, B, Bi, Cd, Eu, Ge, Hf, Hg, In, Li, Nb, Nd, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn. Dash leaders (........) indicate element looked for but not detected]

	1	2	3	4	5
Chemical analyses (weight percent)					
SiO_2	60.1	59.9	61.3	64.8	62.0
Al_2O_3	15.0	15.6	16.3	15.6	15.1
Fe_2O_3	.81	1.5	.64	1.5	.60
FeO	5.9	4.2	4.6	2.4	5.0
MgO	4.6	3.5	6.1	3.0	6.7
CaO	3.4	2.6	.38	1.4	.38
Na_2O	4.0	3.2	4.7	4.6	4.2
K_2O	.43	3.8	1.3	3.0	1.2
TiO_2	.78	.58	.64	.66	.60
P_2O_5	.28	.22	.18	.18	.14
MnO	.23	.07	.11	.07	.07
CO_2	.49	2.6	<.05	1.0	<.05
H_2O^-	.08	.14	.14	.16	.16
H_2O^+	3.2	2.1	3.5	1.7	3.7
Total	99	100	100	100	100
Semiquantitative spectrographic analyses (weight percent)					
Ag	0.0003	0.0003	0.0003	0.0003	0.0003
Ba	.03	.15	.007	.07	.01
Be	<.0001	<.0001	<.0001	<.0001	<.0001
Ce	.01	.007	....	....	....
Co	.002	.0015	.0015	.0015	.0015
Cr	.02	.015	.02	.015	.015
Cu	.002	.002	.0002	.007	.002
Ga	.002	.002	.002	.002	.002
La	.005	.003	....	....	....
Mo	.0003	.0003	....	....	....
Ni	.007	.005	.005	.005	.007
Pb	.003	.0003	.0005	.0005	.001
Sc	.0015	.001	.001	.002	.0015
Sr	.03	.01	.007	.01	.005
V	.01	.01	.01	.01	.01
Y	.002	.0015	.0015	.0015	.0015
Yb	.0002	.00015	.00015	.00015	.00015
Zr	.02	.015	.015	.015	.015

1. Dacite. Porphyry containing abundant gray feldspar crystals in fine-grained grayish-green matrix. Sample location 2,300 ft south, 200 ft east of NW. cor. sec. 30, T. 48 N., R. 26 W. Sample No. P–104–65. Lab No. 165577.
2. Latite. Porphyry containing abundant phenocrysts of feldspar and dark mineral in dense pinkish-gray matrix. Sample location 4,000 ft south, 1,700 ft west of NE. cor. sec. 25, T. 48 N., R. 27 W. Sample No. P–105–65. Lab. No. 165778.
3. Pigeonite andesite. Dark-gray-green relatively massive matrix of coarsely fragmental rock. Sample location 2,900 ft south, 2,550 ft west of NE. cor. sec. 25, T. 48 N., R. 27 W. Sample No. P–106–65. Lab No. 165579.
4. Rhyodacite. Pink-weathering rounded clasts in agglomerate. Sample location 2,700 ft west, 3,500 ft south of NE. cor. sec. 25, T. 48 N., R. 27 W. Sample No. P–107–65. Lab. No. 165580.
5. Dark dacite. Dark-greenish-gray matrix in rock from which P–107–65 sampled. Sample No. P–108–65. Lab. No. 165581.

alined parallel to the layering. The aggregates are chlorite, epidote, and feldspar and perhaps originally were phenocrysts of calcic plagioclase and mafic minerals. Veinlets of quartz and calcite, commonly less than 0.25 mm thick, cross the bands at a high angle. Small amounts of pyrite are scattered through the rock, and microlites of albite are in the sericitic matrix. This rock was probably originally ash fall.

Nearly all samples of the Kitchi Schist contain ferruginous dolomite, some calcite, and possibly other carbonates. Most of the carbonate was derived from mafic minerals and plagioclase during regional metamorphism. But abundant carbonate in the Kitchi east of the county road in the south-central part of sec. 30, T. 48 N., R. 26 W., appears to have been introduced from the nearby Carp River Falls shear zone. Porphy-

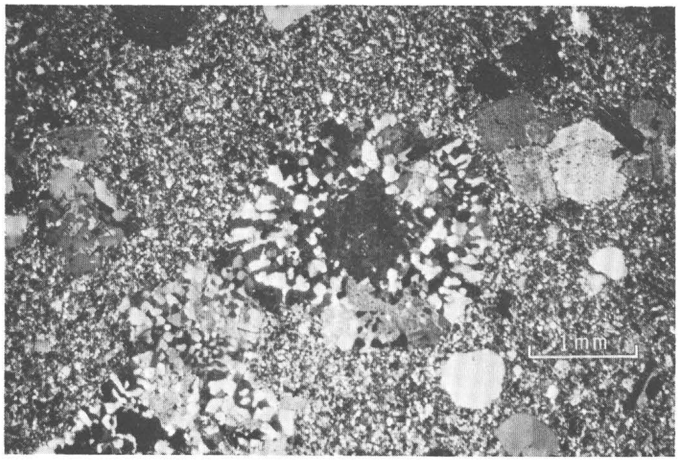


FIGURE 6.—Photomicrograph of quartz porphyry in Kitchi Schist from NE¼ sec. 25, T. 48 N., R. 27 W. Crossed polarizers. Note rim of quartz and feldspar surrounding feldspar crystal in center. Groundmass is sericite and chert.

roblasts and granoblastic mosaics of coarse euhedral carbonate grains form nearly 50 percent of some of the rock in this area.

RELATION TO OTHER FORMATIONS

The limits of the Kitchi Schist are mapped at the boundary between fragmental and nonfragmental metavolcanic rock. No obviously fragmental rock has been excluded from the Kitchi, but some nonfragmental rock has been included. The north boundary between the Kitchi and Mona Schists appears conformable, although no contact has been seen. Possible intertonguing of the two types has been obscured by regional metamorphism. The south boundary of the Kitchi Schist is the Carp River Falls shear zone. South of the shear zone original rock textures have been obliterated; perhaps some of this rock was tuffaceous and fragmental, similar to rocks of the Kitchi. The northeast and east boundary of the Kitchi is obscured by alluvium and glacial material; the map pattern suggests a discordant contact.

RELATIVE AGE OF THE KITCHI SCHIST

Van Hise and Bayley (1897, p. 153) suggested that the Mona Schist is a much metamorphosed phase of the Kitchi. Van Hise and Leith (1911, p. 254) stated "there is every reason to believe the main mass of basic schists composing the Kitchi and Mona Schists is the same formation, the main difference being that the Mona Schist is more metamorphosed and probably contained a larger proportion of finer material."

Exposures in the quadrangle are insufficient to show age relations of the Mona and Kitchi Schists. The map is essentially a cross section of the steeply dipping rocks, and if top directions in both the Kitchi and Mona Schists are consistently to the north, Kitchi Schist must underlie and be older than the Mona Schist.

The Kitchi Schist and the Mona Schist might represent a subaerial and a subaqueous facies of the same volcanism, even though the Kitchi is dacite to latite in chemical composition (table 1) and the Mona Schist is predominantly basaltic. Most of the Kitchi Schist was deposited subaerially, although it contains units reworked by water; the Mona Schist adjacent to the Kitchi Schist is predominantly subaqueous extrusive rock. The center of volcanism probably was in the area west of the quadrangle where coarser agglomerate is found.

MONA SCHIST

DEFINITION, DISTRIBUTION, AND THICKNESS

The Mona Schist was named by Van Hise and Bayley (1895, p. 490) for exposures in the Mona Hills in secs. 27 and 28, T. 48 N., R. 25 W., not named on modern topographic maps. The Mona Schist consists mainly of greenstone, much of it containing conspicuous ellipsoidal structure, and mafic and felsic schist. The mafic schist probably was basaltic to andesitic tuffs originally.

Williams (1890, p. 134–170) divided the greenstones in the Marquette area into a massive greenstone, ferruginous slates he called the "Eureka Series," and banded greenstones. Gair and Thaden (1968, p. 7) divided the formation in the Marquette quadrangle into the lower member and the lower and upper part of the Lighthouse Point Member. The lower member is mainly schistose and massive metabasalt containing pillow structures; the Lighthouse Point Member consists of a lower part that is mainly chloritic and felsic schists and an upper part of amphibolitic schist.

The general division of the formation by Gair and Thaden is followed in this report, but rocks corresponding to the lower part of their Lighthouse Point Member are divided here into the Nealy Creek Member and the sheared rhyolite tuff member. An area of Mona Schist south of the Carp River Falls shear zone and one southwest of the Lighthouse Point Member north of Dead River are mapped as undifferentiated greenstone.

Thickness determination of the formation in the quadrangle is complicated by intrusion of the Dead River pluton, by the broad zone of shearing that extends across Dead River basin, and by the syncline in the Lighthouse Point Member north of the Dead River basin. The maximum width of the formation south of the Dead River pluton is about 13,500 feet: 1,500 feet of undifferentiated greenstone, 9,000 feet of the lower member, and 3,000 feet of Nealy Creek Member. The Lighthouse Point Member forms a broad, gently plunging fold; its true thickness can be estimated only between very wide limits. In the northwestern part of the quadrangle, the member underlies an area about 10,000 feet wide, dipping 60° in the south part to 25° in the north part. Assuming no faulting, the member is 5,500–6,500 feet thick. The total thickness of the Mona Schist is about 24,000 feet. Gair and Thaden (1968, p. 7) estimated it to be between 13,000 and 21,000 feet thick in the Marquette quadrangle.

Most of the Mona Schist is basaltic in composition (table 2), the relatively felsic rocks of the Nealy Creek and the sheared rhyolite tuff members forming only a small part of the formation. Rocks of the Lighthouse Point Member contain a little more SiO_2 than those of the lower member, possibly owing to the intrusion of the Compeau Creek Gneiss.

LOWER MEMBER

The lower member of the Mona Schist is generally composed of fine grained greenstone; large pillow structures are common. Tabular bodies of coarser grained greenstone—originally gabbro, diabase, and possibly pyroxenite—are interlayered with and possibly intrusive into the fine-grained rock, originally a subaqueous basalt. Metamorphism has recrystallized much of the rock and obscured the original rock texture and composition. All is now mineralogically similar. Original

TABLE 2.—*Chemical and semiquantitative spectrographic analyses of Mona Schist*

[Rapid-rock analyses by P. L. D. Elmore, S. D. Botts, Lowell Artis, Gillison Chloe, J. L. Glenn, Hezekiah Smith, and Dennis Taylor, U.S. Geological Survey. Semiquantitative spectrographic analyses for 1, 7 by J. L. Harris, and for 2, 3, 5, 6, 8 by W. B. Crandell, both U.S. Geological Survey. Results of semiquantitative spectrographic analyses are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.1, ..., which represent approximate midpoints of interval data on a geometric scale. The assigned interval for about 30 percent of the semiquantitative results will include the quantitative value. Elements looked for but not detected in the semiquantitative spectrographic analyses: As, Au, Bi, Cd, Ge, Hf, Hg, In, Li, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn. Dash leaders (........) indicate element looked for but not detected]

	Lower member	Nealy Creek member		Sheared rhyolite tuff member	Lighthouse Point Member			
								Felsic augen zone
	1	2	3	4	5	6	7	8
Chemical analyses (weight percent)								
SiO_2	47.7	63.5	64.0	69.3	54.4	49.7	50.5	49.1
Al_2O_3	15.3	14.2	15.1	15.5	13.0	15.8	15.4	15.6
Fe_2O_3	.00	1.0	.82	.89	4.3	2.3	1.9	3.2
FeO	10.9	4.6	4.8	2.1	11.0	9.6	9.5	9.2
MgO	6.3	3.6	3.5	1.4	4.1	6.6	6.3	6.1
CaO	6.1	2.4	2.2	.40	6.8	7.0	9.9	9.4
Na_2O	.10	3.1	3.0	.60	1.4	3.7	2.3	3.2
K_2O	1.6	2.4	2.2	6.1	.77	.70	.48	.50
H_2O-	.08	.02	.00	.13	.00	.00	.03	.00
H_2O+	5.4	2.9	2.8	2.5	2.2	2.7	1.3	1.9
TiO_2	.88	.56	.62	.33	1.1	.77	.81	.89
P_2O_5	.03	.14	.20	.09	.09	.06	.07	.07
MnO	.19	.06	.04	.13	.07	.02	.23	.10
CO_2	4.8	1.4	.18	.06	.05	.31	.46	.19
Total	99	100	99	100	99	99	99	99
Semiquantitative spectrographic analyses (weight percent)								
Ag	....	....	....	....	....	....	0.0005	....
B	....	....	....	0.007	....	....	....	....
Ba	0.02	0.15	0.1	.05	0.015	0.015	.01	0.01
Be	....	....	....	<.0001	....	....	....	....
Ce	....	.01	....	....	....	....	....	....
Co	.002	.002	.002	.001	.002	.007	.002	.003
Cr	.02	.03	.02	.015	....	.05	.015	.015
Cu	.003	.015	.01	.0015	.015	.02	.01	.02
Ga	.0015	.001	.001	.002	.001	.001	.0015	.001
La	....	.007	.003	....	....	....	....	....
Mo	.003	....	.0003	....	.0003	.0003	....	.0003
Nb	....	.005	.0005	....	....	....	....	....
Ni	.007	.01	.01	.01	<.003	.03	.007	.005
Pb	....	.002	.0007	.0003	.0007	.0015	....	.0005
Sc	.002	.0015	.0015	.001	.005	.005	.003	.003
Sr	.0007	.05	.05	.01	.01	.02	.015	.015
V	.015	.015	.02	.005	.03	.03	.015	.02
Y	.0015	.001	.001	.001	.0015	.001	.002	.001
Yb	.00015	.0001	.0001	.0001	.00015	.0001	.0002	.0001
Zr	.0015	.015	.015	.007	.003	.002	.002	.002

1. P–126–65. Lab. No. 165794. 2,600 ft west, 300 ft north of SE. cor. sec. 29, T. 48N., R. 26 W.
2. P–66a–66. Lab. No. W167401. 500 ft east, 750 ft north of SW. cor. sec. 12, T. 48 N., R. 26 W.
3. P–173c–65. Lab. No. W167405. 4,750 ft west, 1,750 ft north, SE. cor. sec. 18, T. 48 N., R. 26 W.
4. P–205–66. Lab. No. unknown. 4,500 ft west, 2,300 ft north of SE. cor. sec. 9, T. 48 N., R. 26 W.
5. P–149a–66. Lab. No. W167398. 4,000 ft west, 250 ft north of SE. cor. sec. 35, T. 49 N., R. 26 W.
6. P–676a–66. Lab. No. W167400. 2,850 ft west, 750 ft north of SE. cor. sec. 4, T. 48 N., R. 26 W.
7. P–37–67. Lab. No. W169301. 2,400 ft west, 1,650 ft north of SE. cor. sec. 25, T. 49 N., R. 27 W.
8. P–151–66. Lab. No. W167399. 3,900 ft west, 4,100 ft north of SE. cor. sec. 2, T. 48 N., R. 26 W.

pyroxene has been uralitized to fibrous amphibole, and calcic feldspar has been saussuritized to a mosaic of epidote minerals, carbonate, and sodium-rich feldspar. Chlorite is common. Original iron minerals, either magnetite or ilmenite, or both, have been altered, at least in part, to pyrite and leucoxene. The member extends in a broad belt across the quadrangle south of the Dead River pluton and north of the middle Precambrian rocks in the Marquette synclinorium. The mapped width of the belt is about 2 miles at the east boundary of the quadrangle and 1½ miles in the central and western part.

Outcrops are rounded knobs and steep-sided hills elongate in a general east-west direction. Cliffs are rare but present in zones of marked shearing alined parallel to foliation. Maximum height of the hills above the general land level is commonly less than 100 feet.

The greenstone generally is dark grayish green to almost black on fresh surfaces and moderate yellow green to dark grayish green on weathered surfaces. Foliation is apparent on weathered surfaces, and the rock commonly breaks parallel to it. As there is no obvious layering or segregation of minerals parallel to the foliation, the foliation probably is tectonic.

Pillow structures are common in many exposures. Some are exceptionally well developed and preserved and excellently exposed on glacially scoured knobs that have been exhumed in roadcuts (fig. 7). The pillows are generally bulbous and slightly elongate, the maximum length ranging from 1–4 feet and the thickness from 1–3 feet. Elongation is generally parallel to the foliation, westerly to slightly north of west; dips are

FIGURE 7.—Pillow greenstone in a glacially polished knob, north side of U.S. Highway 41, SW¼SW¼ sec. 24, T. 48 N., R. 26 W. These bulbous pillow structures are common in the lower member of the Mona Schist.

steeply north to vertical. The tops can be determined in most exposures and without exception are to the north. Cores of pillows are composed of fine-grained greenstone and are bounded by a marginal zone of filled vesicles. Interpillow areas are filled with dark material that commonly is in thin layers conforming to the shapes of the pillows. Short gashlike fractures form an intersecting pattern in many pillows but seldom completely cross a pillow. The presence of pillow structures suggests that much of the lower member was originally subaqueous extrusion.

Fine-grained greenstone generally consists of tabular, twinned, and relatively fresh appearing albite or oligoclase randomly oriented in a mosaic of chlorite, carbonate, and epidote in which are scattered cloudy leucoxene and opaque minerals. Near the SW. cor. of sec. 19, T. 48 N., R. 26 W., the feldspar crystals are well alined and abundant, and "porphyroblasts" of carbonate are scattered through the rock. Amphiboles are generally not present in the fine-grained rock, and it is assumed that, if present, they have been altered to chlorite and carbonate.

Coarse-grained and fine-grained greenstones are mineralogically similar; fibrous amphiboles are more conspicuous, and commonly the feldspars are cloudier in the coarse-grained rock. Relict diabasic texture is shown by plates of tremolite-actinolite as much as 4 mm wide that enclose laths of cloudy feldspar. Chlorite is interstitial to amphibole, and epidote is common along the boundary between the two minerals. Some of the coarse-grained rock contains abundant phenocrysts of altered pyroxene and probably was pyroxenite. Such rock crops out northeast of the center of sec. 24, T. 48 N., R. 27 W., near the west border of the quadrangle.

Some of the massive coarse-grained greenstone probably is layers of extrusive rock, the upper parts of which contain the pillow structures, but some might be intrusive into the fine-grained greenstone.

Quartz and quartz-carbonate veins are widely scattered in the lower member of the Mona Schist; some contain copper sulfides. Some of the veins might be genetically related to diabase, as they occur in areas of negative magnetic anomalies attributed to diabase, although diabase is not common in outcrops adjacent to the veins.

Axinite, a borosilicate of calcium and aluminum, was found by C. E. Fritts (written commun., 1962) in a 3-inch-thick quartz-calcite vein that cuts greenstone bordering the railroad about 1,000 feet east and 2,200 feet north of the SE. cor. sec. 26, T. 48 N., R. 26 W. The axinite crystals are subhedral to anhedral, typically wedge shaped to tabular, and are as large as 12 by 11 by 3 mm. They make up several percent of the vein material. Epidote and fibrous actinolite are also present in the vein. As authigenic tourmaline is common in quartz veins in the Enchantment Lake Formation, possibly the tourmaline and axinite originated from related boron-rich solutions.

NEALY CREEK MEMBER OF THE MONA SCHIST

The Nealy Creek Member of the Mona Schist is a quartz-feldspar-sericite-chlorite schist named for the creek near the SW. cor. sec. 18, T. 48 N., R. 26 W. This unit can be traced from the west boundary of the quadrangle near the central part of sec. 13, T. 48 N., R. 27 W., east to the NE¼ sec. 21, T. 48 N., R. 26 W. The maximum mapped width in this area is about 3,000 feet. The member is bounded on the south by massive greenstone and on the north by the Dead River pluton and, where the plutonic rocks are missing, by the unconformity at the base of the Michigamme Slate in secs. 13 and 18. Rocks of the member crop out along Dead River near the east boundary of the quadrangle in sec. 13, T. 48 N., R. 26 W., and north of the Dead River pluton in secs. 9–12, T. 48 N., R. 26 W. The member is the westward extension of the chloritic and felsic slate in the Lighthouse Point Member mapped in the Marquette quadrangle by Gair and Thaden (1968, pl. 1) and is believed to be largely of volcanic origin.

Rocks of the Nealy Creek Member are generally fine grained, dark gray to greenish gray, and thinly foliated. Fresh surfaces are lustrous with sericite and chlorite. Fine-grained pyrite is widely scattered and brown iron stain is common on weathered surfaces. Other than pyrite, the constituent minerals are generally too small to be identified with a hand lens; however, glassy quartz grains are visible in outcrops bordering the railroad tracks in the southwestern part of sec. 12, T. 48 N., R. 26 W. In the roadcut in the southeastern part of sec. 13, T. 48 N., R. 27 W., the schist contains abundant tiny knots of completely sericitized feldspar (fig. 8). The intrusion of the Dead River pluton in secs. 18 and 21 recrystallized the adjacent schist, and the micaceous minerals and quartz are readily visible in hand specimen.

Thicker layering is evident in some outcrops. Crudely defined layers, a fraction of an inch to 2 feet thick, are conspicuous in the roadcut in the southeastern part of sec. 13, T. 48 N., R. 27 W., whereas well-defined layers 1–3 feet thick separated by sheared rock 1–3 inches thick crop out in the southwestern part of sec. 12, T. 48 N., R. 26 W.

The Nealy Creek Member includes sericitic slate containing randomly oriented chlorite porphyroblasts, quartz-sericite-chlorite schist, and sericitic slate containing sericitized feldspar. The average mode of nine samples of the coarser grained rock is 27 percent quartz (range 19–34 percent); 44 percent sericite and sericitized feldspar (range 30–60 percent); and 29 percent chlorite and (or) biotite (range 17–47 percent). Quartz occurs as angular grains and elongate granoblastic mosaics. Single quartz grains range in size from 0.1 to 0.8 mm and aggregates are as large as 0.5 mm. Feldspar grains range from 0.2 to 0.5 mm, and rounded masses of sericite are 0.5 by 0.7 mm. Chlorite is in irregular patches and in well-formed sheaves as large as 0.4 mm but commonly much smaller. Biotite and chlorite are intergrown adjacent to the Dead River pluton; the relative age of the two minerals was not determined.

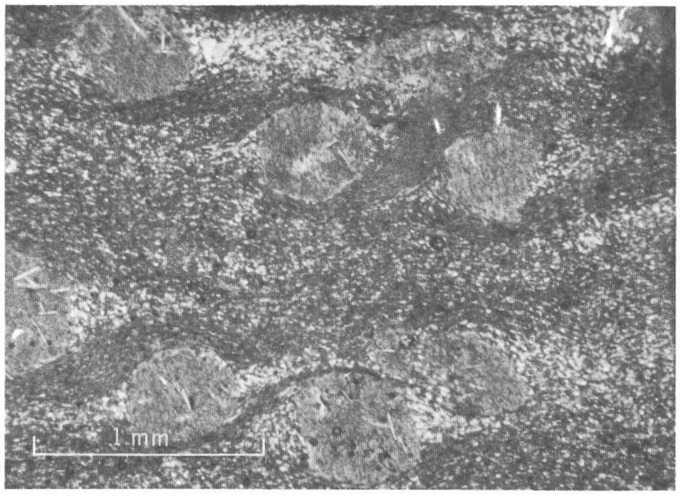


FIGURE 8.—Photomicrograph of schist, Nealy Creek Member of the Mona Schist, from roadcut in SE¼ sec. 13, T. 48 N., R. 27 W., showing knots of sericite interpreted as altered feldspar crystals. Groundmass is sericite, chlorite, chert, and fine-grained opaque minerals. Crossed polarizers.

Accessory minerals include tourmaline, zircon, apatite, epidote, and pyrite. Grains and aggregates of pyrite are generally less than 0.1 mm in size. Epidote is adjacent to some of the pyrite. Zircon is widely disseminated as euhedral crystals less than 0.1 mm long. Porphyroblasts of tourmaline as much as 0.4 mm in size have formed in slate adjacent to the Dead River pluton.

Textures are varied. Sericite-chlorite slate along Dead River Canyon and in secs. 9 and 10 contains randomly oriented quartz and feldspar, as in graywacke. Strongly foliated rock south of the Dead River pluton contains well-alined quartz, feldspar, and chlorite. Recrystallized rocks adjacent to the Dead River pluton contain granoblastic intergrowths of quartz-feldspar in laminae separated by chlorite-biotite.

Cataclastic deformation is obvious in rocks from the railroad cut near the SW. cor. sec. 12, T. 48 N., R. 26 W. Quartz forms subparallel lenses. Feldspar has been rotated and is bounded by elongate patches of fine-grained quartz between alined sheathes of chlorite. Knots of sericitized feldspar in slate in the southeastern part of sec. 13, T. 48 N., R. 27 W., appear to have resulted from cataclastic deformation.

The Nealy Creek Member is predominantly sedimentary or volcanic rock. In texture, much of it is similar to graywacke, but rock fragments are rare, if present. Bedding has not been recognized. Equant and prismatic feldspar grains might have been phenocrysts or pyroclasts, and perhaps the original rock was a tuff. The abundant quartz could be devitrified glass, a byproduct of metamorphism of mafic minerals, or it could have been introduced during intrusion of the Dead River pluton; evidently none occurred as phenocrysts.

Two samples of the Nealy Creek Member are similar in chemical composition to rhyodacite (Rittmann, 1952, p. 95) and to some of the rocks in the Kitchi Schist (table 2).

The gross lithology, texture, composition, and occurrence above the nearby massive greenstone of the Mona Schist suggest that the Nealy Creek Member is of volcanic origin. The variations in texture and mineral content are characteristic of air-fall tuff of intermediate composition. Some of the material might have been reworked by water, but rounded waterworn grains were not seen.

SHEARED RHYOLITE TUFF MEMBER OF THE MONA SCHIST

The sheared rhyolite tuff member of the Mona Schist is composed of felsic quartz-rich volcanic rocks that have been strongly sheared. They are pink to greenish gray, containing phenocrysts of glassy quartz and pink to cream-colored feldspars in a groundmass of fine-grained quartz, sericite, and minor amounts of chlorite. The rocks have a well-developed and steeply dipping cataclastic foliation and commonly break into tabular pieces a fraction of an inch to several inches thick. Conspicuous contrasting lithologies in some outcrops include tabular fragments of medium-grained granitic rock between layers of fine-grained porphyritic volcanic rock (fig. 9).

