Geology of the Florence Area, Wisconsin and Michigan

GEOLOGICAL SURVEY PROFESSIONAL PAPER 633

Prepared under the auspices of U.S. Department of the Interior, Geological Survey; University Extension—The University of Wisconsin Geological and Natural History Survey; Michigan Department of Conservation, Geological Survey Division

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By CARL E. DUTTON

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By Carl E. Dutton

ABSTRACT

The Florence area, in northeastern Wisconsin and an adjacent tract of Michigan, is part of the Menominee iron-bearing "range" of the Lake Superior region. It is in the upland that lies between Lake Superior and Lake Michigan and has an average elevation of about 1,300 feet; the relief exceeds 100 feet only locally. Glacial deposits are extensive and form characteristic hummocky surfaces. Outcrops are commonly small and scattered, but quartzose metasedimentary rocks and mafic metaigneous rocks are well exposed locally on a few ridges and hills and along streams.

Exclusive of intrusive masses, metavolcanic rocks of early Precambrian age underlie much of the southern part of the area, and metasedimentary and metavolcanic rocks of middle Precambrian age are at the bedrock surface elsewhere. Metagabbro, metadiabase, and granite of late middle Precambrian age intrude the lower Precambrian rocks, but only the mafic rocks intrude the middle Precambrian formations. Two very small areas of sandstone of probable Late Cambrian age are present but are too small to be shown on the maps.

The Precambrian formations of the Florence area are correlated with units in either that part of the Menominee range to the east, which is the Iron Mountain–Norway district of southern Dickinson County, Mich., or that to the northwest, which is the Crystal Falls–Iron River district of southern Iron County, Mich. The formations are, however, in various folded segments that have been terminated and displaced by three major northwest-trending faults.

Lower Precambrian rocks are mainly metabasalt and metarhyolite that constitute the Quinnesec Formation of unknown thickness.

Middle Precambrian rocks in the area are divided into two groups. The Baraga Group is composed of the Hemlock(?) Formation, Michigamme Slate, and Badwater Greenstone; and the Paint River Group is composed of the Dunn Creek Slate, Riverton Iron-Formation, Hiawatha Graywacke, Stambaugh Slate, and Fortune Lakes Slate. So far as is known, conformable relations are generally prevalent, except for a disconformity at the base of the Hiawatha Graywacke and the discontinuity of the Riverton in the northwest part of the area. The Hemlock(?) Formation is amphibolite formed from metamorphosed mafic pyroclastic material; its thickness is not known because no older strata are exposed. The Michigamme Slate is predominantly metaargillite and schist but also contains metagraywacke, quartzite, conglomerate, metaagglomerate, and amphibolite. The thickness of the Michigamme is probably from 5,000 to about 20,000 feet. The Badwater Greenstone is almost exclusively metabasalt with minor amounts of phyllitic metaargillite or metatuff and locally thin beds of magnetite-grunerite schist. The thickness of the formation may range from 2,000 to 15,000 feet.

The Dunn Creek Slate is fine-grained quartz graywacke and slate in the lower part and massive and laminated graphitic rock in the upper part; its thickness is possibly 2,500 feet. The Riverton Iron-Formation is a thin-bedded sedimentary unit composed of alternate ferruginous and siliceous layers. The ferruginous layers are siderite, hematite, limonite, and grunerite, in various combinations; the siliceous layers are chert or metachert. The total thickness is about 600 feet. The Hiawatha Graywacke is mainly a breccia in which small chert fragments are enclosed by massive quartz graywacke or by siliceous limonitic material and associated phyllitic quartz graywacke; its thickness is not known but in general is probably not more than 100 feet. The Stambaugh Slate is a moderately magnetic fissile slate with some graywacke and is about 200 feet thick. The Fortune Lakes Slate is gray slate and interlayered graywacke; its exposed thickness is 1,000 feet, but the total thickness is unknown because no younger strata crop out.

Metagabbro and metadiabase intrusive rocks of late middle Precambrian age are mainly elongate bodies that are commonly parallel to foliation in lower Precambrian metabasalt; they also tend to parallel the metasedimentary rocks in the Badwater Greenstone but were not seen in contact with them. Few intrusive relations to country rocks are exposed. Granite dikes and pegmatites that cut metabasalt of the Quinnesec Formation are believed to be part of the Hoskin Lake Granite, which probably underlies most of an area where scattered exposures are exclusively granite. Age determinations of similar granite in the nearby area indicate that the probable age is late middle Precambrian.

Three faults of northwesterly trend, each of which shows relative uplift on the southwest side, divide the area structurally into four units. The northernmost unit contains a northwest-plunging major syncline of which most of the southwest limb is missing because of faulting and erosion. The adjacent unit is mainly a steep inclined south-facing homocline but also contains two synclines and an anticline that plunge southeastward. The third unit is apparently also homoclinal with vertical to steep southerly inclination and top facing southward. The southernmost unit contains foliated metavolcanic rocks that have a northwesterly trend, vertical to steep inclination, and tops facing northward. The Hoskin Lake Granite and most of the metagabbro are in this part of the area.

Metamorphism of the Precambrian rocks is mainly at chlorite grade along the central part of the plunging major syncline and rises to sillimanite grade to the north and to garnet grade to the south. Continuity of isograds has probably been interrupted by faulting.

Iron ore has been the only mineral resource produced, except for sand and gravel that is used locally. Iron ore was first shipped in 1880, and through 1960 a total of about 7,750,000 tons was obtained from six mines. The ore was derived from siderite-chert iron-formation by the oxidation of siderite to hematite or limonite or both and by decrease or removal of chert through leaching or replacement with iron oxide. Ore ranged from 48 to almost 51 percent iron, as mined, and from 52.5 to 56.5 percent iron, if dried. Areas along the projected strike of the Riverton Iron-Formation and along positive magnetic anomalies related to parts of the Badwater Greenstone and Michigamme Slate have been unsuccessfully explored for iron ore by test pits and drill holes.

The potentialities for high-grade iron ore or for low-grade ore amenable to beneficiation are not believed to be favorable. The ore bodies that were mined were all small, and geologic features that might have been conducive to the formation of large ore bodies do not appear to be present. The amount of magnetic or nonmagnetic low-grade ore that is readily available is believed to be rather limited because of the small dimensions at the surface and the steep dip.

INTRODUCTION

LOCATION AND SURFACE FEATURES

The mapped area includes about 170 square miles of Florence County in northeastern Wisconsin and about 40 square miles in the adjacent southeastern part of Iron County, Mich. (fig. 1). It consists of four 7½-minute quadrangles between lat 45°45′ and 46°00′ N. and long 88°7′30″ and 88°22′30″ W. The Florence East and Florence West quadrangles constitute the north half of the area, the Iron Mountain SW and Florence SE the south half.

The Florence area is in the eastern part of the extension of Precambrian rock south of Lake Superior and is closely related geologically to the Crystal Falls and Iron River areas to the northwest in Michigan (fig. 1). These three areas constitute the western part of the Menominee iron-bearing "range" that differs from the eastern part in some characteristics of stratigraphy, structure, and iron ore.

The surface of the mapped area lies generally between 1,200 and 1,450 feet above sea level. It is broadly undulating to somewhat hilly; local relief is commonly less than 100 feet. The lowest and highest parts of the area are about 1,040 and 1,580 feet, respectively.

Glacial till and glaciofluvial deposits extend over most of the mapped area and locally are more than 400 feet thick. Hummocks, numerous swamps, and a few scattered lakes are present. In the east-central part of the area, numerous irregular pits occur in glaciofluvial deposits, and a few of the large depressions are occupied by lakes.

The area is drained by the Menominee River and its tributaries—the Michigamme, Paint, Brule, and Pine Rivers. Dissection along these rivers and their tributaries has partly determined the distribution of outcrops; however, some outcrops that were formerly visible are now covered by artificial lakes. Several prominent interstream ridges and upland tracts have numerous outcrops.

CLIMATE AND VEGETATION

Information on climate and vegetation in Florence County is reported by Hole, Olson, Schmude, and Milfred (1962). The climate of the Florence area is the humid cool-summer continental type. The average of total annual precipitation from 1891 to 1932 was about 30 inches, which includes the average total annual snowfall of almost 60 inches. The 42-year extremes of monthly average temperature are about 80°F in July and 3°F in January.