The sheared rhyolite tuff member crops out from the central part of sec. 10, T. 48 N., R. 26 W., west to both the north and south shores of the Dead River Storage Basin in the central and northwestern parts of sec. 7, T. 48 N., R. 26 W. The east limit of the unit is poorly defined; apparently the rhyolite tuff grades into the Nealy Creek Member. As the rhyolitic rock does not crop out west of sec. 7, it may be truncated by a northwest-trending fault inferred to cross the NE¼ sec. 12, T. 48 N., R. 27 W. The best exposures of the member are near the top of the south slope of the elongate hill in sec. 9, T. 48 N., R. 26 W., on the north shore of Dead River Storage Basin in the SE¼ sec. 8, and on the south shore of the Dead River Storage Basin in the NE¼ sec. 7, T. 48 N., R. 26 W. The mapped width of the member is 1,300 feet in sec. 7 and 1,600 feet in sec. 9.

FIGURE 9.—Sheared rhyolite tuff member of Mona Schist, north shore of Dead River Storage Basin, SE¼ sec. 8, T. 48 N., R. 26 W. Light-colored elongate fragments contain abundant quartz phenocrysts. Remainder of rock is gray and green, sericitic and chloritic, has abundant glassy quartz crystals, and is strongly sheared.

Phenocrysts constitute 10 to more than 50 percent of the rock. Quartz phenocrysts, 0.2–2 mm, are elongate parallel to the foliation, and many have been broken into angular fragments and have granulated boundaries. Feldspar phenocrysts range from 0.4 to 2 mm in size and are commonly sericitized or kaolinized, but alteration to carbonate is common south of the Dead River Storage Basin in sec. 7, T. 48 N., R. 26 W. The quantity and type of phenocrysts vary within the same outcrop. In some layers, feldspar phenocrysts are almost entirely kaolinized and quartz is rare or absent, whereas in adjacent layers quartz phenocrysts are abundant and feldspar is rare, or both quartz and feldspar might be abundant. The variations may reflect layer-by-layer change during volcanism, but some apparently result from shearing that has juxtaposed rocks of contrasting compositions.

Small waferlike masses of light-greenish-gray material, which on wet surfaces are bright apple green, are conspicuous in much of the rock. These are 1/10–¼ inch thick, as much as one-half inch long, and generally are elongate parallel to the axial plunge of tiny drag folds. X-ray analyses by E. W. Tooker, U.S. Geological Survey, indicate this material is about two-thirds muscovite and one-third iron-rich chlorite. Perhaps the wafers are altered lapilli similar to those in the volcanic rocks of the Catoctin Schist in Maryland (Stose and Stose, 1946, p. 21).

The rapid-rock analysis of a sample of the tuff indicates that it is near rhyolite in composition (table 2) and is higher in SiO_2 and K_2O and lower in Na_2O, CaO, and MgO than samples of the Nealy Creek Member or of the Kitchi Schist. Its composition is similar to the felsic rock (intrusive?) in the Lighthouse Point Member of the Mona Schist exposed near Bismark Creek in the SW¼ sec. 33, T. 49 N., R. 26 W. (table 4).

The sheared rhyolite tuff appears to intertongue with the Nealy Creek Member and is mapped as a member of the Mona Schist. It might be a lentil, a result of the isolated extrusion of felsic material, or it might be a broad sill-like body within the Mona Schist. More information concerning its distribution and relation to other rocks will have to await mapping to the west. However, the sheared rhyolite tuff and Nealy Creek members appear to be westward extensions of the chloritic and felsitic schists and slates mapped in the Marquette quadrangle by Gair and Thaden (1968, pl. 1). The strongly foliated aspect of these rocks north of Dead River suggests that they are in a major shear zone between the lower member and the Lighthouse Point Member of the Mona Schist.

LIGHTHOUSE POINT MEMBER OF THE MONA SCHIST

DEFINITION, DISTRIBUTION, AND DESCRIPTION

The Lighthouse Point Member of the Mona Schist consists principally of fine-grained dark-green layered amphibolite (Gair and Thaden, 1968, p. 8). In general, the member corresponds to rocks described by Williams (1890, p. 154–162) as banded greenstone schists. The dioritic group of Rominger (1881, p. 23–31) included rocks of the Lighthouse Point Member.

The Lighthouse Point Member crosses the northern part of the Negaunee quadrangle in a belt 3,500 feet wide at the east edge of the quadrangle and nearly 17,000 feet wide in the north-central part. It forms a syncline plunging gently east-southeast in the eastern part of the area. The Lighthouse Point rocks dip away from the Compeau Creek Gneiss in a belt bordering the gneiss, but along the west boundary of the quadrangle they strike northwest and dip 30°–55° NE. The total thickness of the member is unknown; the minimum thickness, 8,500 feet, is at the west edge of the quadrangle, assuming no repetition by undetected faults subparallel to the layering. The member is 4,500–11,600 feet thick in the Marquette quadrangle (Gair and Thaden, 1968, p. 8).

The member consists principally of alternating layers of fine-grained dark-green hornblende-rich rock and lighter colored plagioclase-rich rocks. Disseminated epidote is conspicuous in some outcrops, and epidote veinlets are not uncommon. The contrasting dark-green and lighter colored layers are ¼–½ inch thick and commonly are segregated into bands as much as 6 inches thick. In some outcrops are long, lozenge-shaped structures similar to boudins or flattened pillows. Gair and Thaden (1968, p. 12) concluded that primary tabular layers and lenses of mafic ash were modified by recrystallization, bedding slippage, and low-angle shearing across bedding, shearing, and some secondary segregation within layers, very locally by boudinage.

The layered amphibolite is essentially identical with that in the Marquette quadrangle (Gair and Thaden, 1968, p. 10–11). Green and blue-green hornblende makes up 50–75 percent of the dark layers. Individual crystals are 0.04–0.1 mm in size, and aggregates are 0.2–1.0 mm across. Plagioclase forms a granoblastic mosaic with epidote or commonly is cloudy with sericite and studded with epidote or clinozoisite; it is interstitial to hornblende and about the same grain size. Epidote and clinozoisite form a small part of the hornblende-rich layers and fill fractures. Pyrite and tiny dots of leucoxene are abundant in some samples.

Layered amphibolite along the east side of a small valley 1,100 feet west and 2,300 feet south of the NE. cor. sec. 2, T. 48 N., R. 26 W., has been strongly altered, principally to carbonate, chlorite, epidote, and plagioclase (albite?). The alteration minerals can be seen alined parallel to well-developed shearing. The amount of altered rock is unknown but probably makes up only a small part of the member, for only one of the more than 20 samples of the member studied were strongly altered.

Layering in the amphibolite commonly is well defined but is obscure in areas where the rock is relatively massive. Elliptical features, 6–12 inches thick and as much as 30 inches long, resemble flattened pillows or cross sections of individual small lava flows (fig. 10) but are much smaller and flatter than most pillows in the lower member of the Mona Schist (fig. 7).

FELSIC AUGEN ZONE

A zone in the Lighthouse Point Member near the contact with Compeau Creek Gneiss contains knots, streaks, and bulbous masses—here called augen—of fine-grained light- to greenish-gray felsic material. The augen zone is very well exposed along the north side of Club Lake near the west border of the SW¼ sec. 33, T. 49 N., R. 26 W., (fig. 11). The augen range from a fraction of an inch to 10 inches across and are scattered to abundant. Fine laminae in the enclosing rock bend around some augen but are transected by others without being distorted. The augen probably were feldspar crystals or feldspar-rich aggregates prior to metamorphism. Much of the amphibolite between the felsic augen zone and the contact with the Compeau Creek Gneiss is streaked with light-gray felsic material, and the rock resembles a mafic gneiss. The light-gray

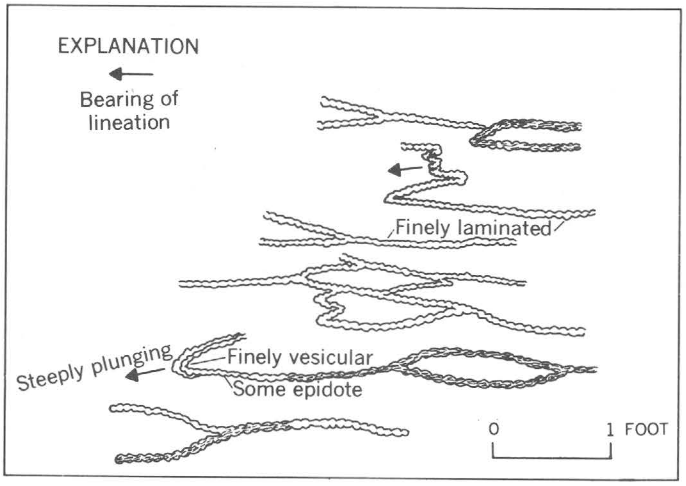


FIGURE 10.—Lenticular structures in layered amphibolite of the Lighthouse Point Member, NE¼NE¼ sec. 6, T. 48 N., R. 26 W. The dark streaks are thinly laminated partings between massive fine-grained yellowish-green rock and may define boundaries of flattened pillow structures or margins of individual lava flows.

FIGURE 11.—Felsic augen, Lighthouse Point Member of the Mona Schist, northeast shore of Club Lake, SW¼ sec. 33, T. 49 N., R. 26 W. Pencil is 7 inches long.

streaks are 1/16–⅛ inch thick, are discontinuous, and form as much as 50 percent of the rock.

The shapes of augen do not clarify their origin. Some small and subrectangular augen with generally sharp boundaries appear to have been feldspar phenocrysts. Some on the larger bulbous masses locally connected to other augen by thin stringers and wisps of felsic material appear to be intrusive. Some rectangular augen originally might have been lithic fragments, whereas other, larger rectangular augen appear to have grown in place as porphyroblasts and transected layering in the amphibolite.

The mineralogy of all augen seems to be identical, even though they are from widely scattered localities. Cloudy sericite and epidote or clinozoisite form the central part of augen. Carbonate is present in some augen; quartz is rare. The material is identical to saussuritized feldspar. Boundaries that might appear straight and sharply defined in hand specimen are seen under the microscope to be irregular and intergrown with hornblende of the enclosing amphibolite. The original material probably was calcic plagioclase. Fine-grained pyrite forms a hairline-thin border on some augen.

Williams (1890, p. 157) described felsic augen in the Brook section of the Mona Schist in sec. 16, T. 48 N., R. 26 W. (Marquette quadrangle) and recognized them as "triclinic feldspar but this has been changed to saussurite***." He considered the augen to be inclusions much flattened by pressure, secretions of the rock itself, or infiltrations (intrusions).

The felsic augen zone, 700–1,000 feet wide, roughly parallels the contact between the Lighthouse Point Member and the Compeau Creek Gneiss from the north boundary of the quadrangle south and southeast to the east boundary, 700–3,000 feet distant from the margins of the gneiss. If the felsic augen are in a single zone, the zone is probably faulted between the center of sec. 34, T. 49 N., R. 26 W. and the NE¼ sec. 3, T. 48 N., R. 26 W. Although the zone was not mapped to the east in the Marquette quadrangle, a massive porphyritic metabasalt, 200–300 feet thick, in the SW¼ sec. 7, T. 48 N., R. 25 W., about 900 feet south of the Compeau Creek Gneiss (Gair and Thaden, 1968, p. 8), may correspond to the felsic augen zone. The felsic augen in the Brook Section in sec. 16, T. 48 N., R. 25 W. (Williams, 1890, p. 156–158) are several hundred feet south of the gneiss in about the same position relative to the gneiss as the zone of felsic augen in the Negaunee quadrangle.

The origin of the felsic augen zone is not clear. The continuity and fairly constant width of the zone suggest that it was originally a feldspar-rich stratum, either of felsic tuff or porphyry, but if this were true, the zone would follow layering in the amphibolite. There is, however, a fairly large discordance between trends of amphibolite layers and the zone of felsic augen in the NE¼ sec. 32, T. 49 N., R. 26 W., and in secs. 1 and 2, T. 48 N., R. 26 W. In the northern part of sec. 2, the felsic augen zone is on the north limb of a syncline, whereas near the south boundary of sec. 1, close to the east edge of the quadrangle, it is on the south limb of the syncline. A northwest-trending fault cuts the rock between the areas in secs. 1 and 2, but this should have no effect on the position of the augen zone relative to the fold axis.

The trend of the augen zone parallel to the contact between the amphibolite and the Compeau Creek Gneiss is a conspicuous and seemingly consistent relation. Perhaps the augen were formed during amphibolitization of the host rock by intrusion of the gneiss and were saussuritized during later regional metamorphism. Comparison of two chemical analyses of augen-bearing amphibolite with other layered amphibolite indicates that there has been no significant addition to the volcanic rocks near the Compeau Creek Gneiss (table 2). Hence the augen either were originally phenocrysts or are metacrysts formed by contact metamorphism.

UNDIFFERENTIATED GREENSTONE

Undifferentiated greenstone is mapped in two separate areas. A band trends west-northwest from near the SE. cor. sec. 5, T. 48 N., R. 26 W., north of Dead River Storage Basin. Another zone extends west from near the Negaunee Cemetery and south of the Carp River Falls shear zone in the southern part of the quadrangle.

The north area of undifferentiated greenstone consists mainly of nonlayered weakly foliated fine-grained metabasalt. Pillow structures are not exposed, but in other respects the rock is similar to the lower member of the Mona Schist. Metadiabase is present as elongate bodies parallel to the foliation. Chert lenses, some containing magnetite, sphalerite, and chalcopyrite, are bounded by coarse-grained metadiabase. Metafelsic rock, some of which might be welded tuff, forms lenses and thin tabular bodies in several outcrops.

The south area is largely sheared metabasalt but contains irregular-shaped masses of felsic rock and some of gray sericitic slate. Pillow structures are exposed in the NE¼ sec. 36, T. 48 N., R. 27 W. Carbonate alteration is conspicuous in some exposures. Tiny octahedra of magnetite are abundant in sheared rock adjacent to the metasedimentary rocks of the Marquette Range Supergroup. Fine-grained crystal tuff(?), similar to rock in the Kitchi Schist, is exposed in outcrops near the Carp River and in the NE¼ sec. 36, T. 48 N., R. 27 W. The crystal tuff(?) and the gray slate may be faulted segments of the Kitchi and the Marquette Range Supergroup. The entire area of undifferentiated greenstone is a zone of sheared rock that may include parts of the lower member of the Mona Schist, the Kitchi Schist, and the Enchantment Lake Formation. Because of the shearing, parts of the different formations are juxtaposed in thin slices that cannot be mapped separately.

COMPEAU CREEK GNEISS

DEFINITION, DISTRIBUTION, AND DESCRIPTION

The Compeau Creek Gneiss was named by Gair and Thaden (1968, p. 18) for gneiss that typically is light colored, foliated, tonalitic, and granodioritic but has dark, chloritic, biotitic, and hornblendic varieties in the northern part of the Marquette quadrangle. Quartz monzonitic and monzonitic varieties are present but not common; true granite is rare. Some darker layers may represent relict sedimentary bedding, but a substantial part of the gneiss is interpreted as siliceous igneous material that intruded the Mona Schist (Gair and Thaden, 1968, p. 26).

The Compeau Creek Gneiss underlies about 6.2 square miles in the northeastern part of the Negaunee quadrangle and borders the layered amphibolite of the Lighthouse Point Member of the Mona Schist.

The gneiss is uniform in the Negaunee quadrangle, generally light pink to greenish gray, foliated, jointed, and weathers reddish brown. No dark chloritic, biotitic, or hornblendic varieties are known. The few thin mafic lenses probably are inclusions of older rock. Metadiabase and diabase dikes have altered the gneiss little, although it is silicified adjacent to some metadiabase. In other areas linear zones of silicified gneiss cross the general trend of dikes. Outcrops are massive and form hills with steep slopes and rounded summits.

COMPOSITION

Quartz, microcline, and plagioclase constitute more than 95 percent of the rock. The modes of typical gneiss are 26–28 percent quartz, 18–20 percent microcline, 44–50 percent plagioclase, 2–7 percent chlorite, and traces of apatite, sphene, epidote, and zircon. Chlorite, the dominant mafic mineral, is probably altered hornblende. Epidote, sphene, and apatite commonly occur adjacent to chlorite. Quartz occurs in granoblastic aggregates 1–2 mm wide and 5–10 mm long. External boundaries of the aggregates adjacent to feldspar are smooth and sharp. Plagioclase is anhedral to euhedral, generally prismatic, and as large as 1.4 by 1.6 mm. The plagioclase is clouded by sericite and clay minerals; chemical analyses (table 3) suggest the plagioclase is oligoclase. Clear and unaltered microcline occurs as discrete anhedral crystals and as highly irregular grains surrounding plagioclase and other minerals. Compositionally the rock is granodiorite.

SILICIFIED ZONES

Silicification is mainly in two zones. One extends from the SW¼ sec. 35, T. 49 N., R. 26 W., to near Bismark Creek, a few hundred feet south of the center of

TABLE 3.—*Chemical analyses and norms of Compeau Creek Gneiss in the Negaunee quadrangle*

[Rapid-rock analyses by P. L. D. Elmore, Gillison Chloe, Lowell Artis, Hezekiah Smith, S. D. Botts, J. H. Glenn, and James Kelsey, U.S. Geological Survey]

	1	2	3
Chemical analyses (weight percent)			
SiO_2	72.9	72.1	74.3
Al_2O_3	14.6	14.6	12.8
Fe_2O_3	.67	....	.38
FeO	.66	.96	.84
MgO	.56	1.4	.85
CaO	1.4	.49	1.2
Na_2O	5.0	4.8	4.2
K_2O	2.9	3.1	3.6
H_2O-	.15	.25	.35
H_2O+	.58	1.8	.75
TiO_2	.23	.21	.11
P_2O_5	.13	.12	.03
MnO	.04	....	.04
CO_2	$<.05$	$<.05$	.29
Total	100	100	100
CIPW norms (weight percent)			
Q	28.68	28.92	31.62
or	17.24	18.35	21.13
ab	42.44	40.35	35.63
an	6.12	1.67	7.78
hy	1.66	4.95	3.16
mt	.93	....	.07
il	.76	.46	.15
C	.14	2.75	.51
ap	1.01	.34	.51

1. Sample No. P–226–66. Lab. No. W167842. SW¼NE¼ sec. 35, T. 49 N., R. 26 W. Typical of most of Compeau Creek Gneiss in the Negaunee quadrangle.
2. Sample No. P–227–66. Lab. No. 167843. SW¼NE¼ sec. 35, T. 49 N., R. 26 W. Adjacent to diabase dike (dike 100 ft thick).
3. Sample No. P–6–67. Lab. No. W169038. SW¼SE¼ sec. 27, T. 49 N., R. 26 W. Red gneiss, appears altered, adjacent to diabase dike (dike is 20 ft thick).

sec. 27, T. 49 N., R. 26 W., and the other strikes northwestward in the north-central part of sec. 27. The margins of the zone in sec. 35 are characterized by alternations of quartz veins and unsilicified gneiss, whereas the central part of the zone is completely silicified with no evidence of gneiss. The most highly silicified rock contains 96.2 percent quartz, less than 1 percent of any single oxide, and, by semiquantitative spectrographic analysis, 0.002 percent barium, 0.003 percent copper, and 0.0005 percent lead. The silicified zone strikes northwest, crossing the trend of metadiabase and diabase dikes. Metadiabase on the hill in the southwestern part of sec. 35 is later than the silicification.

Hematite is abundant in the silicified zones in the NE¼ sec. 28 and the north-central part of sec. 27. Pyrite is common in the silicified zone in Bismark Creek in sec. 26 but is sparse in other silicified zones.

The silicified zones strike at high angles to foliation and dikes and are not parallel to any other known structure. Their distribution pattern suggests a conjugate system of northeast- and northwest-trending veins that might reflect an obscure fracture pattern in the gneiss.

PYRITE-RICH ZONES

Pyrite is abundant in at least four places in the gneiss in secs. 26 and 35, T. 49 N., R. 26 W.—1,800 feet east and 2,100 feet south, 500 feet east and 1,200 feet south, 700 feet east and 500 feet south, and 800 feet east and 1,000 feet north of the NW. cor. sec. 35. Pyritohedrons are scattered through small areas of red gneiss, locally forming about 20 percent of the rock. The pyrite-rich gneiss weathers to a dark brown to black limonite boxwork that contrasts sharply with the nearby light-colored gneiss. A semiquantitative spectrographic analysis of pyrite-rich rock from 500 feet east and 1,200 feet south of the NW. cor. sec. 35 shows the following:

Element	*Percent*	*Parts per million*
Si	(major element)	....
Al	7.0	....
Fe	7.0	....
Mg	1.5	....
Ca	.03	....
Na	3.0	....
Ti	.2	....
Mn		70.0
Ba		300.0
Co		20.0
Cr		1.5
Ga		20.0
Pb		30.0
Sr		100.0
V		15.0
Zr		100.0

NOTE.—No other elements were detected in the analysis.

The cause for localization of pyrite in the gneiss is not known. As occurrences are near edges of outcrops, they might be bordered by undetected faults or diabase. And, since pyrite occurs adjacent to diabase in syenite in lower Precambrian rocks in the southern part of the Palmer quadrangle (J. E. Gair, oral comm., 1966), it may be related to diabase in the Negaunee quadrangle. A diabase dike about 100 feet thick crops out 100 feet south of the pyrite occurrence 1,800 feet east and 2,100 feet south of the NW. cor. sec. 35, but diabase is not known to be near the other occurrences. Well-exposed gneiss-diabase contacts are not rich in pyrite. The apparent pyrite-diabase association may be only coincidental.

STRUCTURE

Measurable structural elements in the Compeau Creek Gneiss are thin zones of sheared rock that might represent faults and foliation marked by lenses of quartz and streaks of chlorite. The foliation strikes uniformly west or west-northwest and dips generally steeply north. Small folds in the foliation, southeast of the stream in the NE. cor. sec. 28, T. 49 N., R. 26 W., plunge steeply west or northwest.

Foliation in the gneiss evidently developed prior to the intrusion of felsic dikes. The relation is demonstrated in one place in sec. 26 (fig. 12), where the contact between the gneiss and intrusive felsic porphyry strikes N. 65° E., dips 30° NW., cutting the foliation of the gneiss, which strikes N. 75° W. and dips 80° NE. The foliation in the dike is subparallel to its boundaries and hence at high angles to the foliation in the gneiss.

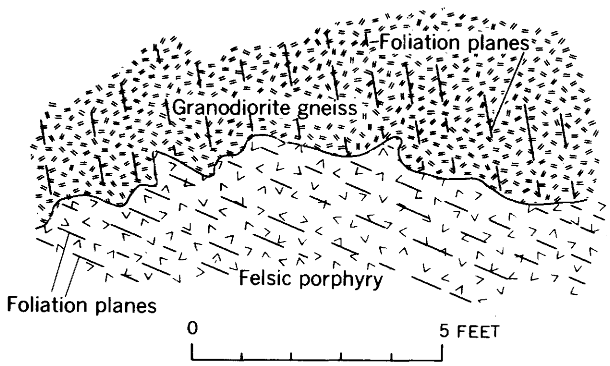


FIGURE 12.—Irregular contact between Compeau Creek Gneiss and felsic porphyry intrusive on east slope of hill in SW¼NW¼NW¼ sec. 26, T. 49 N., R. 26 W. Flow foliation in the intrusive is at a high angle to metamorphic foliation in the gneiss; hence the porphyry probably postdates it.

Narrow shear zones were seen only in widely separated exposures. In one such zone, a few feet wide, on the northeast side of the stream in the NE. cor. sec. 28, T. 49 N., R. 26 W., many narrow quartz veins strike N. 35° W., subparallel to the stream. Perhaps the stream follows the shear zone.

The distribution of diabase and metadiabase dikes probably reflects a late middle Precambrian structural pattern. Metadiabase dikes strike northeast and east and possibly follow a conjugate set of fractures. The diabase dikes strike generally east northeast and cut across the northeast-trending metadiabase.

FELSIC METAVOLCANIC ROCKS

Felsic metavolcanic rock occurs as thin layers and irregular pods in greenstone (shown by letter symbol on pl. 1). The felsic rock generally is medium gray and fine grained, contains conspicuous glassy quartz phenocrysts, and weathers light pink to light gray in high contrast to the dull greenish gray of the surrounding greenstone. Some felsic rock is coarsely porphyritic and weathers to a warty surface on which the feldspar phenocrysts are conspicuous; some is stained dark red by finely disseminated hematite. These rocks are widespread in greenstone and layered amphibolite north of the Dead River but rare in massive pillow greenstone in the lower member of the Mona Schist. Felsic rock occurs in sheared greenstone of the Carp River Falls shear zone near the south edge of sec. 29, T. 48 N., R. 26 W.

Felsic rocks similar to those described herein are known in greenstone of the Quinnesec Formation (Bayley and others, 1966, p. 14–16), the Hemlock Formation (Gair and Wier, 1956, p. 51–54, 66–67), and the Mona Schist (Gair and Thaden, 1968, p. 14). Occurrences in the Quinnesec and Mona were early recognized by Williams (1890, p. 110–123, 152–153).

All the felsic rock is porphyritic, but the amounts of quartz and feldspar phenocrysts range widely. Intricately embayed quartz phenocrysts (0.2–0.6 mm by 0.4–1.2 mm) indicate volcanic origin. Other felsic rock contains no quartz phenocrysts, but potassium feldspar or oligoclase phenocrysts form more than 50 percent of the phenocrysts of some of the rock. Pyroxene(?) and amphibole phenocrysts are conspicuous and abundant locally. Alteration products include sericite, epidote, chlorite, biotite rarely, and carbonate in some rocks containing abundant mafic minerals. The matrix in much of the rock is a granoblastic mosaic of fine-grained quartz and feldspar.

Coarsely porphyritic rock that weathers to a warty surface occurs 2,000 feet east and 3,000 feet south of the NW. cor. sec. 12, T. 48 N., R. 26 W., and 700 feet west and 1,100 feet north of the SE. cor. sec. 6, T. 48 N., R. 26 W. Other coarsely porphyritic rock with conspicuous phenocrysts of feldspar, pyroxene, and amphibole is in an east-trending zone about 1,300 feet north of the south edge of sec. 35, T. 49 N., R. 27 W. Felsic rock containing abundant hornblende phenocrysts crops out 1,300 feet north and 600 feet west of the SE. cor. sec. 25, T. 49 N., R. 27 W., and 2,100 feet north and 300 feet west of the SE. cor. sec. 30, T. 49 N., R. 26 W. The hornblende-rich rocks are syenitic in composition.

The felsic rocks are cataclastically deformed, and some are mylonitized. Quartz phenocrysts are fractured and have been recrystallized to elongate granoblastic mosaics. Feldspar phenocrysts are fractured, and the margins of some are granulated. Large crystals tend to be strongly alined, possibly by original flow banding, but some may be tectonically alined.