Approximately 90 percent of the county is covered by forests in which aspen is abundant and northern hardwoods (mainly sugar maple, elm, yellow birch, and basswood) are common. Oak, pine, and swamp conifers are in limited stands. Forest products are mainly sawtimber, poletimber, pulpwood, and wood for a variety of miscellaneous uses. The annual sales total about $40,000.

About one-half the farm area is in woodland, of which about one-half is pasture. There is cleared land in the vicinity of Florence and the southeast part of the mapped area. The available cropland is used for hay, oats, corn and grass silage, and Irish potatoes.

ACCESSIBILITY

The principal road through the mapped area, a combination of U.S. Highways 2 and 141, trends northwest through the northern part and passes through the village of Florence. Access to and through some of the western part of the area is provided by State Routes 70 and 101. County roads and the roads leading from them permit access to most of the area, and only a few localities are more than a mile from a road. The closest passenger service by bus or by plane is through Iron Mountain, Mich., 15 miles eastward.

The area has about 2,000 inhabitants, half of whom live in three unincorporated communities. Florence has a population of about 800 and is the county seat. The population of Spread Eagle is about 120 and of Commonwealth about 115.

DISCOVERY AND MINING OF IRON ORE

Iron ore was discovered in the Florence area in 1873. The site was developed into the Florence mine, and ore was first shipped in 1880. Shipments from this mine continued through 1931 and totaled approximately

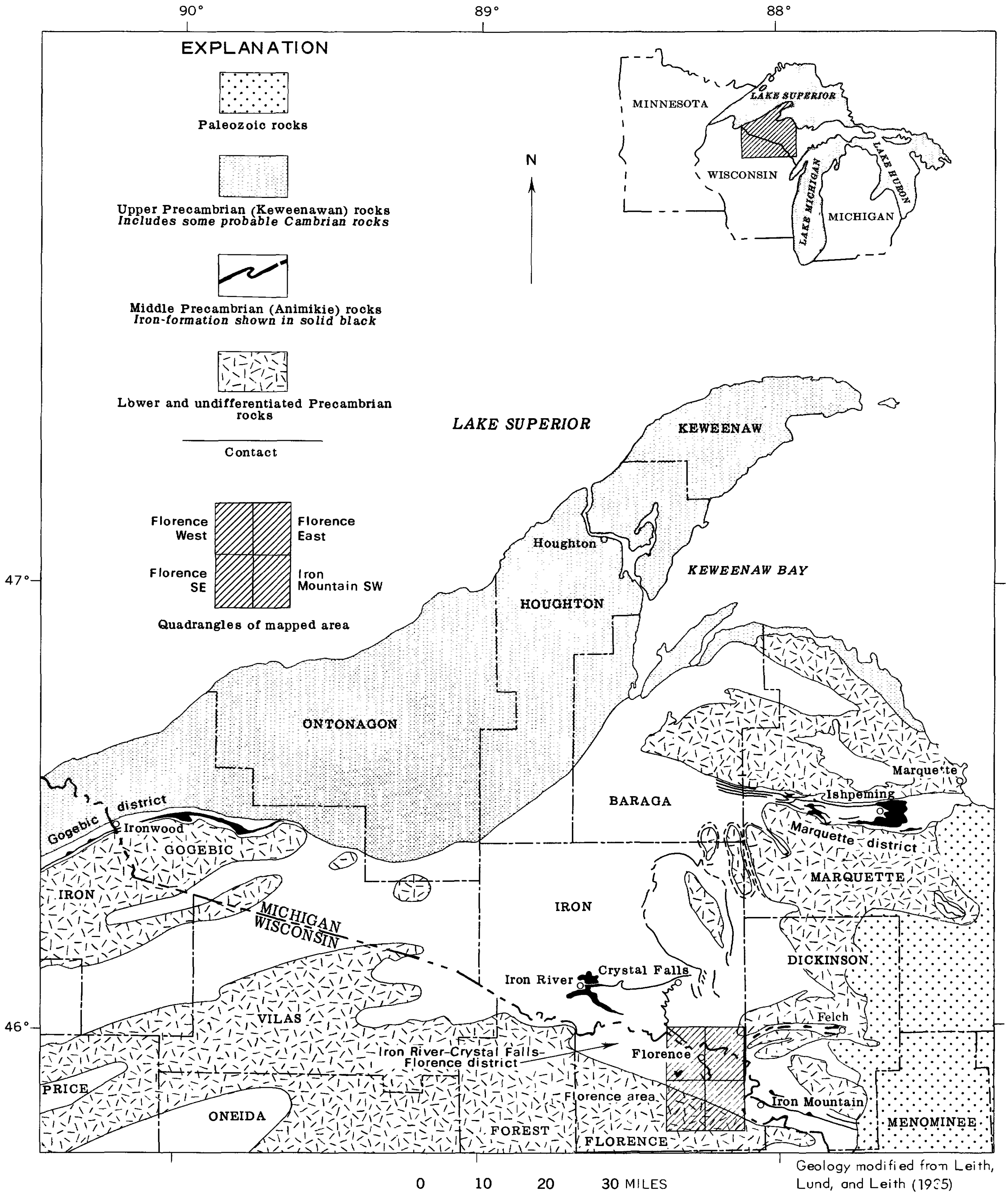

FIGURE 1.—Generalized geologic map of northern Wisconsin and northwestern Michigan showing location of the Florence area.

3,700,000 tons. The second discovery of ore was south of the present village of Commonwealth, and here too ore was first shipped in 1880. The Commonwealth group of mines, which includes the Badger, Buckeye, Commonwealth, and Davidson operations, shipped ore through 1916, and stockpile ore was shipped from 1937 to 1943. The shipments totaled about 3,000,000 tons. More recent shipments, mainly from the Davidson mine in 1953, 1955–57, and 1959–60 and some from the Badger mine in 1959–60, totaled about 342,000 tons. The Ernst mine, near Commonwealth, shipped about 700,000 tons of ore during intermittent operation from 1912 to 1929. A detailed account of the discoveries and early developments was prepared in 1910–12 by W. O. Hotchkiss and is in the files of the Wisconsin Geological and Natural History Survey.

Most mining in the Florence area ceased long ago because of the relatively poor quality of ore, and companies went out of business. Therefore available records of operations are fragmentary at best, and significant geologic data related to the mining are very limited.

PREVIOUS GEOLOGIC WORK

Little previous work has been done in the specific area of the present investigation, but work begun in 1937 in the area adjacent to the east and in 1942 in the area to the northwest provided data on lithology, stratigraphy, and structure that were applicable to the Florence area.

The first geologic reports of significance concerning Florence County, Wis., were by Brooks (1880), Wichman (1880), and Wright (1880). Brooks and Wright studied and mapped the outcrops along the Menominee River and its principal tributaries in areas that are now Florence and Marinette Counties, Wis., and Dickinson and Iron Counties, Mich. Brooks and Wright described the hand specimens, and Wichman the thin sections. They also interpreted local stratigraphy, structure, and economic geology as related to the iron deposits. They divided the sequence of rock units into the Laurentian (granitic gneiss) System and the overlying Huronian (iron-bearing) Series. Rocks in the Florence area, included in the Huronian Series, were divided into three parts:

Upper—Granite (eruptive?), gneiss, hornblende, actinolite, mica, chlorite and quartz schists, iron ores, clay and carbonaceous slates, quartzite, and conglomerate.

Middle—Clay slate and quartzite.

Lower—Dolomite, iron ore, and quartzite.

Van Hise and Leith (1911) briefly described the geology of the Florence area and presented a geologic map based on an outcrop map that had been prepared by W. N. Merriam and assistants in 1904 and partly revised by Hotchkiss in 1910. All sedimentary rocks were included in a single map unit called the Michigamme Slate, a unit which occupies most of the area and within which is a discontinuous iron-bearing member. Areas of intrusives and extrusives exposed north and east of Florence were also shown as a discontinuous unit. This unit and those of granite and gneiss and Quinnesec Schist and other green schists in the south part of the area were all shown as younger than the sedimentary rocks. The granite and gneiss were designated the Keweenawan(?) Series, and all other rocks were included in the Upper Huronian (Animikie Group) of the Huronian Series.

In 1910–11 the Wisconsin Geological and Natural History Survey prepared geologic and magnetic data sheets of township units at a scale of 4 inches per mile for much of Florence County but made no geologic map of the area. An incomplete manuscript in the files of the Wisconsin Geological and Natural History Survey contains lithologic descriptions of the principal rock types but refers to stratigraphy and structure mainly in relation to regional similarities instead of specific interpretations for the Florence area. The great value of these outcrop maps can be better understood after reading the comment of Brooks (1880, p. 445):

> When facts are so scarce, one is so rejoiced in finding them that he almost forgets that he has perhaps waded swamps or clambered through wind-falls, at the rate, with intense labor, of not to exceed five miles a day, maybe for one or several days, and found only a single outcrop. He may have passed within a few rods of others and not observed them, because of trees and brush and fallen timber. The same labor and time would have carried him a hundred miles comfortably on horseback in the far west, with a boundless view and uncovered rocks constantly before him, enabling him to select the points to visit, thus utilizing time and labor to the utmost.

Furthermore, the solution of problems was not and is not assured even when data are locally abundant. Brooks (1880, p. 481) stated:

> I have rarely found so small an area presenting so many outcrops and magnetic attractions, and occupied by so few and well characterized rocks, the structure of which gave me so much trouble as has the district about Lake Eliza [now Keyes Lake], more especially to the N. [north] and W. [west].

Allen and Barrett (1915) described the geology of the iron-bearing areas of Michigan and Wisconsin and proposed a correlation of stratigraphic units. They assigned the formations of the Florence area to two parts of the Huronian Group. Their Middle Huronian Series contained, in ascending order, the Vulcan iron-Formation, Hanbury Slate, Quinnesec Schist, and granite; their Upper Huronian Series contained quartzite and conglomerate.

Leith, Lund, and Leith (1935) suggested revisions of the geology on the basis of compilations and interpretations made subsequent to 1911. Their geologic map of the Florence area has a general similarity to the present concepts, but interpretations of the stratigraphic sequence differ greatly. The formations, except for the younger acidic intrusives, were placed in the Huronian Series and arranged as shown.

- Upper Huronian
  - Michigamme slate
    - Upper slates
    - Iron River iron-formation member
    - Lower slates
  - South belt of Quinnesec greenstone [1]
  - Breakwater quartzite [1]
- Middle Huronian
  - Iron-formation (Little Commonwealth area)
  - Greenstones near Spread Eagle Lake [1]
- Lower Huronian
  - Saunders formation (dolomites and quartzites)
  - Quartzite near Keyes Lake [1]

Lyons (1947) and Emmons and others (1953) investigated masses of medium- to coarse-grained hornblende and plagioclase in and adjacent to the southeastern part of the Florence area. They interpreted the "plagioclase hornblendite" as an intermediate stage in the transformation of basalt that lies to the north to granite that lies to the south. The "plagioclase hornblendite" is classified as metagabbro in the present report.

Other reports contain information mainly about adjacent areas, and additional bibliographic references to previous work are given. James (1951) presented the description, composition, and conditions of sedimentation of an iron-rich sequence of graphitic slate, iron-formation, graywacke, and magnetic ironstone of "Upper Huronian(?) age" in the Iron River area of Michigan. The sequence continues into the Florence area. James (1954) dealt with the occurrence, description, composition, and distinctive features of sulfide, carbonate, oxide, and silicate facies of iron-formation and also discussed the depositional environments.

James (1955) described mineralogic changes of the graywacke-shale suite, basic igneous rocks, and iron-formation in chlorite to sillimanite metamorphic zones in the northern peninsula of Michigan and part of northern Wisconsin including the Florence area. The extent of the zones was shown on an areal geologic map. Much of the Florence area is in the chlorite zone, and the metamorphic grade rises southward to the garnet zone and northward to the sillimanite zone.

James (1958) discussed the geologic relations in Dickinson and Iron Counties, Mich., that led to the recognition and naming of the formations, groups, and series shown in table 1. The nomenclature is in part also applicable to the Florence area (compare table 2).

[1] Stratigraphic position in doubt.

In James, Dutton, Pettijohn, and Wier (1959), a map shows distribution of outcrops, structural data, magnetic data, and indicated or inferred areal geology in the southern part of Iron County, Mich. Brief descriptions of stratigraphic units are given. The geology shown for the northwest part of the Florence area on plate 2 is from the southeast part of that map.

Bayley, Dutton, and Lamey (1966) prepared a comprehensive report on stratigraphy, intrusives, structure, metamorphism, and economic geology in parts of Michigan and Wisconsin east of the Florence area. They included data presented by Prinz (1959). This area is characterized by tracts of crystalline rocks to the north and south of a faulted homocline of northwest-trending and steeply dipping sedimentary rocks of middle Precambrian age. Two faults that trend northwest divide the area into three blocks, relative uplift being on the southwest side of each. The northern block also contains a northwest-plunging syncline of metabasalt that overlies the youngest Precambrian sedimentary formation. The faults, syncline, metabasalt, youngest Precambrian sedimentary formation, and the southern tract of crystalline rocks continue into the Florence area. Aspects of the stratigraphy and structure in the Florence area that contributed to the interpretation in this adjacent area were discussed.

Dutton and Linebaugh (1967) published a map showing the geological relation of the Florence area to other parts of the Menominee range and to other nearby iron-bearing areas in eastern Iron County and central Dickinson County, Mich.

James, Dutton, Pettijohn, and Wier (1968) discussed the stratigraphy, intrusives, structure, and economic geology in part of Michigan north and west of the Florence area. They include a bibliography of previous work. Sedimentary rocks of middle Precambrian age occur in a complexly folded syncline that overlies the previously mentioned metabasalt. The overall structure is a large triangular basin; two of the apices are at Iron River and Crystal Falls, Mich., and the third is near Florence, Wis.

PURPOSE AND METHODS OF THIS INVESTIGATION

Investigation in Florence County, Wis., by the U.S. Geological Survey in cooperation with the Wisconsin Geological and Natural History Survey began in 1955. The purpose was to determine the general stratigraphy, geologic structure, and mineral resources, especially potentialities for iron-formation amenable to beneficiation.

TABLE 1.—*Lithologic sequence of Precambrian rocks in Iron and Dickinson Counties, Mich.*

System	Series		Rock unit				
Precambrian	Upper Precambrian	Keweenawan Series		Diabase dikes and sills (probable age about 1,100 million years)			
				Intrusive contact			
	Middle Precambrian			Granitic intrusive rocks (probable age at least 1,400 million years)			
				Intrusive contact			
				Metadiabase and metagabbro			
				Intrusive contact			
		Animikie Series	Paint River Group	Fortune Lakes Slate			
				Stambaugh Formation			
				Hiawatha Graywacke			
				Riverton Iron-Formation			
				Dunn Creek Slate, with Wauseca Pyritic Member			
			Baraga Group	Badwater Greenstone			
				Michigamme Slate			
				Fence River Formation	Amasa Formation		
				Hemlock Formation, with Mansfield Iron-Bearing Slate Member and Bird Iron Bearing Slate Member			
				Goodrich Quartzite			
				Unconformity			
			Menominee	Vulcan Iron-Formation	Loretto Slate Member		
					Curry Iron-Bearing Member		
					Brier Slate Member		
					Traders Iron-Bearing Member		
				Felch Formation			
				Unconformity			
			Chocolay Group	Randville Dolomite	Saunders Formation		
				Sturgeon Quartzite			
				Fern Creek Formation			
				Unconformity			
	Lower Precambrian			Gneissic granite and other crystalline rocks			Margeson Creek Gneiss (position uncertain)
				Intrusive or replacement contact??			
			Dickinson Group	Six-Mile Lake Amphibolite	Hardwood Gneiss (position uncertain)	Quinnesec Formation (position uncertain)	
				Solberg Schist, with Skunk Creek Member			
				East Branch Arkose			
				Unconformity ??			
				Granite gneiss			
				Quartzite and schist (small bodies included in granite gneiss)			

The results of the examination of the area by the Wisconsin Geological and Natural History Survey in 1910–11 under the direction of W. O. Hotchkiss, State Geologist, are on file at the Wisconsin Geological and Natural History Survey and were of much help in the present study. The available materials include field notebooks, many rock specimens and thin sections, and township maps showing the location and classification of rock exposed or penetrated by test pits and drilling.