Tabular masses of felsic rock generally are concordant with the regional foliation or layering of greenstone. Some felsic rock is localized along the margins of thick dikes or sills of metadiabase. Felsic sills in layered amphibolite are 3–6 feet thick in the south-central part of sec. 4, T. 48 N., R. 26 W., 1½ feet thick in the NW¼ sec. 12, and 10–15 feet thick in the NW¼ sec. 11, T. 48 N., R. 26 W. Felsic porphyry in a mass nearly 60 feet thick crops out below the base of the Reany Creek Formation near the west boundary of the quadrangle in sec. 1, T. 48 N., R. 27 W.

Felsic rock from the south bank of Bismark Creek near the SW. cor. sec. 33, T. 49 N., R. 26 W., is chemically (table 4) similar to the sheared rhyolite tuff member of the Mona Schist (table 2) but contains less SiO_2 than the Compeau Creek Gneiss (table 3). Felsic rock in the Marquette quadrangle (Gair and Thaden, 1968, table 4) and in the Kiernan quadrangle (Gair and Wier, 1956, table 8) contains 1.2–6.9 percent more SiO_2 than the felsic rock near Bismark Creek. The analyzed rock is porphyritic and contains phenocrysts

TABLE 4.—*Chemical and semiquantitative spectrographic analyses of felsic rock (intrusive?) in Lighthouse Point Member of the Mona Schist*

[Rapid-rock analyses by P. L. D. Elmore, Gillison Chloe, Lowell Artis, S. D. Botts, J. H. Glenn, and James Kelsey, U.S. Geological Survey. Semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey. Results of semiquantitative spectrographic analyses are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, ..., which represent approximate midpoints of interval data on a geometric scale. The assigned interval for about 30 percent of the semiquantitative results will include the qualitative value. Elements looked for but not detected in the semiquantitative spectrographic analyses: Ag, As, Au, B, Be, Bi, Cd, Ce, Eu, Ge, Hf, Hg, In, La, Li, Mo, Nb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Y, Yb, Zn]

Chemical analysis (weight percent)	
SiO_2	70.8
Al_2O_3	14.6
Fe_2O_3	1.4
FeO	.92
MgO	.98
CaO	1.3
Na_2O	4.4
K_2O	3.4
H_2O-	.04
H_2O+	1.2
TiO_2	.29
P_2O_5	.18
MnO	.16
CO_2	.22
Total	100
Semiquantitative spectrographic analysis (weight percent)	
Ba	0.07
Co	.0007
Cr	.0015
Cu	.0015
Ga	.001
Ni	$<.003$
Pb	.005
Sc	.0003
Sr	.02
V	.002
Zr	.01

Sample No. P–132–67. Lab. No. W169039. 900 ft east, 500 ft north of SW. cor. sec. 33, T. 49 N., R. 26 W.

of feldspars with ragged borders and small patches of granoblastic quartz as much as 0.5 mm long. The groundmass is a granoblastic mosaic of quartz and feldspar. Grain sizes are 0.06–0.1 mm. Chlorite occurs sparingly in ragged shreds. Leucoxene is rare.

The felsic rock in the Mona Schist in the Negaunee quadrangle is similar to that in other greenstone areas in northern Michigan and is believed to have had a similar origin. Williams (1890, p. 152–153) interpreted the felsic rocks in the greenstone area near Marquette as silicic volcanic rock. Bayley, Dutton, and Lamey (1966, p. 16) concluded that the felsic rocks in the Quinnesec Formation resemble metavolcanic rock but that coarser grained varieties may be intrusive. According to Gair and Thaden (1968, p. 14), some felsic rock in the Mona Schist originally was silicic tuff. The texture, mineralogy, and relative amounts of phenocrysts suggest that the felsic rock in the Negaunee quadrangle is of volcanic origin. Some may be welded tuffs, even though recrystallization has obliterated shards or pumice that might have formed as part of the rock. Some of the felsic rock interbedded with greenstone is texturally and mineralogically similar and might be genetically related to parts of the sheared rhyolite tuff member of the Mona Schist.

DEAD RIVER PLUTON

DEFINITION, DISTRIBUTION, AND AGE

The Dead River pluton is a nonfoliated generally porphyritic composite body of syenite, diorite, and granodiorite that underlies about 3 square miles extending from the west edge of the quadrangle to the western part of sec. 13, T. 48 N., R. 26 W. The best exposures extend west from sec. 23. Most of the rock types can be found south from county road 510 along the east boundary of secs. 15 and 23.

The rocks of the pluton have been called hornblende syenite (Van Hise and Bayley, 1897, p. 176–177) or syenite (Van Hise and Leith, 1911, p. 255, and pl. XVII). The part of the pluton shown on maps by Van Hise and his associates is mainly quartz free, but the larger part of the pluton, beyond the area of their maps, contains 10–20 percent quartz and is granodioritic.

Three facies of the pluton are shown on the map (pl. 1): fine- to medium-grained dark-gray to grayish-pink quartz-free hornblende diorite; pink-weathering porphyritic rock containing widely scattered red feldspar phenocrysts in a greenish-gray medium-grained quartzose matrix; and coarsely porphyritic rock containing abundant feldspar phenocrysts as much as 2 inches long in a dark quartz-free groundmass of hornblende, biotite, feldspar, and minor sphene, magnetite, apatite, and zircon.

The intrusive nature of the pluton is best seen along its south border in sec. 22, T. 48 N., R. 26 W., where the greenstone locally appears to have "soaked up" the plutonic rock. In the SW¼ sec. 18, T. 48 N., R. 26 W., and elsewhere, dikelike fingers of the pluton extend into the adjacent Nealy Creek Member of the Mona Schist.

The age of the pluton is only approximately known. It is younger than the Nealy Creek Member of the Mona Schist, which it intrudes, and older than the Michigamme Slate, which unconformably overlies the pluton. Small bodies of igneous rock, similar to the pluton, intrude greenstone near the south edge of sec. 5, T. 48 N., R. 26 W., and are truncated at the base of the Reany Creek Formation. If these igneous bodies are the same age as the Dead River pluton, and if the Reany Creek Formation is the basal part of the Marquette Range Supergroup, then the Dead River pluton is pre-middle Precambrian in age.

GRANODIORITE PORPHYRY

Granodiorite porphyry composed of subequant to tabular phenocrysts of pink feldspar in a gray-green medium-grained groundmass forms the largest part of the pluton. The rock weathers reddish buff, with phenocrysts of dark-red feldspar against a lighter background. Some phenocrysts are fractured, producing a mildly cataclastic texture.

Phenocrysts of microcline are 10–15 mm long and 5–10 mm wide, commonly are poikilitic or poikiloblastic, with irregular margins, and enclose tabular euhedral plagioclase, or hornblende, biotite, and chlorite. Granophyric potassium feldspar at the margins of some feldspar phenocrysts suggests reaction with the groundmass. The groundmass has mainly a hypidiomorphic granular texture and is composed of plagioclase, microcline, quartz, hornblende, biotite, and (or) chlorite. The groundmass plagioclase, sodic to calcic oligoclase, is cloudy with sericite or other alteration products, and some is rimmed with clear sodic plagioclase. Oscillatory zoning is reflected in the bands of sericitized plagioclase that alternate with less sericitized bands. Patch perthite of microcline in plagioclase and perthite of albite along cleavage planes in plagioclase are common.

The average mode of seven samples of the granodiorite porphyry is 16 percent quartz, 21 percent microcline, 48 percent plagioclase, 5 percent amphibole, 9 percent biotite-chlorite, and 1 percent apatite, zircon, sphene, opaque minerals, and calcite. The chemical composition (table 5) is similar to that of the average hornblende-biotite granodiorite of Nockolds (1954, p. 1014).

TABLE 5.—*Chemical and semiquantitative spectrographic analyses and norms of the Dead River pluton*

[Rapid-rock analyses by P. L. D. Elmore, Lowell Artis, S. D. Botts, Gillison Chloe, J. H. Glenn, and Hezekiah Smith, U.S. Geological Survey. Semiquantitative spectrographic analyses for 1, 2, 3 by J. L. Harris and for 4 by W. B. Crandell, both U.S. Geological Survey. Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, ..., which represent approximate midpoints of interval data on a geometric scale. The assigned interval for about 30 percent of the semiquantitative results will include the quantitative value. Elements looked for but not detected in the semiquantitative spectrographic analyses: Ag, As, Au, B, Bi, Cd, Eu, Ge, Hf, Hg, In, Li, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn. Dash leaders (........) indicate element looked for but not detected]

	1	2	3	4
Chemical analyses (weight percent)				
SiO_2	53.7	65.3	66.5	57.4
Al_2O_3	16.1	15.2	15.4	16.5
Fe_2O_3	3.8	1.0	1.0	2.0
FeO	4.2	1.6	1.7	2.5
MgO	5.3	2.5	1.3	3.0
CaO	5.7	1.8	1.8	4.3
Na_2O	4.4	3.6	4.2	5.7
K_2O	3.5	5.1	4.9	3.7
H_2O^-	.10	.06	.04	.02
H_2O^+	1.4	1.2	1.6	1.4
TiO_2	.75	.43	.35	.40
P_2O_5	.63	.41	.41	.36
MnO	.14	.06	.05	.06
CO_2	.20	1.8	.82	2.6
Total	100	100	100	100
Semiquantitative spectrographic analyses (weight percent)				
Ba	0.1	0.07	0.1	0.15
Be	.00015	.001	.0002	....
Ce	.05	....	.01	.02
Co	.005	.0015	.001	.0015
Cr	.03	.007	.007	.015
Cu	.01	.003	.002	.002
Ga	.002	.0015	.0015	.001
La	.02	....	.01	.015
Mo	.0007	.0003	.0007	....
Nb	....	....	.001	.0005
Ni	.01	.007	.007	.005
Pb	....	....	....	.002
Sc	.002	.0007	.0007	.001
Sr	.15	.03	.03	.1
V	.015	.005	.005	.01
Y	.005	.001	.001	.001
Yb	.0003	.0001	.0001	.0001
Zr	.03	.015	.03	.02
CIPW norms				
Q	....	17.52		3.78
or	20.57	30.02		21.68
ab	37.20	30.39		48.21
an	13.90	6.12		2.22
wo	4.29	....		....
hy	3.89	7.65		9.74
mt	5.57	1.39		3.02
il	1.37	.76		.76
C	....	1.43		2.35
ap	1.34	1.01		1.01
cc	....	....		5.9

1. Sample No. P–212–64. Lab. No. 164095. 1,300 ft east, 1,300 ft south of NW. cor. sec. 23, T. 48 N., R. 26 W. Hornblende diorite.
2. Sample No. P–213–64. Lab. No. 164096. 1,600 ft north, 700 ft west of SE. cor. sec. 15, T. 48 N., R. 26 W. Granodiorite porphyry.
3. Sample No. P–214–64. Lab. No. 164097. 1,000 ft east, 450 ft south of NW. cor. sec. 14, T. 48 N., R. 26 W. Granodiorite porphyry.
4. Sample No. P–829a–65. Lab. No. W167402. 1,200 ft east, 100 ft south of NW. cor. sec. 20, T. 48 N., R. 26 W. Hornblende-biotite syenite porphyry.

HORNBLENDE DIORITE

Hornblende diorite ranges from dark green and fine grained near the south border of the pluton along Midway Creek in the SW¼ sec. 23 to pinkish gray and medium grained near the NW. cor. sec. 23, T. 48 N., R. 26 W. The generally lighter color in the north is due more to an increase in grain size than to a more felsic composition.

The diorite is a near-equigranular mosaic of subhedral amphibole and plagioclase crystals and irregular-shaped aggregates of biotite, chlorite, and potassium feldspar. Amphiboles are green hornblende or light-green actinolite-tremolite in raggedly terminated prismatic crystals or clusters of smaller crystals. Green or brown biotite is marginal to some of the amphibole and is partly or completely altered to chlorite. The cores of some of the amphibole near the south margin of the pluton are lighter colored than the margins and are probably relicts of pyroxene. Plagioclase is tabular to subequant and most is clouded with sericite and clay minerals. Irregular grains of potassium feldspar, mainly microcline, are marginal to, and also within, plagioclase. Where microcline is marginal to plagioclase, the external boundaries approximate crystal outlines, but the contact with plagioclase is irregular and somewhat gradational. Apatite is common in and adjacent to amphibole, and sphene and rutile are common in the chloritized biotite. Tiny round grains of zircon, surrounded by brown pleochroic haloes, are present in the biotite.

The average mode of 10 samples of diorite is 17 percent potassium feldspar, 47 percent plagioclase, 23 percent amphibole, 12 percent biotite and chlorite, and 1 percent apatite, sphene, zircon, epidote, calcite, and opaque minerals. The chemical composition (table 5) is between average diorite and average monzonite (Nockolds, 1954, p. 1017, 1019).

Dark phases of the diorite that occur 1,500 feet south and 2,400 feet east and 2,200 feet south and 600 feet east of the NW. cor. sec. 23, and 300 feet west of the NE. cor. sec. 22 might represent mafic dikes but exposures are too limited to be certain. A sample of such rock contains 35 percent plagioclase, 32 percent hornblende, 27 percent biotite, 3 percent apatite, 2 percent opaque minerals, 1 percent rutile, zircon, and carbonate, and traces of potassium feldspar.

Several northeast- to east-trending dikes of pink fine- to medium-grained alaskite have intruded the diorite in the northwestern part of sec. 23. The alaskite is an inequigranular mosaic of large ragged feldspar crystals surrounded by finer grained feldspar and quartz. The feldspar is principally narrowly twinned cloudy plagioclase but includes microcline. Coarsely crystalline calcite is molded against some of the feldspar grains.

Several eastward-trending quartz veins, 1–4 inches thick, cut the diorite in the SE¼ sec. 15, subparallel to the alaskite dikes. The quartz veins dip about 60° S., whereas the alaskite dikes dip more steeply south or are vertical.

Thin pegmatite dikes occur in the NE¼ sec. 22. They consist of pink feldspar as much as 1 inch in size and minor quartz. Platy specular hematite coats fractures. The pegmatite is generally interlayered with coarse-grained amphibolite near the south border of the pluton and probably represents late magmatic intrusions into the diorite.

PORPHYRITIC SYENITE

Coarsely porphyritic syenite forms broad zones that trend northwestward across the pluton in secs. 17 and 18 and a narrow unmapped dike in the NE¼ sec. 22, T. 48 N., R. 26 W. The porphyry contains grayish-pink perthite crystals in a dark groundmass of hornblende, biotite, fine-grained feldspar, light-brown sphene, and magnetite. The groundmass constitutes one-tenth to more than one-third of the rock. Weathering of the groundmass in places leaves a rough, warty surface of perthite crystals (fig. 13).

Perthite phenocrysts range from about 2 inches to less than one-fourth inch in size. Many are twinned. Phenocrysts "float" in the groundmass, rarely touching one another. There is no obvious alinement of crystals in the porphyry. None appear to be brecciated. Cleavage is pronounced, and some cleavage planes contain calcite veinlets.

The groundmass is similar to the hornblende diorite of the pluton, except that the hornblende appears to be primary rather than altered pyroxene.

The chemical composition of the porphyritic syenite is between that of the hornblende diorite and granodiorite porphyry (table 5). As Na_2O exceeds K_2O, the perthite is probably albitic. The relatively large amount of CO_2 is attributed to secondary carbonate in some of the phenocrysts.

FIGURE 13.—Porphyritic syenite, Dead River Pluton, 2,800 feet west and 1,150 feet north of the SE. cor. sec. 18, T. 48 N., R. 26 W. Large perthite crystals form conspicuous warty surface; groundmass removed during weathering.

The cause of the localization of the porphyritic syenite into zones is not evident. The northwest trend of the zones is subparallel to faults in the Mona Schist south of the Dead River pluton. As the zones of porphyry are along the projection of two faults in the southern and eastern part of sec. 20, T. 48 N., R. 26 W., they might have developed by intrusion or replacement of earlier granodiorite porphyry along the faults.

MIDDLE PRECAMBRIAN ROCKS

Metasedimentary rocks of middle Precambrian age form a belt across the southern part of the quadrangle and underlie the Dead River basin in the central and western parts of the quadrangle. The rocks belong to the Chocolay, Menominee, and Baraga Groups of the Marquette Range Supergroup (Cannon and Gair, 1970) and are unconformable on lower Precambrian rocks. The Chocolay Group comprises the Reany Creek Formation, the Enchantment Lake Formation, the Mesnard Quartzite, the Kona Dolomite, and the Wewe Slate; the Menominee, the Ajibik Quartzite, the Siamo Slate, and the Negaunee Iron-Formation; the Baraga Group, the Michigamme Slate.

CHOCOLAY GROUP

REANY CREEK FORMATION

The Reany Creek Formation underlies an area north of Dead River from sec. 12, T. 48 N., R. 26 W., to about

1 mile west of the quadrangle (Puffett, 1969) and consists of conglomerate, arkose, chloritic slate, graywacke, and boulder-bearing slate. It is the lowermost formation of the Marquette Range Supergroup.

The Reany Creek Formation consists of (1) a basal conglomerate, (2) a middle unit of chloritic slate containing widely scattered granitic boulders and intraclasts of arkose, and (3) an upper unit of interbedded conglomerate, slaty graywacke, and lenses of quartzite and arkose. These types are not differentiated on plate 1.

The formation was deposited on a surface eroded across greenstone and layered amphibolite of the Mona Schist. The upper part of the formation is faulted down against schist and sheared rhyolite tuff of the Mona Schist; the true top of the formation is not known. The thickest part of the formation is more than 3,500 feet in the SW¼ sec. 2 and NW¼ sec. 11, T. 48 N., R. 26 W. Throughout much of its outcrop belt, the formation is 1,500–2,000 feet wide.

Basal conglomerate is in the SW¼ sec. 2, S½ sec. 3, and the S½ sec. 6, T. 48 N., R. 26 W., and in the SE¼ sec. 1, T. 48 N., R. 27 W. In the eastern area, the matrix is coarse arkose, and the boulders, as much as 2 feet in diameter, are predominantly granitic. In the western area, the matrix is chloritic slate, and boulders are mainly of greenstone and reportedly as large as 10 feet across (Engel, 1954). The conglomerate in both areas contains angular blocks of chert-magnetite rock. Boulders have no common orientation and decrease in size upward, from the base of the formation, only in the western part of the east area.

The middle unit is the most widespread part of the formation. It consists mainly of green chloritic slate containing widely scattered granitic boulders and arkose clasts. Some outcrops of only a few square feet contain several boulders; some of several hundred square feet contain only one or two boulders. Clasts of fine-grained pinkish-gray arkose are locally conspicuous. Folded beds are visible in some large intraclasts. Thin beds of arkose, similar to that in the intraclasts, occur in the slate near the SW. cor. sec. 2, T. 48 N., R. 26 W. Beds and intraclasts of arkose are most abundant in the lower part of the middle unit.

Granitic boulders are present in slate near the SE. cor. sec. 6, and in the SW¼NW¼ sec. 11, T. 48 N., R. 26 W. Arkose intraclasts occur in slate on the steep slopes near the east margin of sec. 1, T. 48 N., R. 27 W., and scattered small clasts of granitic rock and arkose are in slate north of Reany Creek in the N½ sec. 9, T. 48 N., R. 26 W.

The upper unit of the Reany Creek Formation consists of interbedded arkose, slate, graywacke, conglomerate, and quartzite along the north shore of the Dead River Storage Basin in secs. 7 and 8 and in and near Reany Creek in secs. 9 and 10, T. 48 N., R. 26 W., and on the hill south of the basin in sec. 1, T. 48 N., R. 27 W.

Beds of conglomerate, 1–3 feet thick, are interlayered with beds of slate and graywacke 3–5 feet thick. Till-like conglomerate consists of boulders of quartzite and granitic rock dispersed in chloritic slate. Large clasts are 1–15 inches in diameter.

Massive and indistinctly bedded fine-grained feldspathic quartzite forms several large lenses in the upper unit of the Reany Creek Formation in the NE¼ sec. 7 and NE¼ sec. 8, T. 48 N., R. 26 W. and near the south edge of sec. 1, T. 48 N., R. 27 W. Future work might prove that the quartzite in sec. 1 belongs to a different formation.

The arkose is massive and pinkish gray; it commonly is coarser grained than arkose in the middle unit of the formation. Interbedded layers of arkose and quartzite south of Reany Creek in the north-central part of sec. 9, T. 48 N., R. 26 W., are as much as 10 feet thick. Arkose also occurs in the NE¼ sec. 7, T. 48 N., R. 26 W. Feldspar is dominant over quartz in the eastern outcrops but is as low as 25 percent in the western outcrops.

The formation appears to dip homoclinally to the south, and evidently no part of it has been repeated. Bedding generally is not well defined. Beds of arkose in the middle unit are commonly broken, and some might have been folded. Chloritic slate in the middle unit is strongly cleaved. Conglomerate and arkose in the upper part of the formation dip steeply to the south.

The formation is bounded by faults on the east and the south. The south part is faulted down against Mona Schist in Reany Creek in the north-central part of sec. 10, T. 48 N., R. 26 W. The formation was not recognized in the Marquette quadrangle and hence probably terminates against faults inferred in sec. 12, T. 48 N., R. 26 W.

The general environment of deposition of the Reany Creek Formation was one in which glaciers were active (Puffett, 1969, p. F20). The isolated boulders in the slate are believed to have been ice rafted. Torrential melt-water streams deposited the layers of conglomerate in the upper unit. The arkose was deposited by subglacial streams. The coarse conglomerate at the base was deposited in U-shaped valleys scoured by alpine-type glaciers.

The exact correlation of the Reany Creek Formation is uncertain. Rocks similar to the Reany Creek Formation in the northwestern part of the Dead River basin might be of Timiskamian age (Marsden, 1968, p. 468). The Reany Creek Formation is similar to the Enchantment Lake Formation in the Marquette syncline and hence might be correlative with the lower part of the Marquette Range Supergroup. There are no meaningful radiometric age data on which to base a correlation.

ENCHANTMENT LAKE FORMATION

The Enchantment Lake Formation is the basal metasedimentary unit of the Marquette Range Supergroup in the Marquette syncline (Gair and Thaden, 1968, p. 27). The type locality is about 2 miles east of the Negaunee quadrangle. The Enchantment Lake Formation east of the Negaunee quadrangle consists of basal conglomerate, arkose, sericitic quartzite, graywacke, and sericitic slate and is lenticular and probably discontinuous along strike.

Rocks assigned to the Enchantment Lake Formation occur between Mona Schist and vitreous Mesnard Quartzite in the Negaunee quadrangle. Exposures are found from near the Negaunee cemetery in sec. 33, T. 48 N., R. 26 W., to near Teal Lake. There are no exposures between the Negaunee Cemetery and the type area in the Marquette quadrangle, a distance of nearly 5 miles. The maximum width of the formation in the Negaunee quadrangle is about 200 feet. The formation is truncated by Ajibik Quartzite near the northeast shore of Teal Lake.

In the Negaunee quadrangle, the Enchantment Lake Formation consists of basal conglomerate, arkosic quartzite, and interbedded sericitic slate and sericitic quartzite. The following measured section crosses one of the better exposures:

Section of the Enchantment Lake Formation

[Described by C. E. Fritts, 1963, about 200 ft west of the east boundary of sec. 31, T. 48 N., R. 26 W.]

Formation	*Lithology*	*Thickness (ft)*
Mesnard Quartzite	Quartzite, massive, vitreous	
Enchantment Lake Formation.	Slate, olive, gray, sericitic	10
	Quartzite	8
	Slate, sericitic; quartzite beds 1–2 in. thick	6
	Quartz, white vein	3
	Slate, minor vein quartz	4
	Quartzite, gray, fine-grained	6
	Slate and quartzite, interbedded; quartzite beds less than 10 ft thick	110
	Conglomerate, white quartz pebbles 1 in. in diameter	3
		150
Mona Schist	Greenstone, thinly foliated and sheared.	

Basal conglomerate contains abundant white quartz pebbles and cobbles as large as 5 inches but more commonly less than 2 inches in diameter. The matrix is commonly feldspathic quartzite or arkose. The arkose consists of angular feldspar, predominantly microcline, quartz grains, and sericitic matrix. Clastic muscovite and detrital and authigenic tourmaline are common, and chert pebbles are a minor constituent. Chlorite is present locally. A granitic terrane appears to have been the source for all the constituents except the chert. Basal conglomerate is well exposed northwest of the cemetery in sec. 33, about 1,500 feet east of U.S. Highway 41, about 300 feet west of U.S. Highway 41, and east of the county road in sec. 31 north of the Beverly Hills area. As large blocks of conglomerate and feldspathic quartzite are present along the Teal Lake outlet in the NW¼ sec. 31, T. 48 N., R. 26 W., the base of the formation probably coincides with the valley.

The formation above the conglomerate consists of interbedded quartzite, feldspathic quartzite, arkose, and potassium-rich sericitic slate (table 6). Lithologies vary greatly from one exposure to the next.

TABLE 6.—*Chemical analysis, in weight percent, of slate in Enchantment Lake Formation*

[Sample from roadcut on U.S. Highway 41, sec. 31, T. 48 N., R. 26 W. From Nanz (1953, p. 53, table 1)]

Oxide	*Percent*
SiO_2	62.79
TiO_2	.52
Al_2O_3	21.11
Fe_2O_3	5.62
FeO	.18
MnO	None
MgO	.19
CaO	.14
Na_2O	.32
K_2O	6.16
P_2O_5	.09
H_2O-	2.62
H_2O+	.03
CO_2	.07
C	.08

A trench cuts more than 100 feet of 3–8-inch beds of gray slate and greenish-gray quartzite of the Enchantment Lake Formation on the north side of the steep hill in the NW¼ sec. 31, T. 48 N., R. 26 W., about 1,000 feet west of the county road. This trench may be the site of a whetstone quarry operated in 1849 and 1850 (Brooks, 1873, p. 21).

The formation has been deposited on sheared greenstone; the contact is well cemented and not sheared. The amount of local relief along the contact cannot be determined.

MESNARD QUARTZITE

The Mesnard Quartzite is the first thick vitreous quartzite above the base of the Marquette Range Supergroup. The Mesnard Quartzite is lenticular and ranges in thickness from a few to nearly 200 feet. It extends nearly across the quadrangle from the east boundary and is truncated in the NW¼ sec. 31, T. 48 N., R. 26 W., by the unconformity at the base of the Ajibik Quartzite.