During the present investigation, all known sources of field data—outcrops, test pits and trenches and drill cores—were examined. Data points were located by plotting on aerial photographs or by compass and pace traversing, and control was related either to points readily identifiable on aerial photos or to known land subdivisions of the township system. Field data were compiled on base maps at a scale of 1:12,000 prepared from planimetric quadrangles of the area at a scale of 1:48,000. Final compilation was on topographic bases of the four 7½-minute quadrangles at a scale of 1:24,000.

Petrographic descriptions are based on examination of about 350 thin sections from the 1910–11 survey and about 475 prepared for this investigation. Percentages of minerals are visual estimates; relative abundance is indicated by "common" if present in all or many parts of the thin section, "subordinate" if present in about half of the fields examined, and "minor" or "rare" if seen only in a few fields.

Approximate composition of plagioclase was determined by common petrographic methods where favorably oriented sections of grains were present. Most determinations were made, however, by the use of a five-axis universal stage (Emmons, 1943); supplementary distinction between albite and andesine was made by reference of feldspar indices of refraction to the index of the embedding medium. Throughout the report, most petrographic descriptions have been set in small type. Thus they may easily be recognized by the reader.

The adjacent southeastern part of Iron County, Mich., was investigated during cooperative studies with the Michigan Department of Conservation, Geological Survey Division. The northwestern part of the Florence West quadrangle was mapped intermittently over a period of years—the extreme northwest corner by Good and Pettijohn (1949), the adjacent area to the southeast by J. E. Gair in 1955, and the remainder of the Michigan part of the quadrangle by H. L. James and K. L. Wier in 1955. The geology of these areas as shown on plate 2 is from James, Dutton, Pettijohn, and Wier (1959). The brief description of geology is based on all the work listed above and James, Dutton, Pettijohn, and Weir (1968).

The eastern part of the Florence area in Michigan was also mapped intermittently. The area adjoining Peavy Pond was mapped in 1950 by R. W. Bayley in connection with his study of the Lake Mary quadrangle to the north (Bayley, 1959). The course of the Michigamme River between Peavy Falls and Lower Michigamme Falls was mapped by James and Bayley in 1951, during a period in which the normal flow had been cut off to permit construction of the dam at the lower falls. The stretch of the river bottom, with abundant outcrop, is now covered by the water behind the new dam. The remainder of this Michigan part of the area was mapped by James and Wier in 1955, and magnetic surveys were made by Wier in 1955 and 1964. Geologic mapping was done on 1:12,000-scale enlargements of the topographic base. All materials that concern this part of the Florence area are taken from a report prepared by James and Wier (unpub. data, 1965).

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GENERAL GEOLOGY

The Florence area is near the southeastern apex of a large mass of middle Precambrian rock in northern Michigan and northeastern Wisconsin (fig. 1); the formations are mainly metasedimentary rocks, including several iron-formations, that are complexly folded and faulted. Extrusive and intrusive igneous rocks are also present. Lower Precambrian rocks include schists, gneisses, and amphibolites that are adjacent to the southwest and to the northeast. Upper Precambrian rocks crop out 40 miles to the northwest as a series of north-dipping basalt flows overlain by clastic strata.

Bedrock of early and middle Precambrian age (table 2 and pl. 4) underlies most of the Florence area but is generally mantled by glacial and glaciofluvial deposits

TABLE 2.—*Rock units in the Florence area*

System	Series			Rock unit	Description
Quaternary	Pleistocene			Glacial deposits	Unconsolidated morainal and glaciofluvial deposits.
Cambrian(?)	Upper Cambrian (?)			Sandstone	Rounded quartz grains cemented by iron oxides.
Precambrian	Middle Precambrian	Animikie Series		Peavy pond Complex	Represented only by hornblende metagabbro.
				Hoskin Lake Granite	Pink, gray, white or mottled granite and some quartz monozonite.
				Metagabbro and metadiabase	Sill-like and irregular masses; now amphibolite.
			Paint River Group	Fortune Lakes Slate	Gray slate and graywacke; more than 1,000 feet thick.[1]
				Stambaugh Slate	Moderately magnetic fissile slate with some graywacke; 200 feet thick.
				Hiawatha Graywacke	Massive nonfeldspathic graywacke, locally few to many fragments of chert; generally 0–100 feet thick.
				Riverton Iron-Formation	Contains iron-rich minerals (siderite, hematite. limonite, magnetite, or grunerite, and various combinations of these minerals) with interlayered chert; 600 feet thick.
				Dunn Creek Slate	Upper part is laminated graphitic slate and massive graphitic breccia; lower part is phyllite and quartz graywacke; 2,500 feet thick.
			Baraga Group	Badwater Greenstone	Mainly metabasalt with some phyllitic rocks and, locally, gruneritic schist; 2,000–15,000 feet thick.
				Michigamme Slate	Mainly metaargillite and schist with some quartzite, conglomerate, agglomerate, and amphibolite; about 20,000 feet thick.
				Hemlock (?) Formation	Amphibolite derived from pyroclastic material; thickness unknown.
	Lower Precambrian			Quinnesec Formation	Metavolcanic and minor amounts of metasedimentary rocks; may be 40,000 feet thick.

[1] All thicknesses are estimates based on inferred width of formation as shown on geologic map. Post-Riverton sequence is undifferentiated in Wisconsin.

of Pleistocene age. Two very small areas of sandstone of probable Cambrian age are present.

Excluding intrusive masses, lower Precambrian metavolcanic and minor amounts of metasedimentary rocks underlie the southwestern part of the mapped area; middle Precambrian metasedimentary and less abundant metavolcanic rocks occupy the remaining part. Late middle Precambrian metagabbro and metadiabase occur in moderate-sized masses in the southeastern part of the area and minor ones elsewhere. Late middle Precambrian granite underlies a tract near the southwest corner of the area and is believed to be present in the extreme southeast corner also.

The distribution of stratigraphic units and the structural geology in the mapped area are determined by three inferred faults that trend northwest and divide the area into four structural blocks. Names given to the structural units, from north to south, are the Brule River, Keyes Lake, Pine River, and Popple River blocks. Much of the geology in this paper is discussed under these structural names.

A major fold, the Commonwealth syncline, occurs in the Brule River block. This structure plunges northwestward and forms one apex of a large triangular basin that contains the Riverton Iron-Formation and associated strata; the other apices of the triangular basin are at Crystal Falls and Iron River (pl. 4). Two anticline-syncline pairs of lesser magnitude have been recognized in the Michigamme Slate in the north part of the block. Similar folding is probably present throughout the stratified rocks of the area, but outcrops are too few to define them. Data in the western part of the Keyes Lake block establish a vertical to steeply dipping homocline and several southeast-plunging folds. Data on attitudes are more limited elsewhere, but the Pine River block is interpreted to be a south-facing homocline with a steep southwest dip, whereas the Popple River block contains ellipsoidal lavas the tops of which face northward in the few places where they are present.

All the lower and middle Precambrian rocks have been metamorphosed. The metamorphism is mostly regional, and well-defined gradients have been recognized (pl. 5). The grade increases outward from the chlorite zone, which is in a belt roughly parallel to the central part of the Commonwealth syncline. The gradient southward is gradual—through a biotite zone to a garnet zone in the southwest part of the area; the gradient northward is more abrupt—through biotite, garnet, and staurolite zones to sillimanite along the northern edge of the area. Locally, faulting has displaced the zone boundaries. Granite bodies are believed to have retarded the metamorphism of gabbro sills in a few places, but this action had only slight effect on the general pattern.

No bedrock is exposed in the northeast corner of the area. However, by extrapolation westward from the Felch trough of Dickinson County (James and others, 1961), it is believed that the tract is underlain by pre-Hemlock strata of the Animikie Series together with pre-Animikie crystalline rocks (table 1). This projection of the strata of the Felch trough is further suggested by a broad magnetic anomaly that extends westward to the east edge of the Florence area.

STRATIFIED ROCKS

LOWER PRECAMBRIAN ROCKS

QUINNESEC FORMATION

The name Quinnesec Schist was used by Van Hise and Bayley (1900) to designate greenstone schists and associated mafic intrusive rocks such as are found at Quinnesec Falls on the Menominee River in southern Dickinson County, Mich. Leith, Lund, and Leith (1935) changed the name to Quinnesec Greenstone. James (1958) applied the term Quinnesec Formation to the belt of greenstone, amphibolite, and schist in southern Dickinson County, Mich., and the adjacent part of Wisconsin. The geographic extent of this formation is not known.

The Quinnesec Formation in the Florence area trends southeastward across the southern part for a length of about 14 miles and a width of about 3–8 miles (pl. 1). Outcrops of the formation have been mapped eastward for 12 miles (Prinz, 1959; Bayley and others, 1966), and the unit continues for an undetermined distance. Exposures that are probably part of the Quinnesec Formation are rare west of the Florence area, and the extent of the unit toward the west and northwest is not well substantiated or delimited by aeromagnetic data (pl. 7).

DESCRIPTION

The Quinnesec Formation in the Florence area is composed of metamorphosed volcanic rocks and minor amounts of sedimentary rocks. Amphibolite and hornblende schist are most common, some associated biotite-quartz schist and grunerite schist are present, and quartzite is exposed at two localities. Felsic metavolcanic rocks and associated sericite schist are prominent rock types in the Quinnesec Formation in Florence County, Wis., but are less prominent eastward along the Menominee River in Marinette County, Wis., and southern Dickinson County, Mich. This felsic rock was not mentioned by James (1958).

AMPHIBOLITE

Most exposures of amphibolite in the Florence area are massive, dark green, poorly foliated, and fine grained. Ellipsoidal structures occur at widely separated localities and range from 1 to 3 feet long and ½ to 1 foot wide. Their shape and arrangement in secs. 12 and 13, T. 38 N., R. 18 E., and secs. 15 and 26, T. 39 N., R. 17 E., indicate that the original upper surfaces of these metamorphosed basaltic flows now face northward. Ellipsoids in a similar structural position occur just east of the mapped area in the northern part of sec. 10, T. 38 N., R. 19 E. In the absence of specific evidence to the contrary, it is believed that the top of the Quinnesec Formation faces northward and that the mafic metavolcanic rocks are older than the felsic ones.

Hornblende and andesine are the principal minerals in the amphibolite, and the ratio ranges from 70:30 to 50:50. The average grain size is about 0.50 mm (millimeter). The most common accessory minerals are magnetite and quartz. Others, which range from common to scarce in various thin sections, are oligoclase, carbonate, biotite, chlorite, clinozoisite, epidote, sericite, and sphene.

The average composition of the plagioclase in 60 percent of the thin sections is An_{30-39} and in 30 percent is An_{40-49} Oligoclase averaging An_{25-29} occurs in 10 percent of the slides. Plagioclase grains are mostly anhedral, but a few relict phenocrysts are present. Twinned grains are not present in all sections but are a minor constituent in many. No zoned grains were seen.

Pleochroism of most of the hornblende is *X*, pale yellow; *Y*, olive green; and *Z*, blue green. The intensity of color differs within individual thin sections and locally within individual grains. Maximum observed extinctions by common methods are 15° to 24° in two-thirds of the slides examined. Hornblende grains are subprismatic with irregular terminations. Twinned grains are generally absent or scarce but are common in several sections. Poikiloblastic texture is common to abundant.

SCHIST

Hornblende schist differs from amphibolite in having well-developed foliation that may or may not be accompanied by an increased percentage of hornblende. Occurrences of hornblende schist in the Quinnesec Formation are indicated on the geologic map (pl. 1) by foliation symbols.

Grunerite schist is exposed in a small area along the west side of the Little Popple River in the northern part of sec. 12, T. 38 N., R. 18 E., and in the southern part of sec. 3, T. 38 N., R. 18 E. Several large angular blocks and a possible small outcrop of grunerite schist in the SE¼ sec. 15, T. 39 N., R. 17 E. are not shown on the map.

Grunerite is predominant in thin sections; it is subprismatic, randomly oriented to moderately well alined, as much as 0.15 by 0.50 mm, but very fine grained and partly radiating at the boundary with lenses and laminae of quartz. The quartz probably represents recrystallized chert and, with crossed nicols, is resolved into a mosaic of grains that are approximately 0.20 mm in diameter and have relatively smooth simple boundaries. Subhedral bluish hornblende as much as 0.15 by 0.50 mm (but generally less) is cut by grunerite blades. Minor amounts of biotite are present.

Biotite-quartz schist in secs. 27, 33 and 34, T. 39 N., R. 17 E., near the west side of the area shown on plate 1, forms rapids in the Popple River and is exposed nearby. This schist is about one-half quartz, with associated biotite and hornblende in evenly divided proportions.

Quartz is anhedral and approximately 0.30 mm in diameter. Biotite is in well-alined elongate grains as much as 0.20 mm wide and 0.50 mm long. Blue-green hornblende may be alined or randomly oriented; grains are commonly elongate and are 0.25 mm wide and 0.75 mm in maximum length. Anhedral twinned plagioclase grains are minor constituents and are approximately An_{30}. Scattered zircon grains are less than 0.05 mm in diameter and have enclosing halos in biotite.

A layer of garnet-biotite schist about 3 feet thick crops out along Wisconsin Highway 101 in sec. 28, T. 39 N., R. 17 E., one-half mile west of the mapped area. The garnets are reddish brown and euhedral; most are less than one-half inch, but some are as much as 2 inches in maximum dimension. A pronounced banded appearance in the schist results from the relative abundance of garnets in some layers.

QUARTZITE

A bed of white to light-gray medium- to coarse-grained quartzite exposed along the north side of Wisconsin Route 101 in sec. 15, T. 39 N., R. 17 E., is approximately 6 feet thick and has hornblende schist on either side. A small irregular exposure of quartzitic rock nearby contains rodlike quartz masses that possibly represent elongate pebbles or lenses. A quartzite bed 8 inches thick was noted in the same roadside exposure that contained the garnet-biotite schist mentioned above.

FELSIC METAVOLCANIC ROCKS

Felsic metavolcanic rocks crop out in an area approximately 7 miles long and 1 mile wide, extending from sec. 15, T. 39 N., R. 17 E., southeastward to at least sec. 34, T. 39 N., R. 18 E. (pl. 1). Small amounts of amphibolite and hornblende schist associated with the felsic rocks are exposed locally in secs. 14 and 2? T. 39 N., R. 17 E. Felsic metavolcanic rocks are also present east of the mapped area in Wisconsin and Michigan along the Menominee River at and near Aurora and Niagara, Wis.

The felsic metavolcanic rock ranges from medium gray with some brownish cast to dark gray on fresh surfaces and from light gray to almost white on weathered surfaces. It generally shows a slight foliation but may be massive or well foliated. Grains less than 1 mm in maximum dimensions predominate, but rounded quartz and subhedral feldspar grains are locally as much as 3 mm. Biotite, muscovite, sericite, and pyrite occur in many specimens.

Typical thin sections consist mainly of anhedral grains of untwinned feldspar and quartz is approximately equal amounts. Classification of feldspar was generally impossible because most individual grains are small, and even in the larger grains the Becke line is very indistinct because of the abundant very fine grained sericite and opaque material, probably hematite. Some untwinned feldspars have at least two indices less than balsam and are believed to be orthoclase, but more grains have at least two indices greater than balsam. A few sections contain plagioclase phenocrysts that have albite or pericline twinning and compositions in the ranges of An_{24-32} and An_{53-61}. Quartz grains range from subangular to rounded. Some quartz that appears to have originally been one grain is resolved into a few or many units when viewed with crossed nicols. The irregular elongation and extinction of feldspar suggests possible deformation, but quartz shows almost no granulation or overgrowth.