The Mesnard was named by Van Hise and Bayley (1895, p. 517) and included the rocks of the Enchantment Lake Formation.

As mapped by Seaman in the hills east of Teal Lake (in Van Hise and Leith, 1911, pl. 19), the Mesnard Quartzite consisted of seven lithologic units. The three highest units of Seaman—red quartzite, purple slate, and cherty quartzite—are placed in the Kona Dolomite in this report (table 7). Only Seaman's fourth or middle unit of vitreous quartzite is here assigned to the Mesnard Quartzite.

TABLE 7.—*Comparison of stratigraphic divisions of the middle Precambrian rocks in the hills east of Teal Lake*
[Cross-rules indicate formation boundaries]

Lithology	Seaman (in Van Hise and Leith, 1911, pl. XIX)	Fritts (1964)	This report
Chert breccia and quartzite; top not exposed	Kona	Kona	
Purplish-gray slate with chert nodules	Dolomite (?)		Kona.
Vitreous quartzite, cross-bedded, ripple-marked			
Ferruginous slate; thin beds vitreous quartzite		Dolomite	
Chert breccia; algal structures			Dolomite.
Vitreous quartzite, cross-bedded, ripple-marked	Mesnard		
Purple ferruginous slate; chert nodules near top			
Sericitic quartzite; thin bedded and slaty in upper part	Quartzite	Mesnard	
Vitreous quartzite, ripple-marked		Quartzite	Mesnard Quartzite.
Sericitic quartzite, slate, arkose, and conglomerate			Enchantment Lake.
Sheared greenstone	Not named.	Not named.	Mona Schist.

Conspicuous outcrops of the Mesnard extend west from the northwest corner of the Negaunee Cemetery in the NE¼ sec. 33, T. 48 N., R. 26 W., and form a nearly continuous ridge to the NW¼ sec. 31, where the Mesnard is truncated by the Ajibik Quartzite. Ridges have steep to overhanging north slopes. There are no outcrops of the formation east from the cemetery to Enchantment Lake some 4½ miles away.

The quartzite is generally fine grained, light gray with pinkish zones, crossbedded, and ripple marked and contains beds as much as several feet thick.

The quartzite contains more than 90 percent quartz and minor sericite, chlorite, and several other minerals (Gair and Thaden, 1968, p. 35). Red angular chert grains and small quartzite pebbles are rare.

KONA DOLOMITE

DEFINITION AND DISTRIBUTION

Van Hise and Bayley (1895, p. 523) named the formation for cherty dolomite interstratified with layers of slate, graywacke, and quartzite in the Kona Hills, about 2 miles south of the southeast corner of the Negaunee quadrangle. According to them (1895, pl. XIII) the Kona of the Negaunee 7½-minute quadrangle is truncated by Wewe Slate near the west edge of sec. 32, T. 48 N., R. 26 W. Van Hise and Leith (1911, pl. XVII) show the Kona as far west as sec. 31, where it is truncated by folded Ajibik Quartzite. In the hills east of Teal Lake, Seaman (in Van Hise and Leith, 1911, pl. XIX) showed the Kona truncated by an east-trending fault at the base of the Ajibik Quartzite. Several beds of slate and quartzite placed in the Mesnard by Seaman are in this report (table 7) considered to be part of the Kona Dolomite.

A major difficulty in mapping the Kona has been that the formation changes markedly across a covered zone, 2½–3 miles wide, between its eastern and western exposures in the quadrangle. The eastern outcrops, in the NE¼ sec. 35 and north half of sec. 36, T. 48 N., R. 26 W., are predominantly of dolomite. The western outcrops, in the SE¼ sec. 33 and the north-central part of sec. 32, T. 48 N., R. 26 W., are of quartzite, ferruginous slate, and chert breccia. Most of the rock in the west area is lithologically similar to the rock of adjacent formations, and this largely explains the differing interpretations of structure and stratigraphy in secs. 31–33 and of the westward limit of the Kona. Early in the present work, it was thought that a siliceous facies of west-striking, south-dipping Kona extended to the west side of sec. 31 and was there truncated by an erosional unconformity at the base of the Ajibik (Fritts, 1964, p. 5–8). That view has gradually been modified, however, following careful review of previous concepts and detailed mapping in secs. 31–33. The stratigraphic and structural relations now recognized in the western area are discussed under the sections "Ajibik Quartzite" and "Eagle Mills Syncline."

EASTERN AREA

The Kona known in the eastern area is mainly fine- to medium-grained pinkish-gray crystalline dolomite and thinly bedded purplish-pink argillaceous dolomite and slate. Hematite stains fine-grained rocks pink to red. Dark chert is conspicuous in places within aggregates of coarsely crystalline dolomite 1 inch or less in diameter. Algal structures are present locally.

Many characteristic features are seen in the following measured section near the old Morgan furnace in the NW¼ sec. 35, T. 48 N., R. 26 W.:

Partial section of Kona Dolomite
[Measured by C. E. Fritts, 1963, in NW¼ sec. 35, T. 48 N., R. 26 W., starting at abandoned railroad near Morgan Creek; offset westward in vicinity of old Morgan furnace; top at south of abandoned quarry west of railroad]

Unit	*Lithology*	*Thickness (ft)*
25.	Dolomite, purplish-gray to moderate-orange-pink, thin-bedded; few thin argillaceous layers	20(?)
24.	Scraped area; debris includes siliceous purplish-gray dolomite containing pink carbonate metacrysts	20(?)
23.	Slate, purplish-gray, and dolomite, purplish-gray to red, interbedded (partly covered)	15–20

Partial section of Kona Dolomite—Continued

Unit	*Lithology*	*Thickness (ft)*
22.	Dolomite, pale-red to pinkish-gray, cherty, fine-grained, thin-bedded; siliceous layers abundant (quarry)	17–18
21.	Dolomite, grayish-pink to purplish-gray, thin-bedded; abundant chert; argillaceous and silty seams; one layer of gray slate 1–2 ft thick; small algal structures in siliceous layers	50
20.	Dolomite, moderate-grayish-red, fine-grained; red carbonate metacrysts in lower part; pale-red dolomite with grayish-pink carbonate metacrysts 1 in. across in upper half; some beds cherty (quarry)	12
19.	Dolomite, light- to moderate-red, fine-grained; interbedded with purplish-gray very fine grained dolomite with purplish-gray argillaceous partings	15–20
18.	Dolomite, grayish-orange-pink to pale-red and pale-purplish-gray; a few layers contain white carbonate metacrysts as much as ½ in. in diameter	15
17.	Dolomite, light- to moderate-red, fine-grained; interbedded with purplish-gray very fine grained siliceous and argillaceous dolomite; argillaceous partings; beds range in thickness from less than 1 mm to more than 1 in.	40
16.	Dolomite, pale-red to yellowish-gray, siliceous, well-bedded; numerous moderate-red carbonate metacrysts ½ in. in diameter; large algal structures, convex upward, several feet long and as much as 2 ft high	45–50
15.	Covered	90–100
14.	Dolomite, pale-red to grayish-red, fine-grained, sandy to silty; purplish-gray argillaceous partings; ripple marks	2–3
13.	Covered	15
12.	Dolomite, pale-red to grayish-red; purplish-gray slaty partings	5
11.	Siltstone, dolomitic, purplish-gray; grayish-orange-pink spots as much as 1 in. across	5–15
10.	Dolomite, purplish-gray and pale-red, fine-grained; purplish-gray slaty partings	10
	NOTE.—Section offset to west	
9.	Slate and siltstone (?), purplish-gray to grayish-red; several beds as much as 3 ft thick of grayish-pink, pale-red, and purplish-gray fine-grained dolomite	70
8.	Siltstone and dolomite, interbedded. Siltstone, grayish-red, ferruginous, dolomitic. Dolomite, grayish-red; silty to "sandy" beds 1 in. thick	30
7.	Quartzite and dolomite, interbedded; quartzite, grayish-red to pale-red, dolomitic. Dolomite, pale-red to grayish-red, "sandy;" dolomite fragments 5–10 mm in diameter	5
6.	Dolomite, pale-red to grayish-red, fine-grained; many cherty layers protrude on weathered surfaces	20
5.	Dolomite, purplish-gray; pale-reddish-brown to moderate-orange-pink layers; siliceous dolomite beds 2 ft thick	40
4.	Dolomite, purplish-gray; interbedded with purplish-gray ferruginous siliceous dolomite with argillaceous partings; siliceous layers protrude on weathered surface; crumpled and brecciated bed 1 ft thick	14
3.	Dolomite, purplish-gray; pale-reddish-brown layers; interbedded with grayish-pink dolomite	5
2.	Dolomite, grayish-pink, siliceous, medium- to fine-grained; purplish-gray dolomite with argillaceous partings near base	3
1.	Dolomite, purplish-gray, fine-grained, "sandy;" layer of siliceous dolomite; carbonate-quartz veins a few millimeters thick cut across beds	3
	Measured thickness of partial section	611–642

The total thickness of the Kona Dolomite in the eastern outcrop area is unknown, as the top and base of the formation are not exposed, but it probably is 900–1,200 feet. The mapped width of 1,500 feet at the east border of the quadrangle is from the Marquette quadrangle.

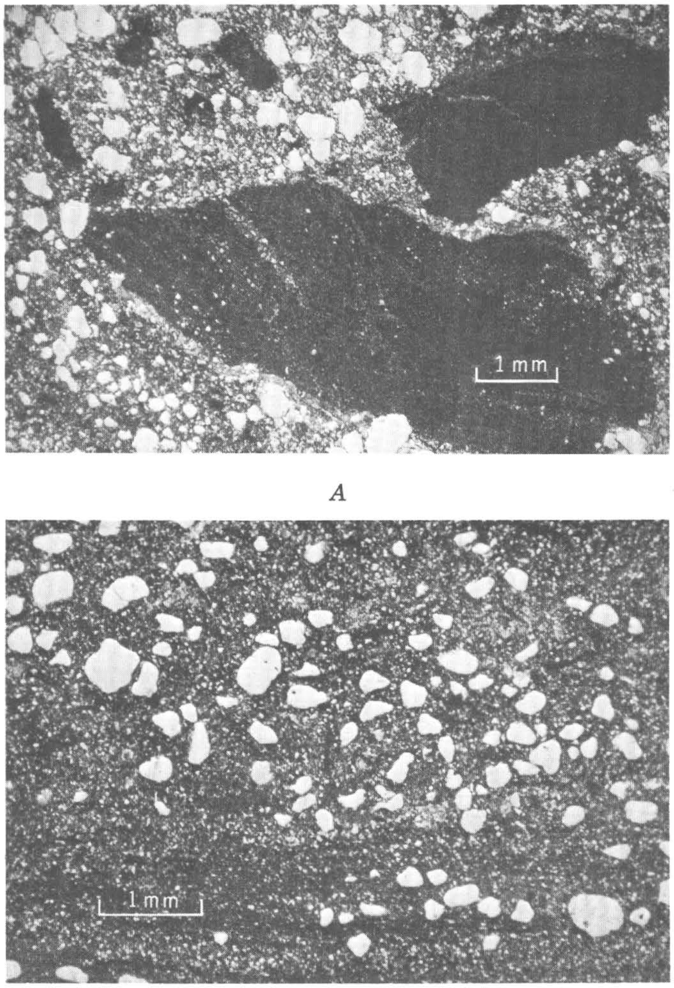
Angular clasts of fine-grained ferruginous dolomite and dispersed clastic quartz grains are common in much of the dolomite (fig. 14*A*). Good examples of lithic fragments are found in unit 7 of the measured section. Some of the "sandy" dolomite in unit 8 and other units in the measured section contain rounded quartz grains, 0.2–0.5 mm in diameter (fig. 14*B*), that were probably dispersed during dolomitization (Dapples, 1959, p. 43).

WESTERN AREA

The western area of Kona Dolomite extends west southwest from the Carp River in the NW¼ sec. 33 to near the west edge of sec. 32, T. 48 N., R. 26 W. In this area the formation includes, from the base upward, sericitic quartzite, purple ferruginous slate with chert nodules, vitreous gray quartzite, a thin chert breccia with algal structures, silty ferruginous slate with thin quartzite beds, and vitreous quartzite overlain by slate and chert breccia (table 7).

Seaman (in Van Hise and Leith, 1911, pl. XIX) assigned most of these units to the Mesnard Quartzite; only parts of the upper two slates and quartzite were questionably assigned to the Kona Dolomite. The sericitic quartzite now placed at the bottom of the Kona Dolomite is in sharp contact with the underlying vitreous Mesnard Quartzite and grades upward into purple ferruginous cherty slate nearly identical to slate in the eastern area of Kona Dolomite. The western area of Kona Dolomite represents an 800–900 foot interval in the lower part of the formation.

The sericitic quartzite at the base of the formation—the red quartzite of Seaman—is pale red to olive gray, massive, generally fine grained, moderately well sorted, and 50–150 feet thick, averaging 100 feet. It consists mainly of angular to subrounded quartz grains 0.1–0.4



A

B

FIGURE 14.—Photomicrographs of Kona Dolomite. *A*, Clastic material from unit 7 of measured section. Large angular clasts consist of fine-grained dolomitic material. Clear subrounded grains are quartz. *B*, "Floating" quartz grains, set in matrix of chert, fine-grained dolomite, and clay. Overgrowths on many of the quartz grains are corroded. Plane-polarized light.

mm in diameter, with a few grains as large as 0.3 by 0.9 mm, set loosely in a crudely foliated sericitic matrix. Subordinate and minor clastic minerals are feldspar, mainly microcline, cloudy plagioclase, zircon, and tourmaline. Some microcline grains have feldspar overgrowths.

The quartzite is distinguishable from the Mesnard Quartzite by being darker, less massive and more slabby, and nonvitreous. The sharp boundary between the two quartzites and the variability in their thickness is evidence for an unconformity between them.

Purplish-gray and brownish-gray quartzose sericitic ferruginous slate forms a large part of the Kona Dolomite in the western area. Quartz makes up 35–55 percent of the rock, clastic feldspar about 5 percent. Ferruginous material is mainly hematite but locally is magnetite. Gray hematitic chert and chalcedonic nodules, ¼–1 inch in diameter, are locally abundant. Some are very irregular and have bulbous protuberances. All probably developed during diagenesis. Bedding is indistinct in many outcrops of the slate and is further obscured by slaty cleavage.

Vitreous gray crossbedded and ripple-marked quartzite—the lower vitreous and the thickest and most nearly continuous quartzite in the Kona—forms a ridge that can be traced from the Carp River westsouthwest to near the west edge of sec. 32. It is bounded above and below by ferruginous slate containing chert nodules. Slickensides indicate differential movement between the quartzite and slate. Other quartzite forms discontinuous layers in the formation (pl. 2).

Distinctive ferruginous chert breccia of platy fragments is at or near the top of the lower vitreous quartzite. Locally a few feet of slate intervenes between the quartzite and the breccia; elsewhere the breccia appears to be an upward continuation of the quartzite. The breccia is 5–15 feet thick in most exposures and varies from a confused jumble of fragments with no systematic distribution to disrupted thin beds, in places folded (fig. 15). Tabular remnants of chert beds and areas of intervening dark ferruginous fine-grained material are generally less than one-half inch thick.

FIGURE 15.—Folded and broken thin chert beds, chert breccia unit, Kona Dolomite: 3,600 feet north and 3,600 feet west of the SE. cor. sec. 32, T. 48 N., R. 26 W. Some crenulations might be silicified algal structures. Coin is 0.9 inch in diameter.

The presence of chert breccia helps in distinguishing the lower Kona quartzite from the Mesnard. Chert breccia also occurs above vitreous quartzite higher in the Kona.

Algal structures in the chert breccia furnish one of the principal kinds of evidence used in correlating the breccia with Kona Dolomite, as such structures are not known in other middle Precambrian formations in the Negaunee area. C. E. Fritts (written commun., 1965) found probable algal structures on the ridge near the NE. cor. sec. 32 and the western part of sec. 33. They are convex upward in cross section, 8–18 inches long, 6–12 inches high, and seem to differ from those in the eastern area of Kona Dolomite by being individual mounds rather than in groups, although original algal colonies in the western area could have been destroyed by the brecciation.

Chemical composition

No carbonate minerals are known in the slate and chert breccia of the Kona, and these rocks contain only small amounts of magnesia, lime, and CO_2 (table 8). If carbonate of magnesia or lime was present in the original sediments, it has been replaced by silica or other minerals.

Copper minerals occur near the base of the Kona in the Marquette and Sands quadrangles (Gair and Thaden 1968, p. 69, 70), and copper carbonate stains sheared slate near the base of the Kona on the west bank of the Carp River in sec. 33, T. 48 N., R. 26 W. However, analyzed samples from the Negaunee quadrangle contain no more than traces of copper (table 8).

Coarse specular hematite is conspicuous in veinlets as much as 3 inches thick in a 2-foot-thick zone in vitreous quartzite on the west slope of the hill near the NE. cor. sec. 32 and along the base of the quartzite on the north side of the hill. Hematite impregnates a fault trending N. 38° W. and bordering slate in the NE. cor. sec. 32. The hematitic zone has been prospected by a few shallow shafts and pits.

WEWE SLATE

The Wewe Slate does not crop out in the Negaunee quadrangle, but by projection from the Marquette quadrangle (Gair and Thaden, 1968, pl. 1), it extends underneath moraine deposits and alluvium in the southeast quarter of the quadrangle. In the Marquette quadrangle, the formation consists of light- to dark-gray, greenish-gray, dull-green, or salmon-colored nonlaminated and laminated slate (Gair and Thaden, 1968, p. 45).

In the Negaunee quadrangle, the Wewe Slate is truncated by the unconformity at the base of the Ajibik Quartzite. The maximum thickness of the formation, at the east edge of the quadrangle, is approximately 1,500 feet.

MENOMINEE GROUP

AJIBIK QUARTZITE

DEFINITION, DISTRIBUTION, AND DESCRIPTION

The Ajibik Quartzite was named by Van Hise and Bayley (1895, p. 540–544) for exposures in the Ajibik Hills northeast of Palmer, Mich., about 3½ miles south of the Negaunee quadrangle. The formation consists principally of vitreous gray quartzite but also contains conglomerate, slate, and graywacke. A thin bed of granules, overlain by distinctively crossbedded quartzite is near the base of the formation and is a distinct marker. The average thickness of the formation in the quadrangle is about 150 feet. Outcrops of the Ajibik Quartzite form conspicuous elongate hills that extend east from Teal Lake for only about 1¾ miles into the west half of sec. 32.

The quartzite consists of interlocking mosaics of quartz fragments 0.2–1.0 mm in size and averaging about 0.5 mm, rare clastic chert, and small amounts of sericite, zircon, tourmaline, and corundum. A thin film of hematite stain is common around many of the chert grains.

Jackson (1950) found detrital tourmaline to be more abundant in the lower than in the upper part of the Ajibik and zircon to be more abundant in the upper than in the lower part. He reported a few grains of gold 30 and 45 feet above the base of the formation about 90 feet east of U.S. Highway 41 in sec. 31, T. 48 N., R. 26 W., from a zone at the approximate stratigraphic position of the chert-granule marker bed. Sampling by geologists of the U.S. Geological Survey failed to find gold in this marker bed. Other heavy minerals reported by Jackson include chlorite, epidote, apatite, hyacinth, pyrite, pyrrhotite, galena, biotite, xenotime, and carbonate. He found that the Ajibik Quartzite differs from the Mesnard Quartzite by containing corundum, detrital rather than authigenic tourmaline, and hyacinth and malacon instead of only hyacinth.

White unstained spots conspicuously dot red quartzite in the east-west ridge north of county road 492 in sec. 31, T. 48 N., R. 26 W. The spots are evenly distributed, round to elongate, and ½–1 inch in diameter. Locally the spots weather out and appear to be pebbles. Close examination, however, reveals that they grade into the red quartzite and are not clasts. The spots are most abundant along the southeast of a northeast-trending fault across the ridge. The hematite staining evidently follows the fault, but the reason for the absence of staining in spots is unknown.

Another distinctive staining feature in the lower part of the Ajibik Quartzite in at least two localities is concentric dark bands of fine-grained manganese min-

TABLE 8.—*Chemical and semiquantitative spectrographic analyses of slates and chert breccia in Kona Dolomite*

[Rapid-rock analyses by P. L. D. Elmore, S. D. Botts, Lowell Artis, Hezekiah Smith, J. H. Glenn, James Kelsey, and Gillison Chloe, U.S. Geological Survey. Semiquantitative spectrographic analyses by W. B. Crandell, U.S. Geological Survey. Results of semiquantitative spectrographic analyses are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, ..., which represent approximate midpoints of interval data on a geometric scale. The assigned interval for about 30 percent of the semiquantitative results will include the quantitative value. Elements looked for but not detected in the semiquantitative spectrographic analyses: Ag, As, Au, Bi, Cd, Ce, Eu, Ge, Hf, Hg, In, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn. Dash leaders (........) indicate elements looked for but not detected]

	Slate below lower vitreous quartzite			Chert breccia unit above lower vitreous quartzite		Slate above chert breccia unit	
	1	2	3	4	5	6	7
Chemical analyses (weight percent)							
SiO_2	62.3	68.8	63.8	90.3	92.4	78.1	74.3
Al_2O_3	15.4	12.9	17.9	2.7	1.6	10.9	12.8
Fe_2O_3	5.5	9.3	6.9	3.4	2.7	3.2	4.3
FeO	.12	.24	.76	.16	.40	.20	.20
MgO	2.4	.99	1.2	.22	.30	1.0	.90
CaO	2.1	.89	.40	.36	.25	.36	.20
Na_2O	.10	.40	.20	....	....	.33	....
K_2O	6.5	4.0	5.2	.72	.23	3.2	4.1
H_2O-	.09	.06	.06	.03	.07	.03	.05
H_2O+	1.6	1.5	2.3	.53	.57	1.4	1.7
TiO_2	.78	.02	.76	.79	.66	.89	.68
P_2O_5	.17	.05	.11	.04	.08	.09	.14
MnO	.18	....	....	.06	....	....	....
CO_2	2.5	<.05	<.05	.05	<.05	<.05	<.05
Total	100	100	99	99	99	100	99
Semiquantitative spectrographic analyses (weight percent)							
B	0.02	0.003	0.003	0.015	....	0.007	0.003
Ba	.05	.015	.02	.003	0.007	.02	.02
Be	.00015	.00015	.0002	....	....	.00015	.00015
Co	.0015	.0005	.001	....	....	....	.0005
Cr	.007	.007	.007	.0007	.0003	.005	.005
Cu	.0003	.001	.0015	.0015	.002	.005	.0005
Ga	.0015	.001	.0015	....	....	.0007	.0007
La	....	.003	.005	....	....	....	....
Li	.01	....	....	....	....	....	....
Mo	.0003	.0005	.0003	....	....	....	.0003
Nb	....	.0003	.0003	....	....	....	.0003
Ni	.007	.003	.003	.001	.003	.002	.005
Pb	.0015	....	....	....	....	....	....
Sc	.001	.001	.0015	.0003	....	.0007	.0015
Sr	.002	.005	.0015	.0003	.0003	.0015	.001
V	.007	.01	.007	.002	.0015	.003	.005
Y	.0015	.0015	.003	....	....	.001	.0015
Yb	.00015	.00015	.0003	....	....	.0001	.00015
Zr	.02	.007	.015	.002	.0007	.01	.02

1. P–16–67. Lab. No. W169055. 4,500 ft north, 1,450 ft west of SE. cor. sec. 32, T. 48 N., R. 26 W.
2. P–19–67. Lab. No. W169058. 3,800 ft north, 3,250 ft west of SE. cor. sec. 32, T. 48 N., R. 26 W.
3. P–22–67. Lab. No. W169061. 3,150 ft north, 3,750 ft west of SE. cor. sec. 32, T. 48 N., R. 26 W.
4. P–17–67. Lab. No. W169056. 4,050 ft north, 1,700 ft west of SE. cor. sec. 32, T. 48 N., R. 26 W.
5. P–20–67. Lab. No. W169059. 3,700 ft north, 3,400 ft west of SE. cor. sec. 32, T. 48 N., R. 26 W.
6. P–18–67. Lab. No. W169057. 4,000 ft north, 1,700 ft west of SE. cor. sec. 32, T. 48 N., R. 26 W.
7. P–21–67. Lab. No. W169060. 3,650 ft north, 3,350 ft west of SE. cor. sec. 32, T. 48 N., R. 26 W.

erals and hematite such as on the north side of U.S. Highway 41 and northeast of the county road leading north from the Beverly Hills division of Negaunee. The largest ring is 4 feet in diameter, and the colored bands are 1–3 inches wide. They resemble liesegang rings and probably resulted from diffusion of the dark-colored minerals.

GRANULE MARKER BED

A unique granule bed about 10 inches thick and overlain by a zone of distinctively crossbedded quartzite about 4 feet thick is near the base of the Ajibik. The bed was deposited on a surface of slight relief on fine-grained quartzite. The granule bed and crossbedded quartzite can be traced along the entire length of the formation in the quadrangle and form a useful marker in defining structure and in differentiating the Ajibik from other quartzites.

The granule bed is a medium- to coarse-grained quartzite containing distinctive granules of pink ferruginous chert and granules of quartzite, vein quartz, and cherty sericitic rock (fig. 16). Grain sizes grade crudely upward from coarse to fine. Vein quartz pebbles, as much as 1 inch in diameter, and limonite stains can be found at the base of the bed. At a few places in the more western exposures and elsewhere, quartzite pebbles are heavily stained with limonite. The granule bed is grayish pink to pale yellowish green and weathers light brownish gray to pinkish gray. The conspicuous

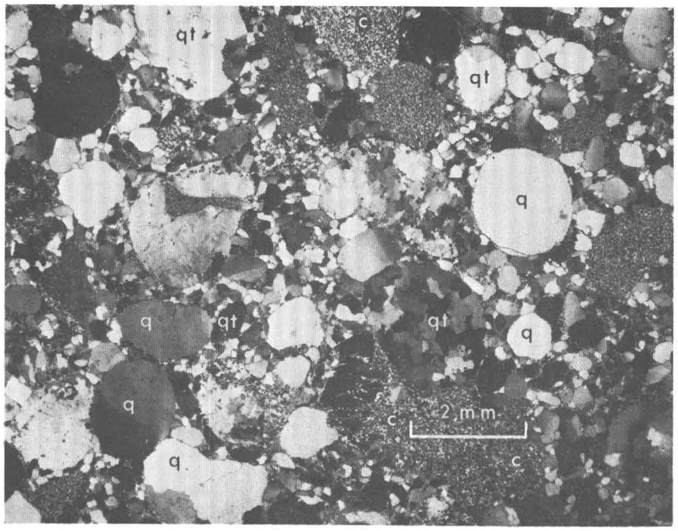


FIGURE 16.—Photomicrograph of chert-granule marker bed in the Ajibik Quartzite. Rounded granules of chert (c), quartzite (qt), and vein quartz (q). From near shore of Teal Lake, 1,650 feet east and 1,800 feet south of the NE. cor. sec. 36, T. 48 N., R. 27 W. Crossed polarizers.

chert granules are rounded to angular, bright pinkish orange to brick red, and constitute about 1 percent of the rock.