Sericite, muscovite, and biotite are generally present, and chlorite and magnetite are less common; each ranges widely in abundance. Biotite, chlorite, and part of the sericite are moderately or well alined, the alinement contributing to the foliation of the rocks. Some sericite is scattered and randomly oriented in much of the feldspar. Epidote-clinozoisite, sphene, and leucoxene are rare.

Felsic metavolcanic rock and associated mafic material are transitional in character and alternate near the contacts, especially in sec. 30, T. 39 N., R. 18 E., along the south shore of the reservoir in adjacent sec. 29, and near the center of sec. 23, T. 39 N., R. 17 E. (pl. 1). This relationship can even be seen in single thin sections; felsic parts composed of irregularly elongate feldspar and subtabular biotite contain lenses and layers in which hornblende is abundant. Some sections are a mosaic of very fine feldspar and quartz, scattered quartz grains as much as 0.5 mm across, and much irregular hornblende. Other sections that are predominantly hornblende with some feldspar and scattered subrounded quartz grains as much as 0.5 mm across seem to be amphibolites with clastic quartz. The character of these mineral assemblages coupled with the interlayered relationships suggests a possible sedimentary accumulation of felsic and mafic materials in transitional zones. Such occurrences might also result from metamorphic differentiation or from intrusion as, for example, in the NW1/4SW1/4 sec. 25, T. 39 N., R. 17 E. (not shown on pl. 1).

These felsic metavolcanic rocks are probably metarhyolite and are included in the Quinnesec Formation in the Florence area. They are also present eastward along the Menominee River as already mentioned. The felsic metavolcanic rocks in the two areas are mineralogic and stratigraphic equivalents and resemble metarhyolites in other parts of the region. Analyses of the felsic rocks along the Menominee River correspond closely to calc-alkali rhyolite and rhyolite obsidian (Bayley and others, 1966, p. 15–16).

Gray slate and phyllitic rock are locally associated with the felsic metavolcanic rocks, especially in sec. 30, T. 39 N., R. 18 E. The principal minerals of the slate are quartz and biotite with accessory chlorite, sericite, possibly some feldspar, and several very small garnets in one section. Phyllitic rock is also dominantly quartz and biotite with accessory chlorite and very incompletely developed poikiloblastic chloritoid.

THICKNESS AND RELATION TO ADJACENT FORMATIONS

The thickness of the Quinnesec Formation is not known. The northeast limit is believed to be along a fault, and the southwest limit is beyond the presently mapped area. To the south, outcrops are sparse and many are granite. The greatest thickness of the formation indicated by outcrops in the Florence area is about 40,000 feet, and although no evidence of folding or faulting is known in this part of the area, some duplication of beds may be present.

No formations older than the Quinnesec have been recognized in the Florence area. Presumably, the relations to younger formations are structural rather than stratigraphic.

CHARACTER OF ORIGINAL ROCKS

The Quinnesec Formation formed principally as a series of massive basalt flows; some flows moved into water, and this resulted in ellipsoidal structures. Rhyolitic flows also were extruded. No pyroclastic material has been recognized, but mud and sand accumulated between periods of extrusions.

Subsequent metamorphism changed the basalt into amphibolite and hornblende schist and the sediments into phyllite, biotite-quartz schist, grunerite schist, and quartzite. The felsic volcanic rocks were little changed except for sericitization of the feldspar.

AGE AND CORRELATION

Van Hise and Bayley (1900) assigned the Quinnesec Formation to the Archean (early Precambrian of present usage). Van Hise and Leith (1911) revised the age to late Huronian (late middle Precambrian). Leith, Lund, and Leith (1935) gave the age as possibly, but doubtfully, Huronian (middle Precambrian). James (1958) tentatively concluded that the formation was of early Precambrian age, which was presumably corroborated by structural data given in this present report on the Florence area. Banks, Cain, and Rebello (1967) suggested that the Quinnesec Formation may be of younger age. Correlation of the Quinnesec Formation with other formations has not been established.

MIDDLE PRECAMBRIAN ROCKS—ANIMIKIE SERIES

BARAGA GROUP

In Iron and Dickinson Counties, the Baraga Group, named for Baraga County, Mich. (James, 1958), contains six formations; the ascending stratigraphic succession is Goodrich Quartzite, Hemlock Formation, Fence River Formation and the probably equivalent Amasa Formation, Michigamme Slate, and Badwater Greenstone. Only the Michigamme Slate, Badwater Greenstone, and rocks questionably assigned to the Hemlock Formation, are present in the Florence area.

The Baraga Group is the most widely distributed unit in the Florence area. It underlies most of the Brule River and Keyes Lake blocks (pl. 2) and the entire Pine River block (pl. 1). It is not in the Popple River block.

The Hemlock(?) Formation is mainly metamorphosed basaltic rocks and associated sedimentary rocks, some of which are iron-bearing. The exposed thickness of each formation in the Baraga Group in the three-county area ranges greatly, and each formation is discontinuous at least locally. The thickness of the Hemlock(?) Formation in the mapped area is not known because it occurs only as the central unit along the axis of an anticline and the lower contact is not exposed. The Michigamme Slate is predominantly interbedded graywacke and slate or their metamorphic equivalents, but in some places the formation contains conglomeratic and quartzitic rocks, graphitic slate, and iron-rich strata.

The Michigamme is about 5,000 feet thick in the northern part of the Florence area but is apparently about 20,000 feet thick in the southern part. The typical Badwater Greenstone is metamorphosed massive basalt, locally ellipsoidal; it contains some tuffaceous rock and some iron-rich strata. The Badwater Greenstone is probably as much as 15,000 feet thick.

The relation of the Baraga Group to the underlying rock units is not known because the lower limit of the Hemlock(?) Formation is not exposed either in the mapped area or an adjacent one. The Baraga Group and the younger Paint River Group are probably conformable in the Florence area. The Baraga Group is part of the Animikie Series of middle Precambrian age and is probably correlative with the Virginia Argillite of Minnesota (James, 1958; Cotter and others, 1965).

HEMLOCK(?) FORMATION

The name Hemlock Formation comes from the Hemlock River in northeastern Iron County, Mich., and was given by Clements and Smyth (1899) to the volcanic rocks in that area. The amphibolite that forms the core of an anticline in the northern part of the Florence area (pl. 2) is questionably assigned to the Hemlock Formation and is the only occurrence known in the mapped area. The rock is well exposed in the southern part of sec. 6, T. 41 N., R. 31 W., along a prominent ridge 50 to 100 feet above the general level of the area.

The amphibolite is black and varies somewhat in grain size and composition. Most of it is massive, and original layering is evident in only a few places. On weathered surfaces, particularly those that cross the foliation and lineation, the rock has the texture of an agglomerate or coarse tuff; irregular fragments weather out in relief from a less resistant matrix. On surfaces parallel to the strike, these "fragments" are seen to be pod- or pencil-shaped units parallel to the low-plunging regional linear structures of the area.

Most of the rock is a foliated fine- to medium-grained aggregate of hornblende and andesine, with lesser amounts of biotite and quartz. Locally the rock contains pod-shaped masses of needlelike black hornblende several inches across, commonly in a matrix that contains much carbonate.

The amphibolite is bounded on both north and south by iron-formation and garnetiferous schist that are assigned stratigraphically to the Michigamme Slate. The contact is exposed at several places in the SW¼ sec. 5 and the SE¼ sec. 6, T. 41 N., R. 31 W. In general, the contact is sharp, without indication of unconformity, but there is some interbedding as indicated by a thin layer of amphibolite in the iron-formation at the north end of the large outcrop in the NW¼NW¼ sec. 8, T. 41 N., R. 31 W. A small wedge of iron-formation exposed approximately 1,000 feet north and 1,000 feet west of the SE corner sec. 6 (not shown on pl. 2) appears to represent a small infold in the amphibolite. The thickness of the amphibolite in this area is not known, inasmuch as it occurs only along the creast of a narrow anticline.