Granules are generally elongate, well rounded, and constitute 20–40 percent of the rock. Some 30–60 percent are composite grains, mainly quartzite. Some quartzite granules resemble chalcedonic chert nodules and perhaps have been derived from the Kona Dolomite.

About 4 feet of distinctively crossbedded reddish-brown medium-grained quartzite overlies the granule bed and grades upward into more evenly bedded quartzite. Differential iron staining increases the conspicuousness of the crossbedding. Quartz grains in this rock form an interlocking mosaic. Overgrowths are rare, sericite is sparsely present, and iron oxide stains many grains. Tourmaline and zircon are virtually the only accessory minerals. Crossbedding is different from that in other parts of the Ajibik. It is small-scale tabular high-angle planar cross-stratification (McKee and Weir, 1953) in which sets of strata are 3–5 inches thick and steeply inclined. The opposing inclination of adjacent sets of crossbeds produces a crude herringbone pattern. The distinctive crossbedding is a good guide to the underlying granule bed.

The granule bed is underlain by fine-grained gray quartzite that weathers pale yellowish brown. Interlocking mosaics of subangular to subrounded quartz grains have a matrix of sericite and minor zircon, tourmaline, and leucoxene. The quartzite below the granule bed is as much as 10 feet thick and grades downward into silty and sericitic slate.

The granule bed might be part of Seaman's conglomerate and slate unit at the base of the Ajibik (Van Hise and Leith, 1911, pl. XIX). As the bedding in the quartzite above and below the marker zone is parallel, there seems to be no reason to consider the locally conglomeratic granule bed as representing a major stratigraphic break. No conglomerate is known below the granule bed in the Ajibik Quartzite in the Negaunee quadrangle.

BASAL AJIBIK

Thin-bedded sericitic slaty graywacke and sericitic slate, less than 50 feet thick, grade up into the quartzite described previously and form the basal part of the Ajibik. Both east and west of U.S. Highway 41, the slate and graywacke beds are intricately folded; fold axes plunge gently to the southeast.

RELATION TO OTHER FORMATIONS

The contacts of the Ajibik Quartzite are not well exposed in the quadrangle. The Ajibik appears to be abruptly overlain by Siamo Slate. Maps of the old Maas mine indicate thick beds of quartzite near the base of the Siamo Slate. Slate correlated with the Siamo crops out a few tens of feet south of the ridge of Ajibik Quartzite on the northeast shore of Teal Lake in the NE¼ sec. 36, T. 48 N., R. 27 W., indicating virtually no gradation there from the Ajibik to the Siamo. East of U.S. Highway 41, the Ajibik and Siamo are separated by a covered interval about 200 feet wide in which the two formations could be interbedded.

The relation between the Ajibik Quartzite and older formation is complicated by pre-Ajibik folding and erosion and by post-Ajibik faulting. Furthermore, the slate in the lower part of the Ajibik is similar to, and likely to be confused with, slates in underlying formations.

The marker bed in the Ajibik extends from U.S. Highway 41 to the northeast shore of Teal Lake and shows that the Ajibik cuts across older formations so that it overlies sheared Mona greenstone at the lake.

An east-west ridge of Ajibik Quartzite lies south of folded beds of the Kona Dolomite in sec. 32, T. 48 N., R. 26 W. (pl. 2). In the eastern part of sec. 31, massive quartzite occurs north of the same east-west ridge of Ajibik Quartzite. The massive quartzite is correlated here with the Ajibik because it is the southeasterly projection of Ajibik Quartzite northwest of U.S. Highway 41, and the marker bed can be traced through part of it. Some of the massive quartzite, however, might be part of the Kona Dolomite or Mesnard Quartzite. The valley along the north side of the east-west ridge marks a fault or an unconformity, or both.

The Ajibik Quartzite overlaps increasingly older rocks between sec. 32 and Teal Lake, as shown above, suggesting a regional unconformity at the base of the Ajibik. The Kona Dolomite and older beds apparently were folded prior to deposition of the Ajibik Quartzite. Folding after Ajibik time and faulting that has duplicated Ajibik west of U.S. Highway 41 have further complicated the structure. The Ajibik east of sec. 32 presumably is underlain by Wewe Slate, as in the Marquette quadrangle to the east. The unconformity at the base of the Ajibik apparently truncates the Wewe and explains its absence west of sec. 33. Faulting along the base of the Ajibik Quartzite (pl. 2) also could be responsible for the truncation of the Wewe.

Tyler and Twenhofel (1952, p. 26) questioned the presence of an unconformity at the base of the Ajibik Quartzite and stated that the Kona Dolomite and the Wewe Slate grade laterally into Mesnard Quartzite, such that in the Teal Lake area, the quartzite mapped as Ajibik may represent Mesnard, Kona, Wewe, and Ajibik time. Tracing the marker bed in the Ajibik Quartzite conclusively proves that the Ajibik Quartzite cuts the Mesnard and Kona west of U.S. Highway 41 and the Kona and possibly the Wewe east of the highway. If the truncation is essentially a result of faulting, however, the evidence is inconclusive as to whether or not the Ajibik Quartzite is the western equivalent of Mesnard, Kona, and Wewe.

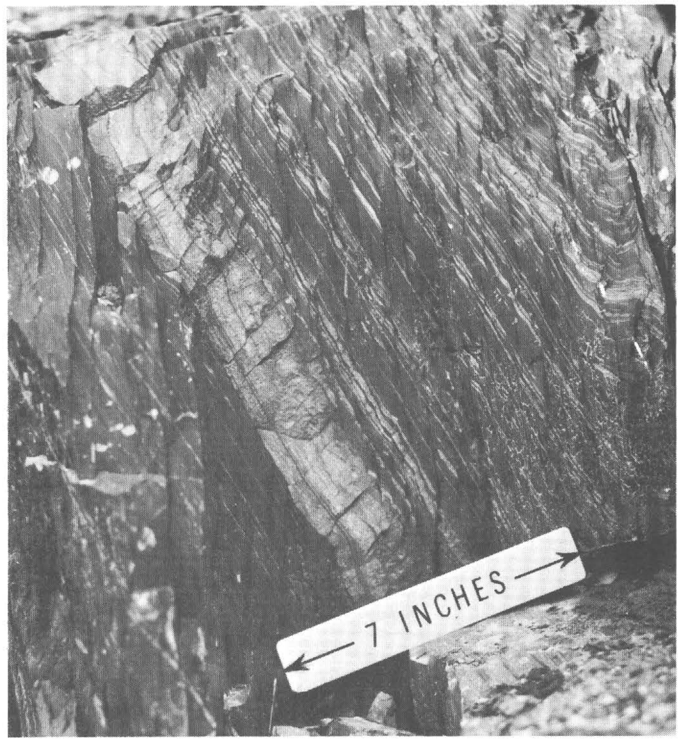


FIGURE 17.—Siamo Slate in roadcut on south side of U.S. Highway 41 in NW¼SE¼ sec. 31, T. 48 N., R. 26 W. Conspicuous near-vertical cleavage in slate does not cut graywacke bed.

SIAMO SLATE

The Siamo Slate was named for exposures between the Ajibik Quartzite and the Negaunee Iron-formation on Siamo Hill, about 2 miles west of the quadrangle (Van Hise and Bayley, 1895, p. 554). Rocks assigned to the Siamo typically are dark-colored slate but include graywacke, quartzite, feldspathic quartzite, and conglomerate. The Siamo Slate underlies a belt about 2 miles wide across most of the southern part of the quadrangle.

Slate is the most abundant rock in outcrop. It consists of alternating dark-gray sericitic-chloritic rock and light-gray sericitic quartz-rich siltstone. Layers are paper thin to nearly half an inch thick; the thicker layers commonly contain wisps and lenses of rocks of contrasting lithology (fig. 17). Boundaries between contrasting lithologic units are sharp at most places, gradations being known only on the northeast shore of Teal Lake in the NE¼ sec. 36, T. 48 N., R. 27 W. Slaty cleavage is conspicuous in all outcrops and commonly is steeper than bedding.

Fine-grained beds in the slate are a mixture of sericite, chlorite, and angular quartz grains generally less than 0.04 mm across. Shreds of muscovite, detrital and authigenic(?) tourmaline, and pyrite are common accessories. Much of the slate contains abundant tiny flecks of a brown opaque mineral that probably is oxidized siderite and obviously helps darken the slate. Well-defined lamination caused by parallelism of aggregates of sericite and chlorite commonly is at an angle to bedding and is parallel to the slaty cleavage.

Siltstone layers in the slate consist of angular quartz grains, rarely larger than 0.1 mm across, set in a fine-grained matrix of sericite and siderite, muscovite, tourmaline (authigenic?), and a red opaque mineral (probably oxidized carbonate). Quartz grains show little rounding, and many have been corroded by clay minerals.

The graded beds in the NE¼ sec. 36, T. 48 N., R. 27 W., consist, from the base upward, of a silty zone about 1 mm thick and a zone about 4 mm thick of increasingly finer grained sericitic and chloritic material. In this rock, slaty cleavage conspicuously crosses the silty graded beds, whereas no cleavage is evident in silty ungraded layers.

Gray-green, tan- to pink-weathering beds of graywacke or quartzite, a few inches to more than 10 feet thick, are within the slates. In general, internal bedding is not present, and the cleavage of the slates does not cut the coarse-grained rock. The rock is moderately well sorted; it is composed of subrounded to angular quartz grains 0.2–0.6 mm across, angular feldspar grains 0.1–0.2 mm across, rare chert pebbles, a few quartzite pebbles, and scattered slate fragments in a matrix of sericite, chlorite, and rare tiny carbonate grains. Tourmaline and zircon are common. Boundaries of quartz and feldspar grains are ragged where corroded by sericite-chlorite matrix. Several thin sections of the rock contain 60–90 percent detrital quartz, 1 percent chert, 5 percent or less feldspar, and 10–15 percent matrix.

The carbonate-rich layers in the Siamo have an unusual texture consisting of narrow, curved, shardlike fragments of quartz and angular feldspar and muscovite 0.1–0.2 mm in diameter, dispersed in a carbonate matrix forming about 50 percent of the rock. Dark prismatic carbonate patches within the carbonate appear to be pseudomorphs of rock fragments. Wisps of chert and sericite or kaolinite occur throughout the carbonate. The carbonate thus appears to have replaced finer grained material and has corroded many quartz grains.

Medium- to coarse-grained greenish-gray feldspathic quartzite crops out along the west boundary of sec. 2, near the south boundary of the quadrangle, and in the railroad cut about 1,000 feet east of the west border of sec. 4. The rock, firmly cemented, is composed of subrounded to well-rounded quartz grains 0.4–1.5 mm across, fresh microcline as much as 1.6 mm long, sericitized plagioclase 0.4–0.6 mm across, sparse chert pebbles as much as 1.8 mm across, and a matrix of sericite and chlorite. The quartz forms about 80–90 percent, the feldspar 3–8 percent, and the matrix 5–10 percent of the rock.

Beds of conglomerate as much as 9 inches thick are exposed for about 100 feet in the railroad cut in the NW¼ sec. 4, T. 47 N., R. 26 W., and grade into the feldspathic quartzite described previously. The conglomerate is composed of glassy quartz grains, one-half inch or less in diameter, angular pink and white feldspar grains averaging about one-fourth inch in size, and rare fragments of granitic rock less than one-half inch in diameter.

Beds of ferruginous and clear chert, generally less than 1 inch thick, occur in upper Siamo Slate in the axial part of the Eagle Mills syncline at the east end of the railroad cut in the NW¼ sec. 4, T. 47 N., R. 26 W., south of Carp River in the SE¼ sec. 33, T. 48 N., R. 26 W., and in the NW. cor. sec. 4, T. 47 N., R. 26 W. The ferruginous material is oxidized siderite and a dark-brown silicate, probably minnesotaite. The ferruginous chert may belong to a gradational zone in the Siamo beneath the Negaunee Iron-Formation, seen in drill core and iron mines.

Pyrite is common in the SE¼ sec. 33 and the SE¼ sec. 35, T. 48 N., R. 26 W., and in the NE¼ sec. 3, T. 47 N., R. 26 W. Magnetite occurs in slate on the ridge north of Carp River in secs. 33 and 34.

An unexposed magnetic unit about 500–1,000 feet above the base of the Siamo, and here correlated with the Goose Lake Member (Tyler and Twenhofel, 1952, p. 118–125), was traced by magnetometer from the east border of the quadrangle to near the center of sec. 34, T. 48 N., R. 26 W., and across the east end of Teal Lake.

CLASTIC DIKES

Clastic dikes in the Siamo Slate are exposed in the roadcut on the south side of U.S. Highway 41, SE¼ sec. 31, T. 48 N., R. 26 W., on the west end of the hill south of the railroad in the NE¼ sec. 4, and in the railroad cut in the NW¼ sec. 4, T. 47 N., R. 26 W. In the NE¼ sec. 4, protuberances extend from layers of graywacke, about 1½ inches thick, into and across adjacent beds of the slate and resemble distorted mudcrack fillings (Shrock, 1948, p. 204, fig. 163). In the NW¼ sec. 4, a clastic dike, 1–3 inches thick, cuts across ferruginous chert about 3 feet thick. In the roadcut on U.S. Highway 41, dikes generally are lenticular, a few inches or less thick, and subparallel to cleavage of the slate. Some dikes lie at an angle to both the cleavage and bedding, and some, though crenulated like ptygmatic folds, cut across evenly dipping beds (fig. 18). No connection between the dikes and a possible source is seen in the roadcut.

The material in the clastic dikes is similar to that in graywacke beds in the slate. Detrital quartz, chert, and feldspar are surrounded by a sericitic chloritic matrix. Iron-rich carbonate forms as much as 60 percent of some of the dikes (Powell, 1969, p. 2589).

Sandstone dikes in the Ordovician Martinsburg Formation in northeastern Pennsylvania also parallel cleavage at an angle to bedding (Maxwell, 1962, p. 287). Maxwell postulated that at the onset of folding in the Martinsburg, fluid sand-water mixtures were extruded from sand beds to positions parallel to newly developed cleavage. The clastic dikes in the Siamo Slate could have formed similarly.

Powell (1969, p. 2589–2593) emphasized that the high carbonate content of the Siamo dikes prevented or destroyed quartz overgrowths and quartz cement that could have prevented mobilization. When high pore pressures developed, during late diagenesis, the mobilized carbonate-rich sandstone intruded into and across adjacent beds, in some places forming dikes parallel to newly formed cleavage.

NEGAUNEE IRON-FORMATION

The Negaunee Iron-Formation underlies an area of about 2 square miles in the southwest part of the quadrangle but is exposed only in a few places. Most of the knowledge about the formation has been obtained from diamond-drill cores and mines.

According to Van Hise and Leith (1911, p. 263), the Negaunee Iron-Formation is composed of sideritic

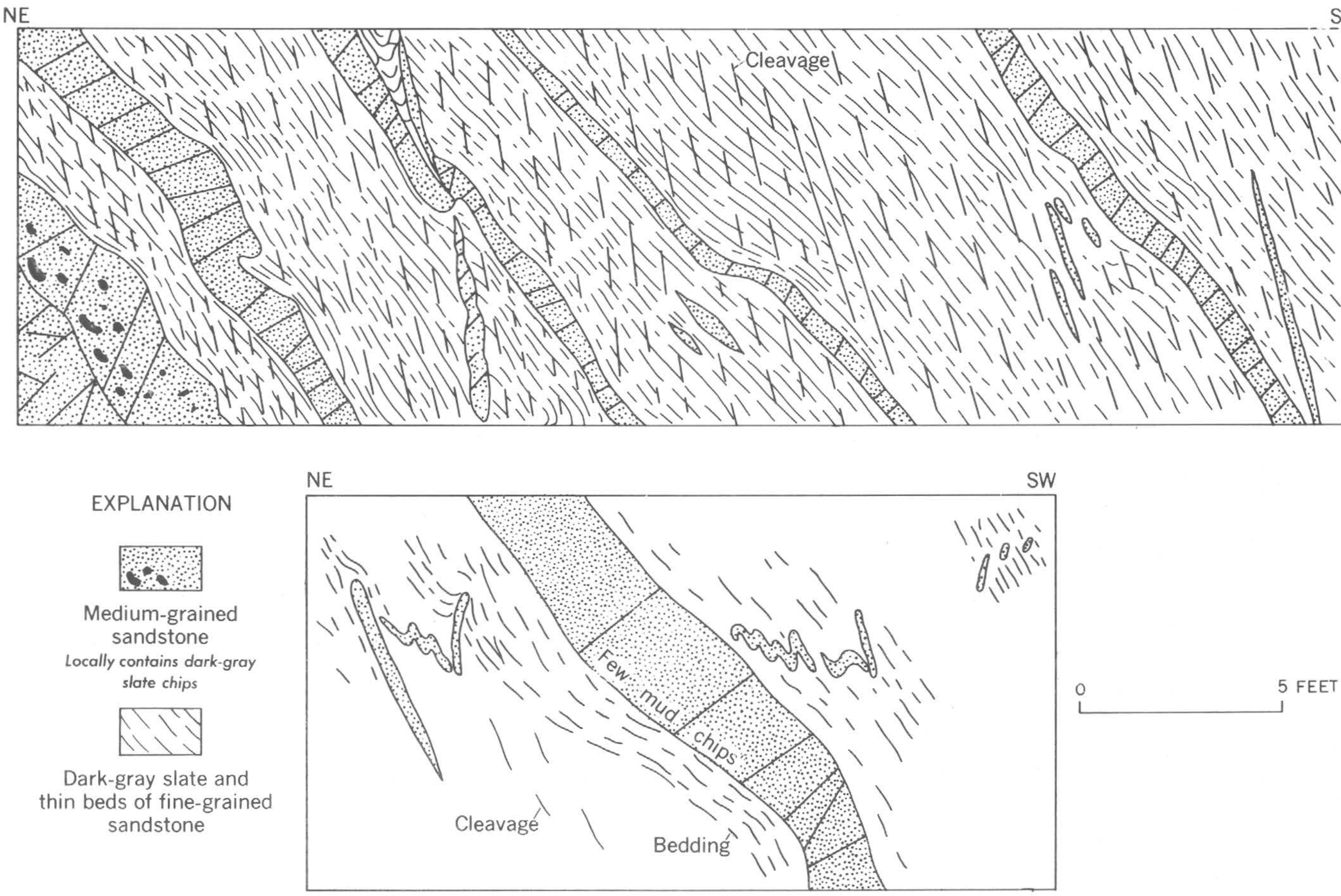


FIGURE 18.—Sandstone dikes in Siamo Slate; roadcut on south side of U.S. Highway 41, SE¼ sec. 31, T. 48 N., R. 26 W.

slate, which may be gruneritic, magnetitic, hematitic, or limonitic, grunerite-magnetite schist, ferruginous chert, jaspilite, and iron ore. Tyler and Twenhofel (1952, p. 128) divided the formation into (1) siderite and chert with subordinate iron silicate and iron oxides, (2) magnetite, grunerite, stilpnomelane, minnesotaite, chlorite, siderite, and chert, and (3) hematite, goethite, martite, specularite, and chert. The first division was considered to represent the original formation, the second to have developed by regional and thermal metamorphism, and the third to be a result of oxidation and leaching. The maximum thickness of the formation in the Ishpeming-Negaunee area is 2,000 feet or more (Tyler and Twenhofel, 1952, p. 130).

The formation is characterized by parallel laminae and beds of chert, chert with sparse iron minerals, iron minerals with sparse chert, and iron minerals. Chert-rich layers, paper thin to one-fourth inch thick, appear to predominate except in areas of ore. The iron-rich beds range from discontinuous wisps to well-developed layers 1–10 mm thick.

Chert layers are granoblastic mosaics of interlocking grains, 0.02–0.04 mm in size, but include quartz grains 0.1–0.15 mm across that may be clastic. A few widely scattered quartz grains, 0.1–0.15 mm across, have not been recrystallized to or replaced by chert. Dusty ghostlike rounded pebbles as much as 1.5 mm across can be seen in some chert layers under the microscope using plane-polarized light but disappear under crossed polarizers because of recrystallization. Presumably the pebbles originally were quartz grains. Rare beds, 1/16–3/8 inch thick, appear to have formed from fine- to medium-grained clastic material; some of these grade crudely upward into what is now fine-grained iron-rich rock. Five such beds occupy one interval of about 1½ inches in a core from the Mather mine B.

Euhedral crystals of siderite(?) are scattered through chert, and mixtures of siderite(?), hematite, magnetite, and goethite form well-defined layers. The iron minerals generally are 0.004–0.02 mm in size—about half the size of chert grains. Probably most of the iron minerals originally were siderite deposited at the same time as the chert; layering is due to a systematic variation of the relative amounts of chert and iron deposited. The hematite and magnetite developed during metamorphism and oxidation of the formation. In the

Negaunee quadrangle, the iron-formation has been strongly oxidized with resultant leaching of the silica and concentration of the secondary hematite and goethite.

Iron-formation composed mainly of red chert and gray hematite (jaspilite) is exposed southwest of the Mather mine B shaft in sec. 1, T. 47 N., R. 27 W. Chert-hematite veins, as much as 3 inches thick, cut the beds. Bedding locally is contorted and brecciated. Parts of the rock are magnetic.

In addition to chert and iron minerals, the iron-formation contains dickite and kaolinite (Gruner, 1946, p. 195; Bailey and Tyler, 1960, p. 172), gypsum, and calcite. The dickite is white, silky, and cements soft earthy hematite breccia; the kaolinite occurs in pockets in dense specularite ore. Secondary carbonate minerals are common; T. M. Han (oral commun., 1967) found that this later carbonate is richer in lime than the original carbonate and replaces preexisting chert, siderite, and other minerals.

There is abundant evidence in the drill cores that iron minerals have been redistributed along fractures cutting the beds and have replaced chert and chert-rich beds (fig. 19). The leaching of chert and replacement of chert by redistributed iron minerals have progressively enriched the original rock in iron, in some places enough to constitute direct shipping ore. Locally, and near the base of the formation, original layering has been obliterated, leaving only wisps of badly corroded chert as evidence of former chert layers.

The thickness of the Negaunee Iron-Formation in the Negaunee quadrangle is known only within rather wide limits. Maps of the Mather and Maas mines indicate a gradational zone between the iron-formation and underlying Siamo Slate in which layers of iron ore, 20–30 feet thick, alternate with typical Siamo Slate through a thickness of some 100 feet. The overlying formation is not present, and it is not known if the top of the formation is in the quadrangle. Normal faults are common with the south side downdropped and have caused apparent variations in thickness. Van Hise and Leith (1911, p. 264) and Tyler and Twenhofel (1952, p. 130) suggested a thickness of 1,000 to more than 2,000 feet. Anderson (1968, p. 510) reported that the formation thickness exceeds 2,000 feet in the Negaunee-Ishpeming area. Cross sections through the Mather mine (pl. 4) indicate that the formation is more than 2,400 feet thick and may be as thick as 3,000 feet.

The iron-rich and silica-rich sediments of the Negaunee Iron-Formation are mainly chemical sediments that, according to James (1966, p. W49–W51), were deposited in shallow troughs adjacent to long-exposed low-lying land masses during intervals in which

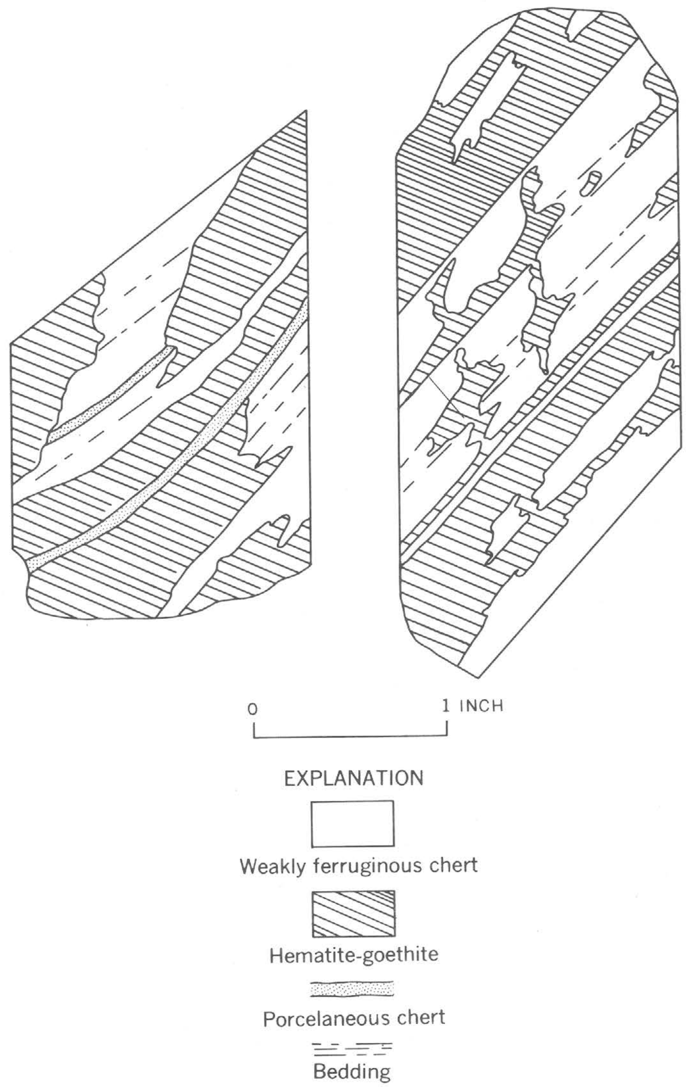


FIGURE 19.—Diamond-drill core of Negaunee Iron-Formation showing pattern of replacement of rock by iron minerals. Much of replacement took place after folding, for iron-rich streaks cut bedding at high angle.

there was neglible contribution of clastic material to the sea. Very stable structural conditions must have prevailed for long periods for the great thickness of iron-formation to develop.