The Hemlock Formation is locally well exposed to the north in the Lake Mary quadrangle (Bayley, 1959) and consists mainly of basaltic flows and pyroclastic rocks with associated slate and iron-formation. The amphibolite in the Florence area was presumably formed from similar extrusive and sedimentary rocks.

The Hemlock Formation is apparently best represented in, and almost restricted to, eastern Iron County, Mich., except for possibly a small area in northwestern Dickinson County, Mich.

It should be emphasized that the questionable assignment of the amphibolite in the Florence area to the Hemlock Formation is based on the assumption that it is in an anticlinal structure. The postulated west-plunging structure should require a progressive widening of the unit eastward, but evidently this does not occur. Two explanations can be invoked: first, that the structure is anticlinal and the Hemlock(?) Formation here originally was no more than a thin lens, that is that the lack of widening to the east is due to an original thinning of the unit; second, that the structural interpretation is incorrect and that the amphibolite and its bordering units are simply lenses within the Michigamme Slate.

MICHIGAMME SLATE

DEFINITION, DISTRIBUTION, AND LITHOLOGY

The name Michigamme Formation was used by Van Hise and Bayley (1895, p. 598) to designate an extensive unit represented by exposures of slate and graywacke and their metamorphosed equivalents on islands in, and the mainland around, Michigamme Lake in the western part of the Marquette district. Van Hise and Leith (1911, p. 267) revised the name to Michigamme Slate.

The principal occurrences of the formation in the Florence area are in two tracts (pl. 4). A north tract underlain by Michigamme Slate lies along and north of the Menominee and Brule Rivers (pl. 2) and continues northwestward and southeastward beyond the Florence area. Exposures in this tract are large and numerous in southeastern Iron County, Mich., but only small and scattered in Florence County, Wis., and rare in Dickinson County, Mich. A south tract extends northwestward across the south half of the mapped area (pl. 1) and is then split into two parts, one of which presumably continues beyond the west side of the Florence area (pls. 2 and 4). Exposures in these areas are generally small and scattered, except for those of quartzite and conglomerate. The Michigamme Slate extends eastward from the south tract into Dickinson County, Mich., for about 20 miles.

The bulk of the formation in the north tract consists of metagraywacke, slate, granulite, and schist; iron-formation is locally present at the base and the top. Probably the most abundant rocks of the formation in the south tract are similar to the sericitic slate that is only locally exposed along the Pine River but presumably underlies extensive intervening areas of thick overburden. The rocks most commonly exposed are, however, quartzite (near Keyes Lakes in the southwest quarter of pl. 2) and quartzitic conglomerate (near the reservoir on the Pine River in the northwest quarter of pl. 1). Other kinds of rock exposed are metagraywacke, grunerite-magnetite iron-formation, amphibolite (metabasalt(?)), and mafic volcanic breccia.

The recognition that the quartzites, conglomerates, and associated rocks in the vicinity of Keyes Lake and of the Pine River are part of the Michigamme Slate is believed to be one of the more significant results of of this investigation. It is based on extension from, and probable continuity with, the Michigamme in the southern part of Dickinson County, Mich. The rocks in the Florence area may be interpreted as younger units than previously known in the Michigamme, as local facies in that formation, or as both.

A thin bed of iron-formation and garnetiferous schist, possibly equivalent to the Amasa Formation elsewhere, separates the Michigamme from the underlying Hemlock(?) Formation. The upper limit of the Michigamme is marked by exposures of the younger Badwater Greenstone along the Menominee and Brule Rivers (pl. 2) and in the northeast corner of the southern part of the area (pl. 1); there is no evidence of erosion. The other areas underlain by Michigamme Slate are believed to be bounded by major faults, and consequently stratigraphic relations are not known.

The thickness of the Michigamme Slate in Wisconsin may be as much as 20,000 feet in the Pine River block of the southern tract where there is least evidence of repetition by folding. The probable thickness of the formation in the northern tract is 5,000 feet, or possibly less.

The Michigamme Slate is the most widely distributed formation in the mapped area, includes a great variety of rock types not previously recognized or described in this area, and exhibits best the effects of regional metamorphism. The discussion of this unit is therefore longer than that of other formations and is divided according to structural blocks from north to south.

BRULE RIVER BLOCK

The basal strata of the Michigamme Slate are exposed in the Brule River block in several places adjacent to the ridge of amphibolite (Hemlock(?) Formation) in secs. 5, 6, and 8, T. 41 N., R. 31 W. This rock consists of an iron-formation, which may be equivalent to the Amasa Formation in the Baraga Group, is no more than 10 feet thick, and does not appear to be continuous. It gives rise to strong magnetic anomalies on either side of the amphibolite ridge that die out to the west and to the east.

Most of the exposed iron-formation consists of granular quartz, magnetite, and lesser amounts of grunerite in layers one-quarter to one-half inch thick, but locally it is a skarnlike aggregate of grunerite, green pyroxene, garnet, quartz, and magnetite in various proportions. The associated schist is micaceous and studded with pink garnets as much as one-quarter inch in diameter.

At least 80 percent of the Michigamme Slate in the northern part of the mapped area consists of approximately equal proportions of metagraywacke and schist in beds ranging in thickness from a few inches to hundreds of feet. Graded bedding is common in the metagraywacke. It is best shown in layers 6 to 12 inches thick; commonly the beds grade from a medium-grained graywacke at the base to schist at the top, but locally, as in the exposures at the dam at Lower Michigamme Falls, the grading is from coarse-grained graywacke to fine-grained graywacke. In many places, notably in the northernmost exposures below Peavy Falls Dam, the original grain size is reversed; that is, original fine-grained argillaceous material in the upper part of a unit now is reconstituted to coarse-grained mica and staurolite. The southernmost occurrence of graded bedding is in the southwestern part of sec. 12, T. 40 N., R. 18 E.; here, the top of the beds is southward, toward the adjacent younger Badwater Greenstone. The graywacke is light to dark gray and greenish gray. Subrounded to rounded quartz grains are abundant, and feldspar grains of similar shape and size are a minor accessory. These minerals, which constitute about one-half of a typical specimen, are accompanied by abundant fine-grained quartz and biotite and minor amounts of epidote-clinozoisite, magnetite, and feldspar.

The uppermost part of the Michigamme Slate in the Brule River area consists chiefly of dark phyllite and slate and also a minor lens of iron-formation. Except for the iron-formation that was seen in pits in the NE¼ sec. 17, T. 41 N., R. 31 W., the rocks are best exposed in outcrops in Michigan along the east side of the Brule River in secs. 12 and 13, T. 41 N., R. 32 W., and in Wisconsin along the west side of the river in sec. 9, T. 40 N., R. 18 E. Graywacke and schist typical

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of the main part of the Michigamme Slate form the northern end of the outcrops and are succeeded to the south by biotite-chlorite-quartz schist, dark garnetiferous phyllite, and dark laminated slate. Minor amounts of interbedded graywacke crop out near the south limit on the west side of the river. The beds referred to the upper unit of the Michigamme dip steeply and are exposed for a distance of about 1,000 feet across the strike, but almost certainly the stratigraphic thickness is considerably less.

The dominant rock type is garnetiferous phyllite. Where fresh, it is black or green, but in much of the area it is weathered and red. The phyllite is fissile; glistening cleavage surfaces parallel bedding and lamination, and garnets protrude from the surfaces. In thin section, brown or green biotite and quartz are the principal minerals; garnet, chlorite, muscovite, and hornblende are abundant in some layers. The garnets, which contain many inclusions, are much larger than the other minerals in the rock, and all show clear evidence of rotation.

At the Wausau exploration in sec. 17, T. 41 N., R. 31 W., a bed of iron-formation occurs within the phyllite. The area has been explored by a number of pits and trenches, most of which encountered only oxidized garnetiferous phyllite. Banded magnetite-quartz iron-formation is abundant, however, in dump materials from the pit farthest to the northeast, and it is exposed 100 feet to the south in the walls of the pit farthest to the southeast. In the pit exposure, the iron-formation is bounded on the south by phyllite. Some of the iron-formation contains grunerite or its alteration products. The deepest pit, shown as a shaft on plate 2, is about 12 feet square and probably was more than 50 feet deep, but there is no indication of iron-formation, nor is there evidence of it in any of the pits and trenches to the west. Considering the east-west trend of the bedding, it seems likely that the iron-formation is a thin lens, probably no more than 10 feet thick, perhaps repeated by folding.