BARAGA GROUP

MICHIGAMME SLATE

DISTRIBUTION, GENERAL DESCRIPTION, STRUCTURE, AND THICKNESS

The Michigamme Slate crops out in the area north and west of the Dead River pluton and south of the sheared rhyolite tuff member of the Mona Schist in the Dead River and McClure Storage Basins. Part of the formation in the W$\frac{1}{2}$ sec. 17 and E$\frac{1}{2}$ sec. 18 was drilled about 50 years ago; logs and a skeletonized drill core helped in extending units exposed only in the central part of sec. 15. A thin magnetite-rich argillite was traced by magnetometer.

Basal conglomeratic quartzite of the Michigamme rests unconformably on the Dead River pluton and Nealy Creek Member of the Mona Schist and is overlain by thin-bedded graywacke containing a magnetite-rich argillite zone, chert-goethite-hematite iron-formation, chert conglomerate, and pyritic and carbonaceous metasiltite and slate (fig 20). Some graywacke beds are carbon rich.

The Michigamme through much of its extent forms a simple homoclinal sequence of beds dipping moderately to steeply north but is folded into a northwest-plunging syncline in the western part of sec. 14, T. 48 N., R. 26 W. Some slate along the county road in the NW¼ sec. 16 shows a reversal of dip, which suggests local folding. Intricately folded slate is exposed north of the east footing of the Hoist Dam in the SW¼ sec. 9. Cleavage commonly dips more steeply north than bedding but locally dips to the south. Basal Michigamme quartzite cannot be traced north across the axial part of the syncline in sec. 14 and perhaps is truncated by faulting.

The thickness of the Michigamme Slate in the quadrangle can be determined only within wide limits. The formation up to and including the chert-conglomerate above the iron-formation is 1,500–2,000 feet thick. The area of the formation broadens, and the unit above the chert conglomerate may thicken westward. The upper limit of the formation is a fault along the south boundary of the sheared felsic tuff. Assuming a homoclinal sequence, the formation is 4,500–5,000 feet thick at the west edge of the quadrangle.

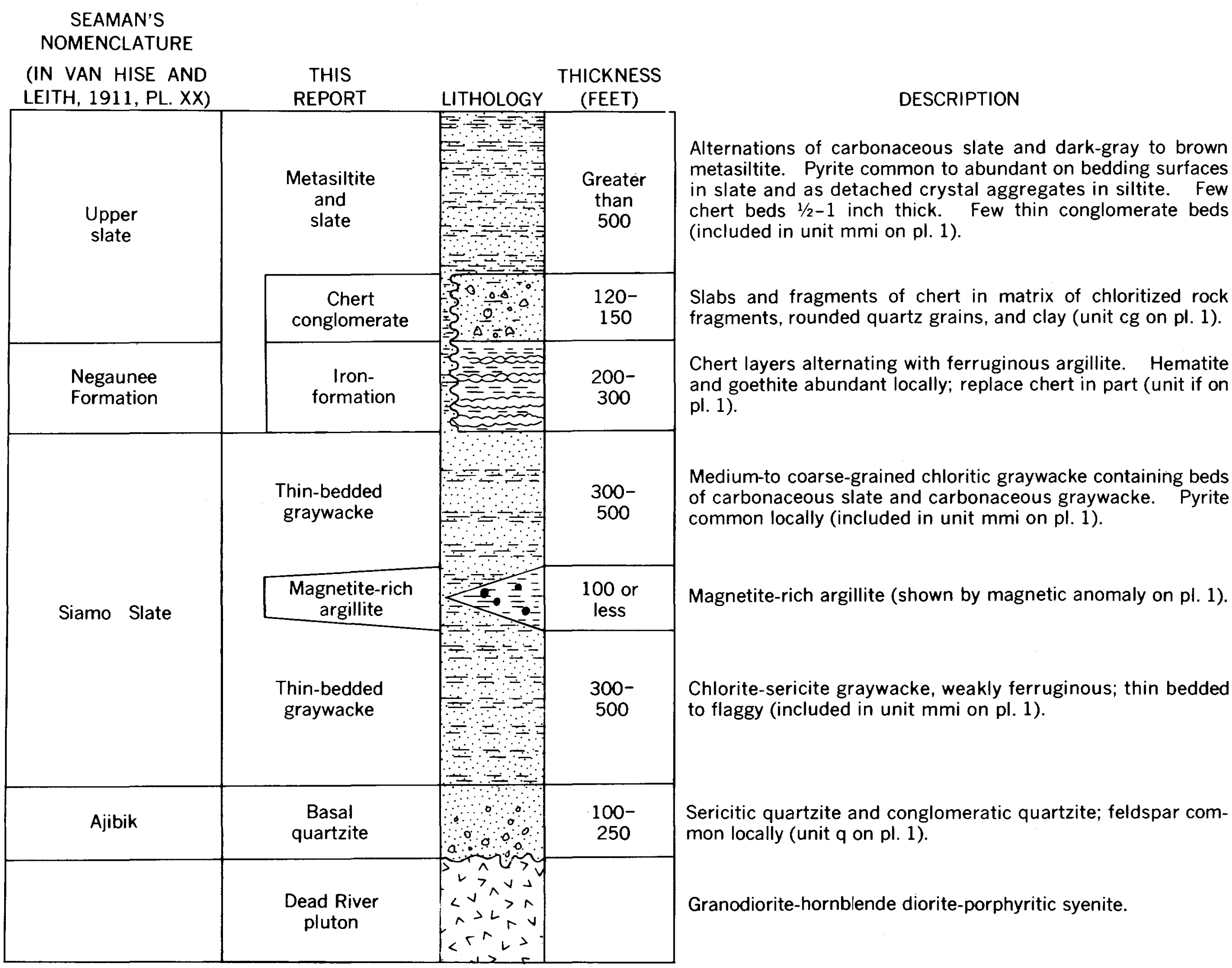


FIGURE 20.—Generalized columnar section of the Michigamme Slate, Dead River basin.

BASAL QUARTZITE

Feldspathic, sericitic, and locally conglomeratic quartzite is exposed near the mapped unconformable contact with the Dead River pluton and older rocks, in sec. 13, T. 48 N., R. 27 W., and to the east in the west-central part of sec. 14, T. 48 N., R. 26 W. The average thickness of the unit is about 200 feet.

The quartzite is grayish but in the western part of the quadrangle is speckled by pink- to cream-colored feldspars. Coarse clasts of vein quartz, slate, and granite rock as large as 1½ inches are present in and west of sec. 18 and in sec. 14, T. 48 N., R. 26 W. Crossbedding is conspicuous in outcrops in the eastern part of sec. 13, T. 48 N., R. 27 W.

In addition to quartz, the rock contains 2–4 percent microcline, 3–10 percent chert pebbles, 5–7 percent rock fragments, and 5–10 percent sericitic matrix, plus zircon, tourmaline, and leucoxene. The rock is poorly sorted; detrital grains and rock fragments are 0.5–8.0 mm in size. Rare chloritized clasts probably were hornblende or other mafic minerals. East of sec. 17, T. 48 N., R. 26 W., the quartzite is finer grained.

The quartzite on the northeast side of the McClure Storage Basin in sec. 14, T. 48 N., R. 26 W., is underlain by beds of sericitic slaty graywacke, exposed at the water's edge near the mouth of the south-flowing tributary 1,200 feet west of the center of sec. 14 and on top of the hill in the SW¼NW¼ sec. 14.

The absence of quartzite north of the hill in the SW¼NW¼ sec. 14 and the narrow, deep ravine trending east-northeast between outcrops of granodiorite about 1,000 feet east of the quartzite-topped hill suggest an east-northeast-trending fault. A linear negative magnetic anomaly that extends east-northeast from the quartzite hill to the narrow ravine may represent a diabase dike along a fault.

THIN-BEDDED GRAYWACKE, METASILTITE, AND SLATE

Thin-bedded dark-gray to reddish-brown iron-stained graywacke, about 500 feet thick, overlies the basal quartzite gradationally and includes magnetic argillite that will be described separately.

Fine-grained graywacke beds, 2–10 mm thick, alternate with laminated clay-rich rock of lesser or greater thickness. Quartz grains, 0.1–0.3 mm in diameter, locally have overgrowths; quartz is in thin shreds in the clay-rich beds. Elongate, moderately well rounded feldspar grains, mainly microcline, less than 0.33 mm in diameter, constitute 5–10 percent of the rock. Magnetite and hematite are more abundant in the clay-rich layers in the coarser grained rock. Chlorite is common. Accessory minerals include tourmaline, zircon, and carbonate. Yellowish-brown flakes of mica are conspicuous on weathered surfaces. Carbon darkens some of the rock in the NE¼SW¼ sec. 15.

Slate and metasiltite underlie much of the Dead River Storage Basin in an area that widens from about 1,500 feet in the north-central part of sec. 15 to more than 6,000 feet at the west boundary of the quadrangle. Outcrops are few, widely separated, and generally small. Most outcrops are near the crest of hills, in beds of streams, or in manmade excavations. The largest is at the spillway of Hoist Dam in the NW¼ sec. 16.

The slate and metasiltite are thin bedded, medium gray to dark gray, and locally tinged red to yellowish brown by iron stain. Bedding tends to be obscure and is manifest more by coloration than by differences in grain size. Darker rocks are carbonaceous, and some are graphitic. Pyrite is common in the more carbonaceous rocks and forms seams as much as 5 mm thick parallel to bedding. Chert layers are present in some outcrops. Conspicuous slaty cleavage crosses the bedding at a high angle in most outcrops.

Near the center of sec. 16, T. 48 N., R. 26 W., is a sequence typical of exposed parts of the formation. Porcelaneous rock containing a 2½-cm layer of silty material is overlain by a 10–15-mm bed of massive fine-grained black carbonaceous rock, and this rock is overlain by alternating light- and dark-gray beds, 1–2 mm thick. The less-carbonaceous rock weathers gray to pinkish brown.

The slate bordering the spillway of the Hoist Dam in the NW¼ sec. 16, T. 48 N., R. 26 W., is gray and dark gray and occurs in silty and clay-rich carbonaceous and noncarbonaceous layers that range in thickness from paper thin to more than 1 inch. Silty layers contain angular and shardlike particles of quartz. Pyrite is common in silty beds. The outcrops are splotched by a film of red, brown, and yellow stain resulting from oxidation and hydration of iron minerals.

Most of the quartz grains in the silty bands are subequant and angular, ranging from 0.1–0.2 mm across. Many quartz grains, however, are elongate and somewhat curving, similar to shards; this suggests that they were originally glass fragments. Fine-grained volcanic material might have been added to the slate-forming sediments. The sharp boundary between layers of distinctly differing grain size further suggests a blanket-type deposition that would result from ash fall.

Detrital grains other than quartz are shreds of muscovite and discrete subequant masses of clay that might originally have been feldspar grains. A few grains of feldspars are present in some sections.

CARBONACEOUS GRAYWACKE

Carbon in graywacke along and south of the road in the S¼ sec. 15, T. 48 N., R. 26 W., pervades much of the matrix and possibly masks clay. Leucoxene is conspicuous.

Carbon is abundant in graywacke on the northwest bank of the north-flowing stream about 400 feet south of the east-west county road in the SW¼ sec. 15; 8.74 percent total carbon includes 8.7 percent that is organic (table 9). Carbonaceous graywacke located about 650 feet south of the road contains 1.58 percent total carbon and organic carbon is 1.5 percent. The rocks also contain comparatively large amounts of V_2O_5 (table 9).

TABLE 9.—*Carbon content of graywacke from Michigamme Slate*

[Total carbon determined by induction furnace, mineral carbon gasometrically, and organic carbon by difference, by I. C. Frost; V_2O_5 determined colorimetrically by E. J. Fennelly. Both samples from along bank of north-flowing small stream in NE¼SW¼ sec. 15, T. 48 N., R. 26 W.]

Sample No.		Carbon (percent)			V_2O_5
Serial No.	Field No.	Total	Mineral	Organic	(percent)
D127537	P-157-64	8.74	0.03	8.71	0.10
D127538	P-159-64	1.58	.04	1.54	.085

Dark-gray carbonaceous rock below the ferruginous chert zone in a diamond-drill hole in the SW¼ sec. 17, T. 48 N., R. 26 W., correlates roughly with the carbonaceous graywacke in the SW¼ sec. 15, showing that the carbonaceous zone is at least 2 miles long.

The presence of carbon in much more than trace amounts is one of the main reasons for assigning these rocks to the Michigamme Slate. No carbonaceous rock is known in older rocks of the Marquette Range Supergroup. Van Hise and Bayley (1897, p. 453) described similar rocks in the Michigamme Slate north of Champion, Mich., about 20 miles to the west as follows: "The coarser-grained graywackes contain comparatively little feldspar and a small amount of interstitial material. They are largely cemented by enlargement. They therefore approach quartzite. They are, however, always discriminated from the quartzites of the Ishpeming Formation by the presence of black carbonaceous material between grains." Van Hise and Bayley also mentioned (1897, p. 454) an association of ferruginous chert and carbonaceous rocks.

The source for the carbon in the graywacke is not known. Carbonaceous slate higher in the Michigamme is typically euxinic, very fine grained, and rich in pyrite. The distribution of carbon in the graywackes in thin films around coarse quartz grains and as pervasive "replacements" of the matrix suggests that it has been introduced into the rock. The bulk of the carbon is obviously from organisms, but what type is not known. Ovoid features in the overlying iron-formation might represent organisms present shortly after deposition of the carbonaceous graywacke (fig. 22).

MAGNETITE-RICH ARGILLITE

Magnetite-rich argillite occurs from 300 to 500 feet above the basal quartzite, producing a magnetic anomaly discovered during a ground-magnetometer survey of the area (pl. 1). The argillite crops out on the south side of the county road about 1,000 feet east of the west edge of sec. 18, near the top of the steep slope on the boundary between secs. 17 and 18, and near the center of the SE¼ sec. 15, T. 48 N., R. 26 W., and the anomaly extends from the west boundary of the quadrangle to the SE¼ sec. 15. The full thickness of the argillite is unknown, but outcrops and magnetic data suggest about 100 feet.

The magnetic rock is fine grained, firmly cemented, indistinctly bedded, dark gray to purplish gray, and breaks with a conchoidal fracture. Tiny magnetic crystals are abundant. The rock is composed mainly of sericite but also contains angular quartz grains, less than 0.04 mm across, shreds of muscovite and biotite or stilpnomelane, and some layers of feldspathic, sideritic graywacke 0.5–2.0 mm thick.

Two analyzed samples of the magnetic argillite (table 10) are from outcrops nearly 1 mile apart; the nearly identical results suggest a uniform composition for the unit. The total iron is 12.1–12.2 percent, and the calculated magnetite is 16–17 percent. The high values for K_2O and the low percentages of MgO, CaO, and Na_2O reflect the sericitic content and scarcity of chlorite. The marked predominance of ferric to ferrous oxide, together with the lack of sodium oxide and potassium oxide, suggests that the argillite was deposited in an oxidizing environment from materials that had been well weathered. The well-developed crystals of magnetite, the scarcity of clastic quartz, and the rich argillaceous matrix rule out a black sand origin and indicate that the magnetite was recrystallized from preexisting iron-rich minerals during low-grade regional metamorphism.

IRON-FORMATION

Iron-formation, consisting of bedded chert-goethite-hematite with interbedded red and gray ferruginous argillite, crops out north of the east-west county road in the NE¼SW¼ sec. 15, T. 48 N., R. 26 W. (figs. 21, 22).

Chert layers 6–15 mm thick and goethite-hematite layers 2–5 mm thick form beds 1–5 inches thick. Argillite beds are paper thin to about 1 inch thick. Beds

TABLE 10.—*Chemical and semiquantitative spectrographic analyses of magnetite-rich argillite in the Michigamme Slate*

[Rapid-rock analyses by P. L. D. Elmore, S. D. Botts, Gillison Chloe, Lowell Artis, J. H. Glenn, Hezekiah Smith, and Dennis Taylor, U.S. Geological Survey. Semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey. Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, ..., which represent approximate midpoints of interval data on a geometric scale. The assigned interval for about 30 percent of the semiquantitative results will include the quantitative value. Elements looked for but not detected in the semiquantitative spectrographic analyses: As, Au, Bi, Cd, Ce, Ge, Hf, Hg, In, Li, Nb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn. Dash leaders (........) indicate element looked for but not detected]

	1	2
Chemical analyses (weight percent)		
SiO_2	58.4	57.3
Al_2O_3	14.2	14.0
Fe_2O_3	11.3	11.0
FeO	5.6	6.0
MgO	1.7	1.7
CaO	.26	.34
Na_2O	.00	.03
K_2O	5.7	6.1
H_2O-	.15	.12
H_2O+	1.7	1.9
TiO_2	.59	.59
P_2O_5	.12	.19
MnO	.07	.02
CO_2	.09	.05
Total	100	99
Semiquantitative spectrographic analyses (weight percent)		
Ag	....	0.0001
B	0.003	.003
Ba	.05	.05
Be	....	.0001
Co	.002	.001
Cr	.015	.015
Cu	.007	.007
Ga	.0015	.0015
La	.005	.005
Mo	.0007	.0007
Ni	.002	.002
Pb	....	.0015
Sc	.0015	.0015
Sr	.005	.005
V	.005	.01
Y	.002	.002
Yb	.0003	.0003
Zr	.02	.02

1. P–169–65. Lab. No. 166031. 1,750 ft north, 150 ft east of SW. cor. sec. 17, T. 48 N., R. 26 W.
2. P–180–65. Lab. No. 166032. 2,550 ft north, 1,000 ft east of SW. cor. sec. 18, T. 48 N., R. 26 W.

are tightly folded in some outcrops. Fingerlike projections of iron minerals locally replace the chert at nearly right angles to bedding. If the orientation of the replacements was controlled by gravity, replacement must have occurred prior to folding. The approximate thickness of the unit is 200–300 feet.

The mapped extension of the iron-formation westward from section 15 is based on sparse evidence. The core below conglomeratic rock from the diamond-drill hole in sec. 17 has been removed but is presumed to have been iron-formation. The missing interval is about 200 feet long, and this compares closely with the estimated thickness of the iron-formation. In the brief logs available for the core from the hole drilled in sec. 18, jasper was recorded from a depth of 35 feet, the top of bedrock, to 175 feet. This interval, too, is about the right length and position for the iron-formation. Boulders of ferruginous chert were found west of sec. 15, in an area underlain by the Dead River pluton near the crest of a northeast-trending hill in the SE¼ sec. 16. The roots of an upturned tree carry chips of iron-formation, and a prospect dump contains boulders of iron-formation. A westward extension of the iron-formation in sec. 15 is the most likely source of these glacially transported pieces of iron-formation. The unit cannot be traced east of the central part of sec. 15.

CHERT CONGLOMERATE

The conglomerate above the iron-formation in the Michigamme consists of slabs and rounded fragments of gray nonferruginous chert, as much as 1 foot in maximum dimension, in a matrix of dark-gray-green coarse-grained graywacke. Outcrops are confined to the SE¼NW¼ sec. 15, T. 48 N., R. 26 W., near county road 510 (fig. 21). Boulders of the conglomerate are common west of sec. 15, the conglomerate was intersected by the diamond-drill hole in sec. 17, and conglomerate is exposed on the north side of the county road in sec. 13 a few hundred feet west of the quadrangle. Exposures of the conglomerate east of the outcrops in sec. 15 are unknown. The mapped width of the conglomerate in sec. 15 is 150 feet; assuming an average dip of 65° N., the thickness is 140 feet. The conglomerate is unconformable on the folded iron-formation. The upper contact is not exposed but seems to be gradational through a thickness of about 20 feet in the drill hole in sec. 17.

The conglomerate does not appear to have been derived from the known rock stratigraphically below, as it contains no fragments of ferruginous chert, graywacke, and carbonaceous rock. Many mafic and felsic clasts in the conglomerate are definitely volcanic, and none are of granitic rock. As abundant round quartz grains could be phenocrysts freed from felsic porphyries, their roundness might not represent long weathering or transport.

The conglomerate is markedly different from the overlying fine-grained carbonaceous and pyritiferous slate and, in the drill hole in sec. 17, carbonaceous slate and fine-grained graywacke.

The conglomerate is unusual, not a classic basal conglomerate derived from erosion of underlying rock and gradational upward into successively finer grained clastic rocks. The conglomerate contains fragments of volcanic rock, and in contrast the overlying rock is similar to sediments deposited in euxinic environments. Therefore the conglomerate is interpreted as having formed during a period of volcanism in which thick tuff deposits accumulated, then was disturbed by landslides or other gravity-activated mechanisms that dumped material into the site of deposition.

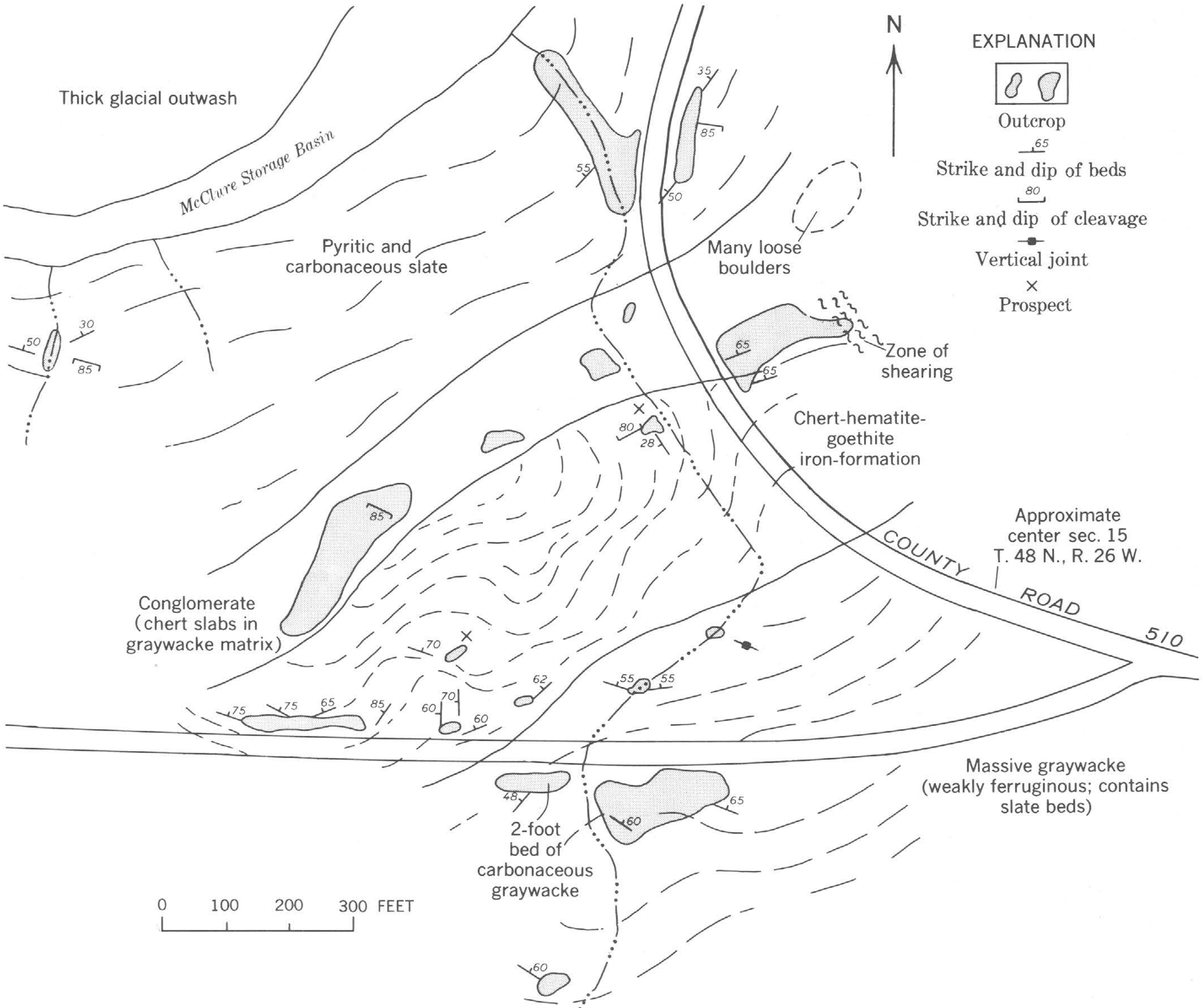


FIGURE 21.—Details of Michigamme Slate near center of sec. 15, T. 48 N., R. 26 W.

MAFIC INTRUSIVE ROCKS

Metadiabase, metagabbro, and diabase form dikes and sills and a few irregular-shaped bodies in the Negaunee quadrangle identical to such rock in the Marquette and Sands quadrangles (Gair and Thaden, 1968, p. 51–52, 57–59). Metagabbro is probably early Precambrian in age, metadiabase is of several ages, some definitely early Precambrian, and diabase is of Keweenawan age.

METAGABBRO

Two masses of metagabbro intrude the Lighthouse Point Member of the Mona Schist in the northwestern part of the quadrangle and probably are related to metadiabase in the same area. The rock is massive, nonfoliated, dark greenish gray, medium grained, and without diabasic texture. It is composed largely of blue-green raggedly terminated hornblende with sievelike texture and saussuritized feldspar. Minor minerals are carbonate, quartz, magnetite, and leucoxene.

The chemical composition (table 11) is nearly identical to that of layered amphibolite of the Lighthouse Point Member of the Mona Schist (table 2) and diabase and compares closely with that of metagabbro in the Marquette quadrangle (Gair and Thaden, 1968, p. 50, table 17).

METADIABASE

Metadiabase dikes and sills(?) intrude all units of early Precambrian age, Siamo Slate, and the Negaunee

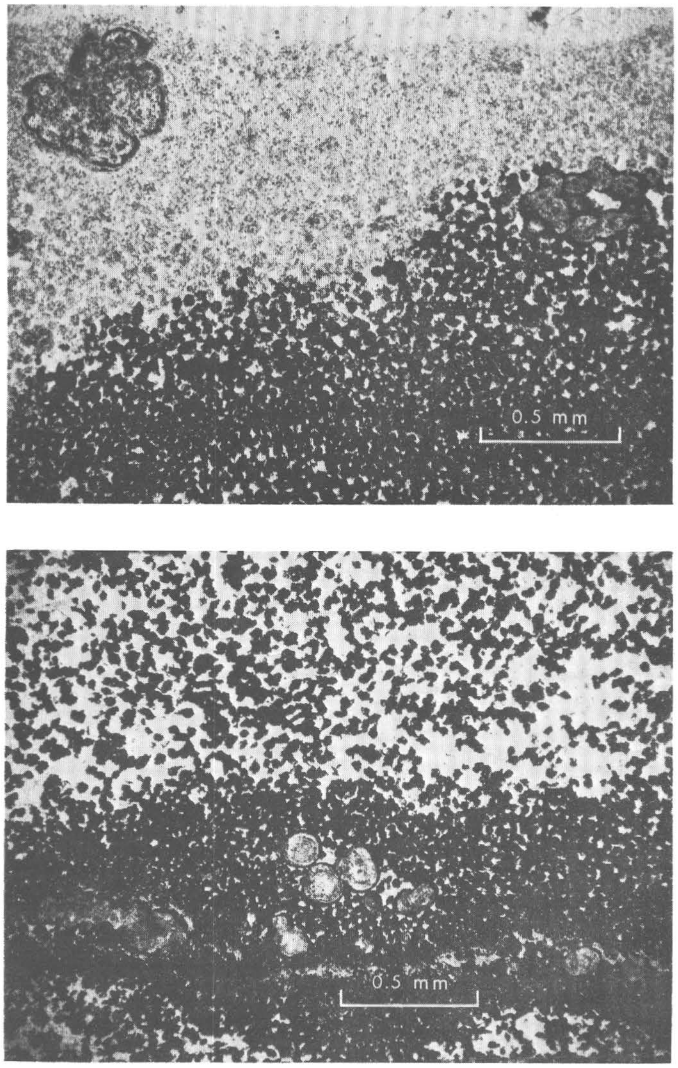


FIGURE 22.—Photomicrographs of iron-formation in the Michigamme Slate in roadcut near center of sec. 15, T. 48 N., R. 26 W. Light areas are chert; opaque grains are hematite and goethite; note gradational boundary between chert and iron-rich layer. Globules are light yellowish gray, noncrystalline, generally bordered by dark rims, and may have been primitive organisms. Plane-polarized light.

Iron-Formation. Most of the metadiabase is dark gray to gray green, fine to medium grained, and massive. Some in the Mona Schist is very coarse grained to porphyritic, containing dark-green phenocrysts as much as 5 mm long. Inclusions of greenstone in the Dead River pluton in sec. 14, T. 48 N., R. 26 W., closely resemble the metadiabase of the dikes. As metadiabase is less easily recognized in the Mona Schist than in the Compeau Creek Gneiss or the Dead River pluton, undoubtedly there are more metadiabase bodies in the Mona greenstone than are shown on plate 1.

The metadiabase is composed of cloudy sericitic plagioclase studded with epidote minerals, raggedly terminated dark-green hornblende, patches of carbonate, and mixtures of pyrite, leucoxene, and hematite from original ilmenite or titaniferous magnetite. Diabasic texture can be recognized in much of the rock and is conspicuous on some weathered surfaces. The original texture has been obliterated in some of the rock because metamorphism recrystallized pyroxene to hornblende and patches of carbonate. Some metadiabase composed mainly of stubby hornblende crystals is probably metapyroxenite.

Most dikes trend eastward to northeastward. Exceptions are the northwest-trending dikes in and south of the Dead River pluton west of sec. 20, T. 48 N., R. 26 W. Dikes are less than 100 feet to more than 300 feet thick.

Elongate bodies of coarse-grained metadiabase, 200–1,500 feet thick, intrude the Lighthouse Point Member of the Mona Schist north of Dead River and are parallel to regional foliation. Some of these are trun-

TABLE 11.—*Chemical and semiquantitative spectrographic analyses of mafic intrusive rocks*

[Rapid-rock analyses by P. L. D. Elmore, Lowell Artis, S. D. Botts, Gillison Chloe, J. H. Glenn, Hezekiah Smith, and James Kelsey, U.S. Geological Survey. Semiquantitative spectrographic analyses for 1 by J. L. Harris and for 2 by W. B. Crandell, both U.S. Geological Survey. Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, ..., which represent approximate midpoints of interval data on a geometric scale. The assigned interval for about 30 percent of the semiquantitative results will include the quantitative value. Elements looked for but not detected in the semiquantitative spectrographic analyses: As, Au, B, Be, Cd, Ce, Eu, Ge, Hf, Hg, In, La, Li, Nb, Pd, Pt, Re, Sb, Sn, Ta, Th, Tl, U, W, Zn. Dash leaders (........) indicate element looked for but not detected]

	1	2
Chemical analyses (weight percent)		
SiO_2	50.7	51.0
Al_2O_3	14.5	13.5
Fe_2O_3	2.9	1.7
FeO	9.0	10.1
MgO	6.2	8.9
CaO	11.0	8.1
Na_2O	2.5	2.5
K_2O	.40	.74
H_2O-	.27	.04
H_2O+	.93	1.9
TiO_2	1.2	.56
P_2O_5	.19	.06
MnO	.14	.25
CO_2	<.05	.06
Total	100	99
Semiquantitative spectrographic analyses (weight percent)		
Ag	....	<0.0001
Ba	0.015	.007
Co	.005	.003
Cr	.01	.005
Cu	.02	.02
Ga	.0015	.0015
Mo	.0003	....
Ni	.01	.005
Pb	.0007	....
Sc	.007	.005
Sr	.02	....
V	.05	.02
Y	.003	.001
Yb	.0003	.0001
Zr	.005	.003

1. Diabase. P–228–66. Lab. No. W167844. 3,150 ft north, 2,950 ft west of SE. cor. sec. 35, T. 49 N., R. 26 W.
2. Metagabbro. P–36–67. Lab. No. W169301. 4,000 ft north, 2,400 ft west of SE. cor. sec. 25, T. 49 N., R. 27 W.

cated by the unconformity at the base of the Reany Creek Formation.

Reddish-brown weakly magnetic altered granophyre 2,000 feet north and 1,500 feet east of the SW. cor. sec. 10, T. 48 N., R. 26 W., is mapped as metadiabase. The mafic minerals are altered to chlorite, feldspars are clouded with sericite, and hematite stains the nonopaque minerals.

Two carbonatized greenish-gray dikes are in the bottom of Dead River Canyon about 800 feet west of the east edge of sec. 14, T. 48 N., R. 26 W. The dikes are 18–30 inches thick, strike N. 20°–45° W. and are nearly vertical. Megascopically they appear porphyritic because of light-gray patches resembling feldspar phenocrysts. Examination of the rock in thin section shows it to be composed of abundant tiny leucoxene grains in a matrix of carbonate and minor chert. Apparent phenocrysts are areas of carbonate devoid of leucoxene. A dike of similar rock occurs in the Enchantment Lake Formation in the Marquette quadrangle (Gair and Thaden, 1968, p. 51).

DIABASE

Diabase dikes have intruded nearly all rock units in the quadrangle, but none is known on the north limb of the Eagle Mills syncline. The diabase is dark brown to black, fine to medium grained, and weathers rusty brown. Diabase can be distinguished from metadiabase in the field, as small fragments of the former are attracted to a magnet, whereas fragments of most of the metadiabase are not.

The dikes range in thickness from a few inches to nearly 100 feet and are as much as several hundred feet to more than 2 miles long. The presence of dikes is indicated by narrow negative magnetic anomalies. Many diabase dikes shown on the geologic map (pl. 1) were extended across areas of no outcrop by such magnetic data.

The diabase consists mainly of labradorite and augite with minor amounts of magnetite. Olivine is present in some dikes and is commonly altered to iddingsite or serpentine minerals. Quartz occurs in some dikes as granophyric intergrowths with feldspar. Commonly the dikes containing quartz are reddish brown, but not all reddish dikes in the area contain granophyric quartz.

Diabase dikes trend eastward or a few degrees north of east except for one that trends northeastward across secs. 5 and 6, T. 48 N., R. 26 W.

STRUCTURE

Layered rocks of middle Precambrian age are downfolded into, and separated by unconformities from, lower Precambrian rocks. Vertical displacement along shear zones has been important locally in juxtaposing rocks of different age. Anticlines cannot be mapped between the downfolded areas; this suggests that most of the synclines were developed essentially as a result of relative uplift of the lower Precambrian rocks rather than by regional compression. The main structural features in the quadrangle are synclines, shear zones, normal faults, and at least two reverse faults (fig. 23).

FOLDS

Three large synclines are present in the quadrangle. The Eagle Mills syncline plunges gently west across the southern part of the area on the north limb of the Marquette synclinorium, most of which is outside the quadrangle. Michigamme Slate occupies a northwest-plunging syncline near the west border of sec. 14, T. 48 N., R. 26 W., but with truncation of the north limb by the fault along the Dead River shear zone, only the south limb continues across the quadrangle west of sec. 14. The south-dipping rocks in the Reany Creek Formation probably correspond to the north limb of the syncline but are separated from the south limb by the Dead River shear zone. A syncline in the layered amphibolite of the Lighthouse Point Member of the Mona Schist that plunges gently east-southeast south of the Compeau Creek Gneiss apparently was formed where uplift of the gneiss reversed the generally northeastward dip of the amphibolite.

Several smaller folds are present in the area. A southeast-plunging syncline and smaller associated anticlines that possibly formed by drag along faults, all overturned in part, complicate the north limb of the Eagle Mills syncline in the NE¼ sec. 32 (pl. 2). Anticlines in the Michigamme Slate are indicated by opposing dips in the NW¼ sec. 16, T. 48 N., R. 26 W., but the magnitude of the folding is indeterminate because of poor exposures.

EAGLE MILLS SYNCLINE

The Eagle Mills syncline is well delineated by the bedding attitudes in the Siamo Slate. South of Carp River, the beds dip 35°–60°, generally northeast; north of Carp River, 20°–35°, generally south. The axis of the syncline follows approximately the course of the Carp River in the southeastern part of the quadrangle, but the fold plunges to the west, whereas the river flows to the east. The syncline passes through the Maas-Negaunee mine (pl. 4) and into the Mather mine B, where it is cut off by the Jackson fault. The probable eastern extension of the Eagle Mills syncline reaches the NE¼ sec. 6, T. 47 N., R. 25 W. (Gair and Thaden, 1968, pl. 1), where it corresponds to the north limb of

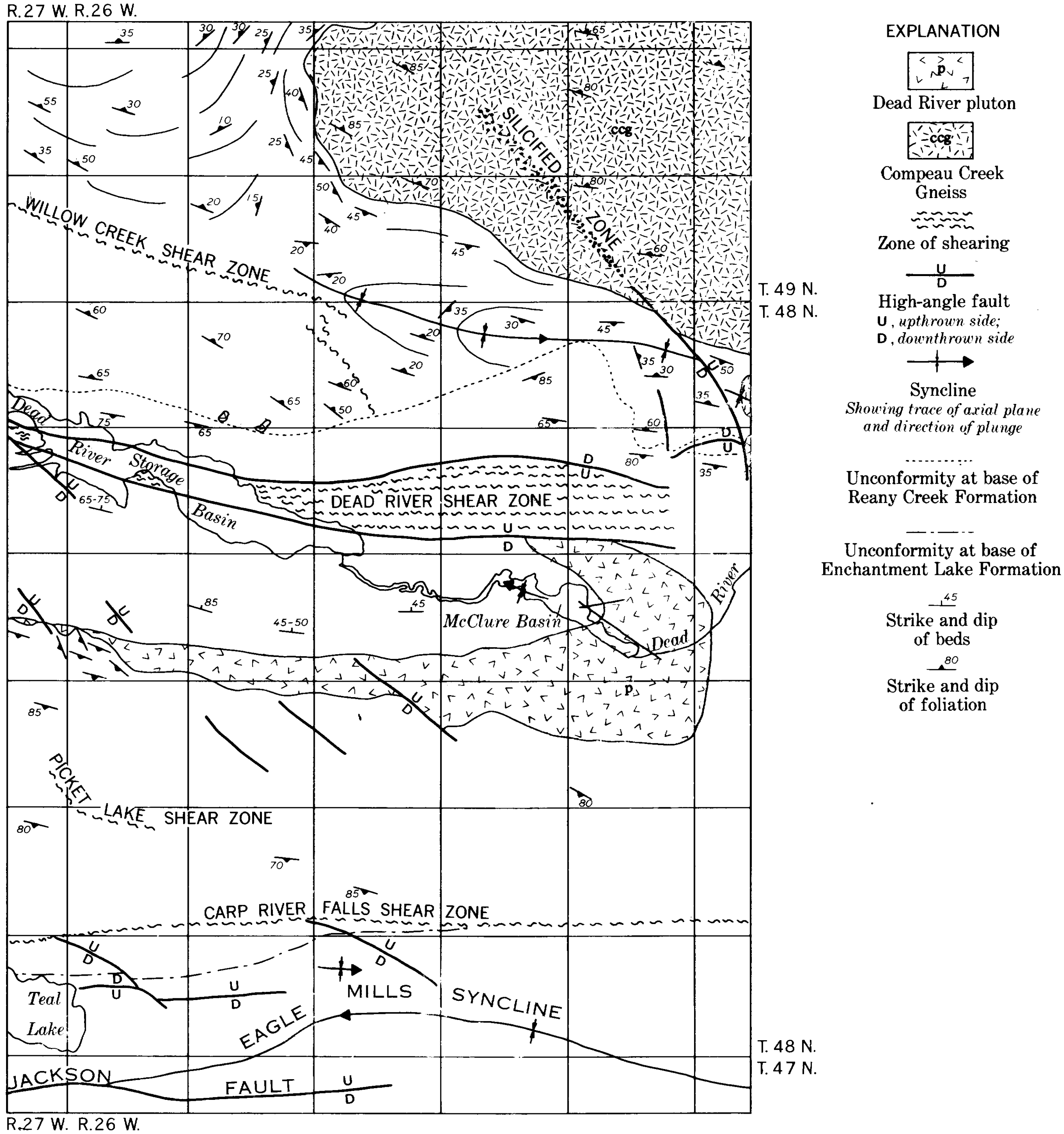


Figure 23.—Major structures and intrusive igneous masses in Negaunee quadrangle.

the Marquette synclinorium. The axis of the syncline arches broadly to the north on a north-south axis.

NORTH LIMB OF THE EAGLE MILLS SYNCLINE

The complex structure of the Kona Dolomite and other formations in the hills east of Teal Lake was mapped at a scale of 1:6,000 (pl. 2). Beds in most of the area dip homoclinally to the south or southeast; the upper quartzite of the Kona occupies a syncline about 1,000 feet northeast of the center of sec. 32, and the quartzite and adjacent slate are in an isoclinal syncline overturned to the south about 1,800 feet west-northwest of the center of sec. 32.

The Kona Dolomite extends only a very short distance west of sec. 32. Because the Kona is in a southeast-plunging syncline in sec. 32, only the lower part is exposed in that area; dolomitic beds from higher in the section do not appear in the axial part of the syncline. An east-trending fault along the steep cliffs at the west edge of sec. 32 juxtaposes Ajibik Quartzite and Kona Dolomite. West of there, the Ajibik truncates the Kona in part on an unconformity and in places along a fault that juxtaposes the Mesnard Quartzite.

The east-plunging folds contrast with the westward plunging Eagle Mills syncline and are not readily explained. East-plunging folds in the Kona Dolomite, 6 miles east in the N½ sec. 32, T. 48 N., R. 25 W., are related to a large cross-fold reflecting an uplift of basement rocks south of the Marquette synclinorium (Gair and Thaden, 1968, p. 63, pls. 1, 4).

SYNCLINE IN THE LIGHTHOUSE POINT MEMBER OF THE MONA SCHIST

The regional northeastward dip of the Lighthouse Point Member changes near its contact with the Compeau Creek Gneiss such that dips are west along the west side of the gneiss and south along the south side. The resulting syncline plunges southeastward south of the gneiss and northwestward west of the gneiss. The amphibolite evidently was turned up near the margins of the gneiss, either at the time of intrusion or later.

SHEAR ZONES AND FAULTS

DEFINITION

Shear zones shown on the map (pl. 1) indicate faults or fault zones too wide to be shown by a single line; some indicate special areas of broken rock along which there is no evidence of measurable offset.

CARP RIVER FALLS SHEAR ZONE

The Carp River Falls shear zone (C. E. Fritts, written commun., 1965), exposed near rapids in Carp River in the SE. cor. sec. 29, T. 48 N., R. 26 W., is marked by altered phyllonitic metavolcanic rock that can be traced east and west to near the edges of the quadrangle (pl. 1). The zone is indicated on the map as a narrow, well-defined structure, but the symbol marks only the north limit of a broad zone of sheared and altered lower Precambrian rocks. The sheared rocks, mapped as undifferentiated greenstone, have their greatest mapped width about 1,500 feet, in the NE¼ sec. 31, T. 48 N., R. 26 W.

The Carp River Falls shear zone apparently is part of the deformation belt (Gair and Thaden, 1968, p. 60–61) along the north margin of the Marquette synclinorium. The full width of the zone of shearing is not known, as only moderately deformed middle Precambrian rocks cover the southern part of the sheared older rocks.

The sheared rocks have been intensely altered. Good exposures of the altered rock in the shear zone are on the north side of U.S. Highway 41 near the south boundary of sec. 29, T. 48 N., R. 26 W. (fig. 24). Sericite, chlorite, carbonate, and leucoxene are the most conspicuous alteration products. Weathered surfaces are commonly stained brown from oxidized iron minerals. Quartz-carbonate veinlets form an anastomosing network in some rock. Copper minerals are present locally. Analytical data suggest that the altered rocks are enriched in CaO and CO_2 (table 12).

Along the Carp River Falls shear zone in the eastern part of the quadrangle, middle Precambrian rocks are juxtaposed with the oldest Precambrian rocks in the area. The vertical displacement is unknown but could be thousands of feet. Nearly vertical lineation on shear surfaces suggests that horizontal movement was slight or has been obscured by later downdip movement. In the east, the shear zone is along the contact between the Mona Schist and the Enchantment Lake Formation. Near the north boundary of sec. 33, the trend of middle Precambrian rocks turns west-southwest, whereas the Carp River Falls shear zone strikes nearly due west. This divergence in strike between the shear zone and the middle Precambrian rocks suggests the younger rocks were folded prior to the latest movement along the shear zone. The shear zone might have been an important structure formed in early Precambrian time, and movement along it could have been repeated through later Precambrian time.

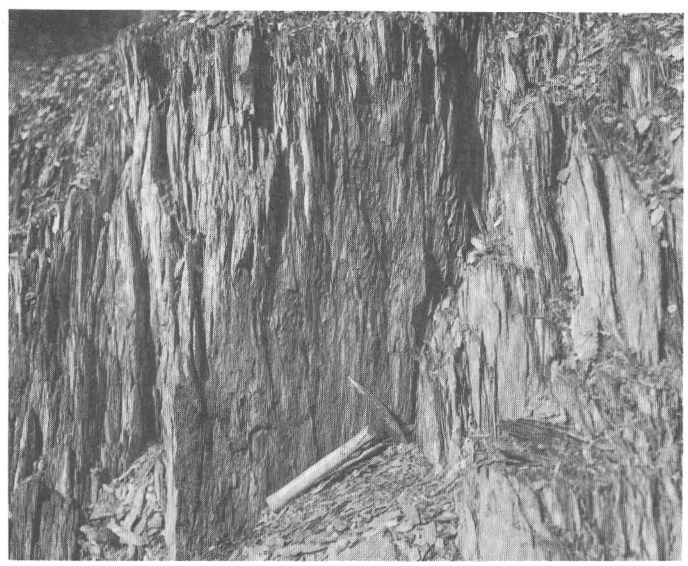


FIGURE 24.—Phyllonitized greenstone in the Carp River Falls shear zone exposed on north side of U.S. Highway 41 near south border of sec. 29, T. 48 N., R. 26 W. (For analysis of rock see table 12, column 1.)

TABLE 12.—*Chemical, semiquantitative spectrographic, and heavy-metal analyses of rocks in the Carp River Falls shear zone*

[Rapid-rock analyses by P. L. D. Elmore, S. D. Botts, Lowell Artis, Gillison Chloe, Hezekiah Smith, and Dennis Taylor, U.S. Geological Survey. Semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey. Heavy-minerals determination by atomic absorption by Claude Huffman and J. D. Mensik, U.S. Geological Survey. Results of semiquantitative spectrographic analyses are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, ..., which represent approximate midpoints of interval data on a geometric scale. The assigned interval for about 30 percent of the semiquantitative results will include the quantitative value. Elements looked for but not detected in the semiquantitative spectrographic analyses: Ag, As, Au, Be, Bi, Cd, Ce, Ge, Hf, Hg, In, La, Li, Nb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, Zn. Dash leaders (........) indicate element looked for but not detected]

	1	2	3	4	5	6	7
Chemical analyses (weight percent)							
SiO_2	42.1	47.7	66.2	58.9	42.8	62.7	62.8
Al_2O_3	10.9	15.3	14.4	15.8	10.9	13.9	14.2
Fe_2O_3	2.1	.00	1.0	.91	.69	1.9	1.0
FeO	8.4	10.9	.92	7.9	9.1	4.2	4.7
MgO	4.6	6.3	1.9	5.8	8.4	2.7	2.9
CaO	10.6	6.1	3.3	.63	8.5	2.8	3.5
Na_2O	.26	.10	2.3	.76	.19	.59	.55
K_2O	1.7	1.6	3.2	2.0	1.3	2.8	2.4
H_2O^-	.18	.08	.14	.17	.11	.15	.08
H_2O^+	3.2	5.4	1.4	4.7	3.5	2.7	2.3
TiO_2	.88	.88	.53	1.2	.91	.52	.50
P_2O_5	.05	.03	.11	.00	.13	.10	.16
MnO	.28	.19	.10	.10	.38	.16	.13
CO_2	13.9	4.8	4.4	.28	13.0	3.9	4.8
Total	99	99	100	99	100	99	100
Semiquantitative spectrographic analyses (weight percent)							
B	....	....	0.07	....	....	....	....
Ba	0.01	0.02	.03	0.02	0.015	0.03	0.03
Co	.0015	.002	.0015	.003	.003	.002	.0015
Cr	.015	.02	.005	.007	.007	.015	.02
Cu	.015	.003	.0007	.007	.05	.003	.005
Ga	.001	.0015	.001	.0015	.001	.001	.001
Mo	....	.003	....	.0005	.0003	.0003	....
Ni	.005	.007	....	.007	.005	.01	.007
Pb	.0015	....	....	.001	.0007	.0007	....
Sc	.002	.002	.001	.005	.002	.001	.001
Sr	.005	.0007	.007	.0007	.002	.01	.007
V	.015	.015	.007	.02	.015	.01	.01
Y	.003	.002	.0015	.003	.002	.0015	.001
Yb	.00015	....	.0001	.0003	.0002	.00015	.0001
Zr	.0015	.0015	.01	.01	.007	.01	.007
Heavy-metal analyses (ppm)							
Copper	90	28	13	50	160	25	38
Zinc	64	100	10	100	120	43	51
Lead	(all samples less than 25)						

1. P–125–65. Lab. No. 165793. 3,000 ft west, 150 ft north of SE. cor. sec. 29, T. 48 N., R. 26 W. Sericitic chloritic greenstone with knots of quartz-carbonate and limonite. Strongly sheared and highly altered. (See photograph, fig. 24.)
2. P–126–65. Lab. No. 165794. 400 ft east of P–125–65. Assumed to be unaltered equivalent of P–125–65.
3. P–127–65. Lab. No. 165795. 1,020 ft east, 350 ft north of SE. cor. sec. 30, T. 48 N., R. 26 W. Pinkish-gray sericitic carbonatized felsic porphyry with scattered pyrite. Along north margin of Carp River Falls shear zone.
4. P–128–65. Lab. No. 165796. 1,650 ft west, 850 ft south of NE. cor. sec. 36, T. 48 N., R. 27 W. Gray "unaltered" slate; sericitic, chloritic, few chert veinlets, sparse calcite.
5. P–129–65. Lab. No. 165797. 100 ft downslope north from P–128–65. Altered equivalent of P–128–65. Carbonatized chloritic slate with chert and muscovite. Some limonite and chalcopyrite.
6. P–130–65. Lab. No. 165798. 1,700 ft west, 350 ft south of NE. cor. sec. 36, T. 48 N., R. 27 W. Strongly sheared felsic tuff (?) in Carp River Falls shear zone. Quartz-sericite-carbonate chert rock; few angular and subrounded quartz grains.
7. P–131–65. Lab. No. 165799. 2,600 ft south, 400 ft west NE. cor. sec. 36, T. 48 N., R. 27 W. Identical to P–130–65. Along trace of Carp River Falls shear zone.

DEAD RIVER SHEAR ZONE

The Dead River shear zone lies within the sheared rhyolite tuff member of the Mona Schist between the northwestward trending faults that bound the tuff. For most of its extent in the Negaunee quadrangle, the zone thus is in a horst of lower Precambrian rocks bounded on the north and south by middle Precambrian rocks. The width of the shear zone ranges from about 800 feet near the west border of the quadrangle to about 3,400 feet in sec. 10, T. 48 N., R. 26 W. The southeastern extension of the shear zone is not well defined near the east border of the quadrangle and was not found in the Marquette quadrangle (Gair and Thaden, 1968, pl. 1).

The amount of vertical offset on the faults bounding the shear zone is unknown but could be several thousand feet. On the south side of the shear zone where the sheared rhyolite tuff member and Michigamme Slate are juxtaposed, the offset is greater than the entire Marquette Range Supergroup below the Michigamme Slate plus an unknown thickness of lower Precambrian rock. On the north side of the shear zone, the sheared rhyolite tuff member and the stratigraphically equivalent Nealy Creek Member of the Mona are faulted against the Reany Creek Formation. The minimum vertical displacement on the north side of the shear zone exceeds the thickness of the Lighthouse Point Member of the Mona Schist.

The Dead River shear zone probably controls the north limits of the Dead River basin. The northwest projection of the shear zone lies along the northeast edge of the sedimentary rocks in the Dead River area (Seaman, in Van Hise and Leith, 1911, pl. XX). The projection of the shear zone to the southeast across the Marquette quadrangle meets a conspicuous reentrant in the shoreline of Lake Superior (Gair and Thaden, 1968, pl. 1).

The most recent movement in the shear zone must have occurred in late middle Precambrian or early late Precambrian time after Michigamme Slate deposition and before Keweenawan diabase intrusion. A northwest-trending metadiabase dike crosses the south boundary of the shear zone without offset in the SE¼ sec. 10, T. 48 N., R. 26 W., indicating that some metamorphism occurred after the faulting.

The Dead River shear zone is one of many northwest-trending structures in northern Michigan that have largely controlled the location and extent of basins of metasedimentary rocks. Older rocks have been relatively uplifted and younger rocks depressed, escaping the planation that removed younger rocks from other areas.

OTHER SHEAR ZONES

The Willow Creek shear zone in the northwest quarter of the quadrangle and the Picket Lake shear zone in the southwest quarter of the quadrangle are poorly defined.

The Willow Creek shear zone is represented in several small but widely scattered outcrops. Irregular-shaped streaks of felsic rock in dark-gray-green amphibolite about 150 feet south of the NW. cor. sec. 4, T. 48 N., R. 26 W., appear to be fragments of a once-continuous body of felsic rock. The streaks are 1–5 inches thick by 5–18 inches long and generally lens shaped. Fragments of felsic rock in amphibolite in the N½SE¼ sec. 31, and 2,000 feet south and 500 feet east of the NW. cor. sec. 31, T. 49 N., R. 26 W., are similar to those near the NW. cor. sec. 4.

The Picket Lake shear zone trends west and northwest from Picket Lake in the NW¼ sec. 30, T. 48 N., R. 26 W. Fragments of greenstone in quartz-carbonate vein are direct evidence for this shear zone. Steep cliffs that parallel the trend of the vein northwest of Picket Lake afford indirect evidence of faulting.

NORMAL FAULTS

Well-defined faults along which relative offsets can be measured are few in the quadrangle. Those that are most easily recognized strike at high angles to layering, but there probably are undetected faults that parallel layering in the greenstone or metasedimentary rocks.

Many faults in the quadrangle have a conspicuous northwest trend, dip at a high angle or vertically, and are assumed to be normal faults. The faults in secs. 20, 25, and 26, T. 48 N., R. 26 W., are indicated in part by conspicuous declivities in the land surface, but their relative displacements are unknown.

REVERSE FAULTS

At least two high-angle reverse faults are known in the quadrangle: one in the NW¼ sec. 12, the other east of Teal Lake in sec. 31, T. 38 N., R. 26 W. The fault in sec. 31 has repeated the Ajibik Quartzite; that in sec. 12 cuts the Reany Creek Formation and has repeated the contact between the Lighthouse Point Member of the Mona Schist and the Reany Creek.

GEOLOGIC HISTORY

The earliest recorded geologic event in the quadrangle was the volcanism in early Precambrian time that gave rise to the Kitchi Schist and the Mona Schist. Subaerial volcanism produced the coarse agglomerate and lapilli tuff of the Kitchi Schist and subaqueous extrusions of basalt, the pillow structures in the Mona Schist. Basaltic ash falls and intermittent intrusions, extrusions, and ash falls of more felsic rock formed the Lighthouse Point Member of the Mona Schist. The volcanic rocks were later tilted and foliated.

The Compeau Creek Gneiss intruded the Lighthouse Point Member of the Mona Schist, metamorphosed it to amphibolite, and tilted or dragged the layered rocks upward around the margins of the gneiss.

Probably in late early Precambrian time, felsic rocks of the Dead River pluton intruded the lower member and the Nealy Creek Member of the Mona Schist, and diabase dikes and sills intruded many of the lower Precambrian rocks.

Diastrophism closed early Precambrian time. The land was deeply eroded. Glaciers deepened valleys in the Lighthouse Point Member of the Mona Schist and deposited sediments of the Reany Creek Formation—the earliest deposits of the Marquette Range Supergroup.

The bevelled lower member of the Mona Schist was covered by mixtures of quartz and quartz-feldspar sand from a granitic terrane. Seas inundated the rocks, and the clean sands of the Mesnard Quartzite formed as lenticular shelf deposits. Carbonate rocks of the Kona Dolomite were deposited in shallow seas and algal colonies — the earliest evidence of life on this planet — flourished. The seas deepened and the pelitic sediments of the Wewe Slate accumulated.

Another period of erosion bevelled the Mesnard Quartzite, Kona Dolomite, and Wewe Slate. Clean sands of the Ajibik Quartzite formed another shelf deposit similar to the Mesnard Quartzite. Detritus from the Kona Dolomite accumulated in a granule marker bed in the lower part of the quartzite. The seas deepened and mud and mixtures of mud and coarser detritus were deposited as a delta. Flood-swollen streams carried coarse gravels into the upper part of the deposit.

A long period of structurally stable conditions followed during which iron-rich and silica-rich sediments of the Negaunee Iron-Formation accumulated in shallow troughs adjacent to long-exposed low-lying land masses (James, 1966, p. W50).

Uplift and erosion followed the lithification of the Negaunee Iron-Formation. Blocks, cobbles, and pebbles of iron-formation were deposited on the eroded surface of the iron-formation. At the time that the iron-rich rocks of the present Negaunee Iron-Formation were being eroded, parts of the Dead River pluton were being exposed to erosion. During later incursions of the sea, the pyritic and carbonaceous pelitic sediments of the present Michigamme Slate accumulated. Volcanism contributed detritus to a conglomerate overlying iron-formation in the lower part of the Michigamme Slate.

Diastrophism followed, marked by crustal displacements along northwest-trending zones and crumpling of rocks along west-to-northwest-trending axes. This interval of deformation marked the close of sedimentation in middle Precambrian time.

Low grade regional metamorphism converted mafic rocks to greenstone and pelitic rocks to chloritic-sericitic slate. Later, in late Precambrian (Keweenawan) time, diabase dikes were intruded.

There is little evidence in the quadrangle of the geologic history between the close of Precambrian time and the Pleistocene glaciation. Glacially transported blocks of sandstone believed to be of Early Cambrian age are widely distributed and might represent deposits that covered the area in early Paleozoic time. Some glacial erratics are of fossiliferous Paleozoic limestone. Undoubtedly, a vast amount of bedrock was eroded, but detritus from this erosion is not known in the quadrangle. The soft iron ore bodies were formed during this long interval by the leaching of silica and redistribution of iron minerals in the Negaunee Iron-Formation.

Pleistocene glaciation was the latest major geologic event in the area. Accumulations of debris as much as 200 feet thick were left by melting of the glaciers. Structural rebound after disappearance of the ice interrupted preexisting drainage; the modern drainage is nonintegrated, and swamps and nongraded streams are common.

MAGNETIC SURVEYS

AEROMAGNETIC SURVEY

The aeromagnetic survey of an area that includes the Negaunee quadrangle shows a magnetic high related to the Dead River pluton, a magnetic high trending northwest from the SE. cor. sec. 5, T. 48 N., R. 26 W., and some east-west linear magnetic lows caused by Keweenawan diabase dikes (Case and Gair, 1965). A general decrease in magnetic values over the Negaunee Iron-Formation in the southwest quarter of the quadrangle is probably caused by oxidation of the iron-formation (Case and Gair, 1965, p. 5).

GROUND MAGNETIC SURVEYS

Ground magnetometer surveys were made during the winter months when lakes and swamps were frozen. Traverses were made at 300-foot intervals; readings were generally taken every 100 feet along traverses, but every 50 feet above steep magnetic gradients. Standard procdure was to establish a base station which was reoccupied at intervals of 2 hours or less and from which each day a correction graph was made for fluctuations in the earth's magnetic field. Magnetic readings in a particular part of the area were corrected to a common base, but base stations in the several widely separated areas surveyed were not calibrated with one another or to a common base.

Ground magnetic surveys were in four areas in the quadrangle, covering a total area of approximately 6 square miles. Three of the surveys are discussed subsequently. The fourth sought unsuccessfully to determine if there is a marked magnetic gradient along the north and south margins of the sheared rhyolite tuff member of the Mona Schist and is not discussed further.

GOOSE LAKE MEMBER OF THE SIAMO SLATE

A narrow linear magnetic anomaly was traced from the edge of the quadrangle in sec. 36, T. 48 N., R. 26 W., northwest to near the center of sec. 34, T. 48 N., R. 26 W. (pl. 1). There are no outcrops of the magnetic bed, but its position within the Siamo Slate suggests that it is the Goose Lake Member (Tyler and Twenhofel, 1952, p. 118–125). The average width of the magnetic ridge is 200–250 feet. The total relief, at right angles to the trend of the anomaly, is 500–800 gammas.

A narrow east-trending magnetic zone with relief of 350 gammas passing under Teal Lake in sec. 36, T. 48 N., R. 27 W., is in the correct position to be the Goose Lake Member. The anomaly could not be traced through the residential area east of the lake.

The absence of a magnetic anomaly westward from sec. 34 toward Teal Lake might be due either to lensing out of the Goose Lake Member or to its oxidation. The anomalies described evidently are too low in magnetic relief or too limited in extent to be indicated on the aeromagnetic map.

ZONE OF MAGNETIC ARGILLITE UNIT IN MICHIGAMME SLATE

The magnetic argillite in the Michigamme Slate south of Dead River can be traced by ground magnetic surveys from the west edge of the quadrangle to the SE¼ sec. 15, T. 48 N., R. 26 W. The argillite is 100–300 feet thick and affects the readings of only 1 or 2 stations in traverses across it. The magnetic relief, a few hundred gammas to as much as 5,000 gammas, is due to differences in the amount of oxidation of the slate and thickness of overburden. On the aeromagnetic map the anomaly evidently is masked by higher magnetic values over the Dead River pluton.

The anomaly is discontinuous and poorly defined in sec. 16, T. 48 N., R. 26 W., and to the east. One or two linear anomalies of low intensity might have been caused by the argillite. As no anomaly could be traced around the east end of the syncline at the northeast shore of McClure Storage Basin, it is likely that the unit either has lensed out there or is oxidized.

ANOMALY NORTH OF DEAD RIVER

A ground magnetic survey (pl. 3) more closely defined the aeromagnetic anomaly (Case and Gair, 1965) extending northwest from the SE. cor. sec. 5, T. 48 N., R. 26 W. The anomaly on the aeromagnetic map is as much as 2,000 feet wide (about 500 ft above the earth's surface); however, the ground survey revealed that the anomaly is generally less than 300 feet wide at ground level.

The anomaly source is in layered chert-magnetite rock that is bordered by coarse-grained metadiabase. Chert layers range in thickness from less than one-half inch to more than 1 inch and are locally brecciated. Pyrite is common. Magnetite is concentrated along parting planes between layers. Fine-grained purplish-brown sphalerite is contained in a few exposures in the N½SE¼ sec. 6, T. 48 N., R. 26 W. The full thickness of the chert-magnetite rock is unknown; where exposed in the roadcut near the SE. cor. sec. 5, it is a few feet thick, but in sec. 6, T. 48 N., R. 26 W., it is about 180 feet thick.

The chert-magnetite rock is probably a metasedimentary unit of early Precambrian age. It extends for several miles northwest of the quadrangle but is limited on the southeast by the unconformity at the base of the Reany Creek Formation. The relation between the magnetic unit and bordering metadiabase is not known. Perhaps diabase sills were intruded into a sedimentary sequence and gave rise to the magnetite by contact thermal metamorphism or metasomatism. The presence of sphalerite suggests such contact effects of the metadiabase. Exploration for base-metal sulfides, therefore, could be guided by magnetic surveying.

ECONOMIC GEOLOGY

Iron ore is the most important mineral product in the Negaunee quadrangle and has been mined since the late 1840's. Widely scattered veins contain mainly copper minerals with lesser amounts of zinc and lead sulfides; some of the veins have been explored in shallow shafts, but no production is known. A small amount of Kona Dolomite in the NE¼ sec. 35, T. 48 N., R. 26 W., was quarried for flux in the old Morgan furnace that went into blast November 27, 1863 (Brooks, 1873, p. 35) and operated for several years. Greenstone was quarried north of the Morgan Heights Sanatorium for use in roofing slate. Rock from the Enchantment Lake Formation, quarried in 1849 and 1850 (Brooks, 1873, p. 21) near Teal Lake in the NW¼ sec. 31, T. 48 N., R. 26 W., was sawed into blocks for use as whetstones. Several pits were the source for gravel in 1968.

IRON

HISTORY

Iron ore was discovered near Negaunee, Mich., in 1845 (Brooks, 1873, p. 14) a few hundred feet southwest of the Negaunee quadrangle. Some ore from the original location (Jackson) was mined in 1846 and reduced in a catalan forge adjacent to the Carp River near the NE. cor. sec. 32, T. 48 N., R. 26 W., on February 10, 1848 (Brooks, 1873, p. 17). The Morgan furnace, in the NW¼ sec. 36, T. 48 N., R. 26 W., produced 337 tons of iron in 1863. Remnants of kilns that supplied charcoal to Morgan furnace can be seen today in the SW¼ sec. 12, SE¼ sec. 17, T. 48 N., R. 26 W., and near the SW. cor. sec. 33, T. 49 N., R. 26 W. In 1872, 5,213 tons of steel were produced from ore that consisted of 75 percent specularite (hard ore) and 25 percent hematite (soft ore).

Iron ore was shipped to Pennsylvania in 1850 and 1852; after the ship canal at Sault Ste. Marie, Mich., opened in 1856, regular shipments were made to the lower Great Lakes (Marsden, 1968, p. 492).

Large-scale mining operations started about 1870 in secs. 6, 7, 8, and 18, T. 47 N., R. 26 W., (Brooks, 1873, p. 50). Several large underground mines, dating from 1887, are in the southwest quarter of the quadrangle along the limbs and trough of the Eagle Mills syncline, westward from near the east limits of the iron-formation; from east to west, the mines are the Barassa, Negaunee, Adams, Maas, and Mather B. The Mather mine B includes old properties formerly known as Cleveland Hematite, East New York, Iron Center, and Ames, parts of which extend outside the Negaunee quadrangle. All except the Mather mine B were inactive in 1968. Production data are tabulated in table 13.

TABLE 13.—*Summary of iron ore production in the Negaunee quadrangle*

[Source: The Lake Superior Iron Ore Association and The Michigan Department of Conservation, Geological Survey Division]

Name of mine	Location	Years of production	Type of ore	Total production (tons)
Adams	T. 48 N., R. 26 W.: SW¼SW¼ sec. 32. T. 47 N., R. 26 W.: NW¼NW¼ sec. 5 and E½NE¼ sec. 6.	1913–24	Soft, red, nonbessemer	242,348
Barassa	T. 48 N., R. 26 W.: SW¼SE¼ sec. 32.	1903 (an old exploration in 1903)		8,768
Maas	T. 47 N., R. 26 W.: NW¼NW¼ sec. 5 and N½N½ sec. 6. T. 48 N., R. 26 W.: E½E½SW¼ sec. 31 and W½SW¼ sec. 32.	1907–67	Soft, red, bessemer and nonbessemer.	21,311,386
Negaunee	T. 47 N., R. 26 W.: NW¼ sec. 5 and E¼NE¼ sec. 6. T. 48 N., R. 26 W.: SW¼ sec. 32.	1887–1949	Soft, red, nonbessemer	22,735,479
Mather B	T. 47 N., R. 27 W.: sec. 2 (except N½NE¼NE¼) and sec. 1 (except N½N½NW¼).	1950–67		18,491,331
Total				62,789,312

TYPES OF ORE

According to Anderson (1968, p. 51), iron ore consists of (1) high-grade direct-shipping "soft" ore, (2) high-grade direct-shipping "hard" ore, (3) siliceous ore, and (4) concentrates and agglomerates (pellets) from low-grade iron-formation. "Soft" ore is porous, friable, earthy to semiplastic, and made up chiefly of hematite and martite with minor amounts of goethite, unreplaced chert, and silicates (mica, chlorite). "Hard" ore is hard, dense, and compact, has low porosity, and is composed of magnetite, martite, dense compact hematite, and specularite; this ore constitutes the lump ore.

Marsden (1968, p. 464) gave the important components of ore from the Marquette Range as follows:

Type of ore	Fe	SiO_2	P	Mn	Al_2O_3	S	Moisture
Average nonbessemer	52.40	4.47	0.532	0.27	2.56	....	7.68
Average pellets	63.04	7.02	.038	.09	.86	....	1.20
Average siliceous ore	36.92	43.71	.028	.07	.58	....	2.29
Lump ore	61.77	6.46	.110	.28	1.85	0.005	.50

The average iron content of primary iron-formation approximates 26 percent (dried), and the average iron content of altered Negaunee Iron-Formation approximates 31 percent (dried) (Anderson, 1968, p. 510).

Production from mines in the quadrangle has been direct-shipping "soft" ore. No hard ore has been produced. In recent years some of the "soft" ore has been agglomerated into pellets.

The bodies of "soft" ore contain more than 50 percent iron. Areas adjacent to the ore bodies might have been enriched to as much as 40–50 percent iron but generally are not minable for direct-shipping ore. The ore bodies discussed in this report are those containing direct-shipping ore; information about them has been obtained from the records of the mining companies.

ORE BODIES

The generalized shape of the ore bodies in the Negaunee Iron-Formation is shown on plate 4. The ore is in the lower part of the Negaunee Iron-Formation and is thickest and most continuous in troughlike structures or where the contact between the Siamo Slate and the Negaunee Iron-Formation flattens. Ore bodies are as much as 260 feet thick and 1,400 feet wide (measured at right angles to the general plunge of the troughlike structures). The ore is confined to the trough of the Eagle Mills syncline in the eastern part of the formation and can be traced southwestward into the Mather mine B, where it is downdropped to the south along the Jackson fault. The Cambria-Jackson ore body, shown between sea level and 500 feet in altitude on the 9,400-foot-west, 9,800-foot-west, and 10,200-foot-west fences, appears to have been localized adjacent to metadiabase dikes rather than to a fold. A zone of sheared rock that forms the north boundary of the ore in the Maas and Negaunee mines might represent a fault that cannot be recognized in rocks at the surface.

Metadiabase cuts the ore bodies in all the mines, and a thick metadiabase sill is above some of the ore in the Mather mine B, particularly on the downdropped side of the Jackson fault. Locally the ore is thicker on the updip side of dikes, but ore is not present above all dikes cutting the iron-formation or is not obviously thicker above dikes than elsewhere in an ore body.

Some of the first mining of "soft" ore was above metadiabase sills (Anderson, 1968, p. 512), but no ore from that type of environment was being mined in 1968. The ore in general was high in iron and low in sulfur and phosphorus.

The ore extends to the deepest part of the Negaunee Iron-Formation in the Negaunee quadrangle. Workings of the Negaunee mine extend from near the surface, at an altitude of about 1,000 feet, down the plunge of the structure to a point about 150 feet below sea level some 5,000 feet to the west. Deep workings in the Mather mine B are 1,500 feet below sea level. The contact between the Siamo Slate and the Negaunee Iron-Formation limits the bottom extent of the ore bodies.

ORIGIN

The "soft" iron ore bodies are enriched parts of the Negaunee Iron-Formation. Enrichment was the result of at least two processes: the oxidation and redistribution of iron minerals and the leaching and removal of chert and other noniron minerals. It is assumed that the base of the iron-formation, where the ore bodies are now found, originally was compositionally similar to unoxidized, nonleached iron-formation.

Downward percolating solutions were important in concentrating the ore minerals. Structural traps for the solutions are the troughlike features along the Negaunee-Siamo contact and intersections between dikes and bedding. Marsden (1968, p. 504) suggested that some magmatic or hydrothermal assistance to induce circulation is required, although most of the solutions were oxygenated surface waters that moved downward through the formation.

The progressive enrichment in the iron-formation can be seen in drill core from the Mather mine B. The upper parts of the formation consist of alternations of chert and iron-rich laminae. With increasing depth, the chert beds become corroded and replaced by iron minerals. Within the ore bodies, near the base of the iron-formation, the rock is a mass of layered hematite and goethite that contains only a few wisps of chert.

Immense quantities of silica and other noniron minerals were removed by the iron-enrichment process. There is no clue as to the final destination of these materials.

BASE-METAL SULFIDE DEPOSITS

Base-metal sulfides including chalcopyrite, galena, sphalerite, and, rarely, tetrahedrite occur in quartz and quartz-carbonate veins, in fractures in the Dead River pluton, in the chert-magnetite iron-formation north of Dead River, and in conglomerate near the base of the Reany Creek Formation (table 14). The little exploration work done suggests that these occurrences cannot be considered likely sources for base metals.

VEIN DEPOSITS

The veins that contain the base-metal sulfides may be all quartz with only scattered crystals of carbonate, mixtures of quartz and carbonate, or predominantly carbonate with minor amounts of quartz. The carbonate is light-tan to buff ferruginous dolomite or ankerite. Chlorite is common in some veins. The veins in sec. 26, T. 48 N., R. 26 W., contain pink to red albite.

TABLE 14.—*Sulfide-bearing quartz or quartz-carbonate veins in the Negaunee quadrangle*
[Distances measured from southeast corner of section]

Location	Orientation	Thickness (ft)	Sulfides (in addition to pyrite)	Development
300 ft west, 4,200 ft north, sec. 26, T. 48 N., R. 26 W.	N. 70° E., vertical.	5–6	Chalcopyrite	Short adit, shaft (depth?). Foundations of old building. No sign of production.
2,250 ft west, 3,500 ft north, sec. 26, T. 48 N., R. 26 W.	N. 55° E., vertical.	.2–.8	do	None. Possibly this is an extension of that above.
950 ft west, 2,600 ft north, sec. 26, T. 48 N., R. 26 W.	Due west, vertical.	2–4	do	None.
3,000 ft west, 2,650 ft north, sec. 28, T. 28 N., R. 26 W.	N. 75° W., 80° S.	1.5–2	Chalcopyrite, tetrahedrite.	Shaft about 5 ft deep.
4,200 ft west, 3,900 ft north, sec. 30, T. 48 N., R. 26 W.	N. 80° W., vertical.	10	Chalcopyrite	Several shallow prospect pits.
1,600 ft west, 4,200 ft north, sec. 36, T. 48 N., R. 27 W.	N. 85° W., 85° S.	.1–.2	do	None.
2,000 ft west, 4,400 ft north, sec. 22, T. 48 N., R. 26 W.	(?)	.3	Chalcopyrite, galena.	Do.
700 ft west, 1,100 ft north, sec. 14, T. 48 N., R. 26 W.	N. 50° E., 60° S.	1–1.5	Chalcopyrite tetrahedrite(?).	Do.
1,300 ft west, 1,000 ft north, sec. 14, T. 48 N., R. 26 W.	N. 50° W., 80° N.	Very thin. Adjacent to thin mafic dike.	Chalcopyrite	In face of quarry for railroad ballast.
4,400 ft west, 1,300 ft north, sec. 4, T. 48 N., R. 26 W.	N. 20° E., 85° S.	.8–1.2	Chalcopyrite, sphalerite, galena.	Several shallow prospect pits.
1,400 ft west, 1,800 ft north, sec. 33, T. 49 N., R. 26 W.	N. 30° E., 30° S.	2	Chalcopyrite	None.
2,200 ft west, 550 ft north, sec. 10, T. 48 N., R. 26 W.	N. 60° W., vertical.	1.8–2	do	None. Vein occurs within diabase.
1,200 ft west, 1,650 ft north, sec. 3, T. 48 N., R. 26 W.	(?)	.1–.2	do	None.
800 ft west, 2,650 ft north, sec. 3, T. 48 N., R. 26 W.	(?)	.1–.2	do	Do.

The sulfides are randomly distributed and constitute no more than a few percent of the vein material. Chalcopyrite grains and aggregates are as much as three-fourths inch wide. Sphalerite encloses shreds of, and appears to be younger than, the chalcopyrite. Galena is rare but forms cubes as much as one-fourth inch across, intergrown with sphalerite in the vein in sec. 4. Tiny grains of tetrahedrite occur in two of the veins but represent only a small percentage of the copper minerals.

The thickest and most promising sulfide-bearing vein, in the NW¼ sec. 30, T. 48 N., R. 26 W., consists of several quartz stringers in a zone 10–15 feet thick, extending along strike for several hundred feet. Some tourmaline is in the vein. A shallow shaft explored part of the vein and found some chalcopyrite-rich rock. Dump material appears to contain less than 1 percent copper.

Veins appear to be randomly distributed, although the base-metal occurrences south of Dead River may be spatially related to diabase or metadiabase (Puffett, 1966, p. 1311). Some are near magnetic lows that commonly are crossed by diabase dikes. A chalcopyrite-bearing quartz vein, 2,200 feet west and 550 feet north of the SE. cor. sec. 10, T. 48 N., R. 26 W., is within a diabase dike. At 950 feet west and 2,600 feet north of the SE. cor. sec. 26, T. 48 N., R. 26 W., sulfides are adjacent to metadiabase. The chert-magnetite iron-formation north of Dead River contains scattered sulfides near its contact with coarse-grained diabase. Diabase or metadiabase is not exposed near the other base metal sulfide occurrences. There are miles of diabase or metadiabase elsewhere in the quadrangle, but no base-metal sulfides are known to be associated with them.

SULFIDES IN THE CHERT-MAGNETITE IRON-FORMATION

Base-metal sulfides are known in widely separated areas in the chert-magnetite iron-formation bounded by coarse-grained metadiabase north of Dead River. After the iron-formation was delineated magnetically, soil samples were taken at 100-foot intervals along it and analyzed for copper, lead, and zinc. Generally, they contain less than 30 ppm (parts per million) copper, less than 25 ppm lead, and 25 ppm or less zinc. A sample from 1,100 feet west and 2,100 feet north of the SE. cor. sec. 6, T. 48 N., R. 26 W. (pl. 3) contained 150 ppm copper, 125 ppm lead, and 500 ppm zinc; another sample from 1,850 feet west and 1,200 feet south of the NE. cor. sec. 1, T. 48 N., R. 27 W., contained 60 ppm copper, less than 25 ppm lead, and 125 ppm zinc. Blocks of iron-stained cherty rock containing much fine-grained purplish-brown sphalerite were found near shallow prospect pits about 100 feet upslope from the location of the sample containing high values in the SE¼ sec. 6. A sample of the mineralized rock contains 700 ppm copper and 10,000 ppm zinc as determined by semiquantitative spectrographic analysis. Soil samples from east and west of the sample with high values, in the same relative position to the prospect pits, did not contain anomalous amounts of metal.

BASE METALS IN CARP RIVER FALLS SHEAR ZONE

Copper and zinc are present in and near the Carp River Falls shear zone (table 12). Copper is most abundant in rocks richest in CO_2. High values for zinc are not necessarily in the samples having high copper, but zinc values do appear to correlate with the FeO content. Chalcopyrite has been found in chloritic slate near the shear zone, but sphalerite has not been recognized.

GOLD

Samples from nine widely separated localities in the quadrangle were analyzed for gold. Three were of copper-bearing veins, two were of pyrite-rich gneiss, and four were of quartz veins or pyrite concentrations in the Lighthouse Point Member of the Mona Schist. A sample of an 8-inch-thick quartz vein from 350 feet west and 600 feet south of the NE. cor. sec. 32, T. 49 N., R. 25 W., contained 1.4 ppm gold. The other samples contained either less than 0.02 ounces gold per ton or less than 0.06 ppm gold.

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