Another occurrence of ferruginous rock, which is possibly iron-formation and is at or near the upper limit of the Michigamme Slate, is known, but does not crop out, at the Spread Eagle exploration (pl. 1) in secs. 8 and 9, T. 39 N., R. 19 E., on the south side of the Florence syncline. Records of exploration and fragments in dumps indicate that hematitic siliceous slate, or argillite with some chert, is present and was probably derived from gray-green slate or argillite. Solid hematitic material is rare. Records of limited underground workings indicate an iron content that ranged from 25 to 57 percent.

The progressive metamorphism of the Michigamme Slate in this block is indicated by the presence of biotite in the few southernmost exposures along the Brule River, garnetiferous phyllite for about 1 mile north from the Brule River, then staurolitic rock to Peavy Falls Dam, and sillimanite schist to beyond the northern limit of the mapped area.

KEYES LAKE BLOCK

The Michigamme Slate is presumably the most widespread formation in the Keyes Lake block, but exposures are common only in the vicinity of Keyes Lake. These rocks are predominantly quartzite with associated slate and phyllite. The quartzite and a probable facies change at the southeast terminus will be discussed first, and then strata younger than the quartzite in areas east and northwest of Keyes Lake will be described.

Quartzite

The metasedimentary unit that probably has the greatest number of exposures in the northern half of the Florence area is a quartzite that crops out from sec. 32, T. 40 N., R. 18 E., northwestward for a little more than 4 miles to sec. 14, T. 40 N., R. 17 E. The thickness is mainly from 500 feet to 1,000 or even 3,000 feet locally (Nilsen, 1965). The highly resistant rock forms prominent ridges to the east and northwest of Keyes Lake and has many glacially polished surfaces. This unit is composed predominantly of massive, medium-grained, white to pink, vitreous quartzite with a few interlayers of conglomerate. Locally, thin layers of quartzose sericitic phyllite occur. Pebble layers in the quartzite are as much as 12 inches thick and are composed of pieces of oval to rounded quartz or jasper about 1 inch in diameter. Red to brown diffusion color banding extends along or across joints and bedding and also occurs as small to large irregular patches. Crossbedding is common in secs. 24 and 25, T. 40 N., R. 17 E., and uniformly indicates that the top of the quartzite is to the southwest

Examination of the quartzite in thin section shows mostly recrystallized quartz grains that range from subangular to well rounded and average about 0.20 mm but are as much as 1 mm in maximum dimension. Suturing of grains is slight to absent. Intergranular sericite is a common to minor constituent and in one thin section has an interpenetrating relationship with quartz at the boundary of the grains. In some thin sections subhedral fine-grained magnetite is a common accessory. Zircon and leucoxene are minor accessory minerals and are generally restricted to a few laminae in an otherwise homogeneous quartzitic rock.

This quartzite unit near Keyes Lake was studied in detail by Nilsen (1965) whose mapping indicates that the isolated area of quarzite shown east of the thickest part of the main belt is composed mainly of two discontinuous basal units. The maximum thickness of 3,000 feet is exposed at this location. Nilsen's paleocurrent analysis of crossbedding indicates that the predominant current direction was toward the southeast. He inferred that the site of deposition was a shallow, partly barred, nearshore basin.

The quartzite is at least locally underlain by sericitic phyllite and minor amounts of interbedded sericitic quartzite; this unit is shown in figure 2 but not on plate 2. There are only a few small exposures in the NE¼ sec. 25, T. 40 N., R. 17 E., and the SE¼NW¼ sec. 31, T. 40 N., R. 18 E.; sericitic phyllite was penetrated by test pits in the SE¼ sec. 31 and the SW¼ sec. 32, T. 40 N., R. 18 E. The quartzite unit is overlain by a variety of strata that will be described later for areas east and northwest of Keyes Lake.

A probable abrupt facies change at the southeast end of the quartzite belt is marked by poorly exposed martitic quartzite, quartzose phyllite, and associated strata. The martitic quartzite in secs. 31 and 32, T. 40 N., R. 18 E., encouraged exploration in the Little Commonwealth area, presumably so named in reference to the then active group of mines near the village of Commonwealth about 2 miles to the east. The geology of the area (fig. 2) was investigated in detail by R. W. Johnson, Jr. (1958, p. 24–33), and the following descriptions are taken from his report.

The unit labeled martitic quartzite in figure 2 is a highly quartzose rock that locally contains an abundance of martite (oxidized magnetite). This quartzite unit and the associated ferruginous rocks into which it grades have previously been informally designated the Little Commonwealth iron-formation.[1]

Most of the rock is composed of thin laminations or lenses of quartzite delicately interbedded with layers of dark-brown argillite that generally contains large amounts of martite. However, some quartzite beds and lenses are more than 5 feet thick locally, and the quartzitic rock that is fragmented and strewn within the associated material gives the appearance of an intraformational breccia or a very angular conglomerate. Within the dark-brown argillaceous layers, isolated quartz grains are common. The distribution of the martite in the argillite is erratic, in some places being almost absent but elsewhere constituting nearly the entire layer.

Minor constituents in the martitic quartzite are iron silicates, garnet, mica, martite, and a few tourmaline crystals. In thin section, microcrystalline platy mineral aggregates and mica flakes are commonly chaotically distributed within the rock, but these are restricted to certain laminae. The platy minerals are mainly chlorite; concentrations of sericite or muscovite and, rarely, pale-brown biotite are present locally. Crushed globular clusters of anhedral pale-pink to red garnet are common.

Martite is most abundant near the exploratory shafts (fig. 2) and where best crystallized is in the form of octahedra. Some relatively unoxidized rock containing magnetite instead of martite has been found in the northwestern part of the Little Commonwealth area and has been penetrated at depth in the drilling. The occurrences of magnetite at depth and of an anomalous magnetic high in the general Little Commonwealth area indicate that the oxidation of the magnetite to martite is a surface feature.

The unit labeled quartzose phyllite and garnet quartzite in figure 2, though gradational, differs sufficiently from the more ferruginous associated rocks to constitute a mappable unit within the Little Commonwealth area. The quartzose phyllite of this unit is largely restricted to the central part of the area and is exposed in several trenches and test pits. The fresh rock is gray, compact, finely laminated, very fine grained, and lustrous with a few thin scattered lenses of fine-grained quartzite. It weathers to a dull red or reddish brown. The rocks commonly show slaty cleavage and minor crenulations, but exposures are too small to allow study of cleavage-bedding relationships.

In thin section, the rock is a very fine grained mixture of roughly equal amounts of mosaic quartz and ragged flakes of chlorite. In some specimens sericite or muscovite takes the place of the chlorite. The more quartzose phases of the unit closely resemble the vitreous quartzite near Keyes Lake, except for noticeably more sericite. Phyllitic rocks containing abundant sericite are seen in thin section to contain blue-green tourmaline in well-developed small columnar crystals and a few small grains of zircon.

The garnet quartzite part of the unit is abundant in the eastern part of the area shown in figure 2, but exposures are small. It is associated with the martitic quartzite and the stilpnomelane-garnet slate and may grade into these other rock types. The garnet quartzite is massive to poorly laminated, medium grained, gray, and weathers dark reddish brown or brownish gray. Isolated rounded glassy grains of quartz, generally about 0.1 to 0.5 mm in diameter, are common. Pale-red garnets are abundant. They occur as equant crystals and as irregular granular clusters that apparently follow bedding planes. Drill cores contain thin dark-green ferrostilpnomelane laminae that are most abundant near the base of the unit.

Thin sections of the quartzite show a very fine grained quartz mosaic containing small plates, microcrystalline clusters, and schistose laminae of pale-green chlorite, clusters of green stilpnomelane, and mashed porphyroblasts of red garnet. Green

[1] W. O. Hotchkiss, 1920, Wisconsin Geological and Natural History Survey unpublished report; H. R. Aldrich, 1932, unpublished report on the geology of the Little Commonwealth exploration.

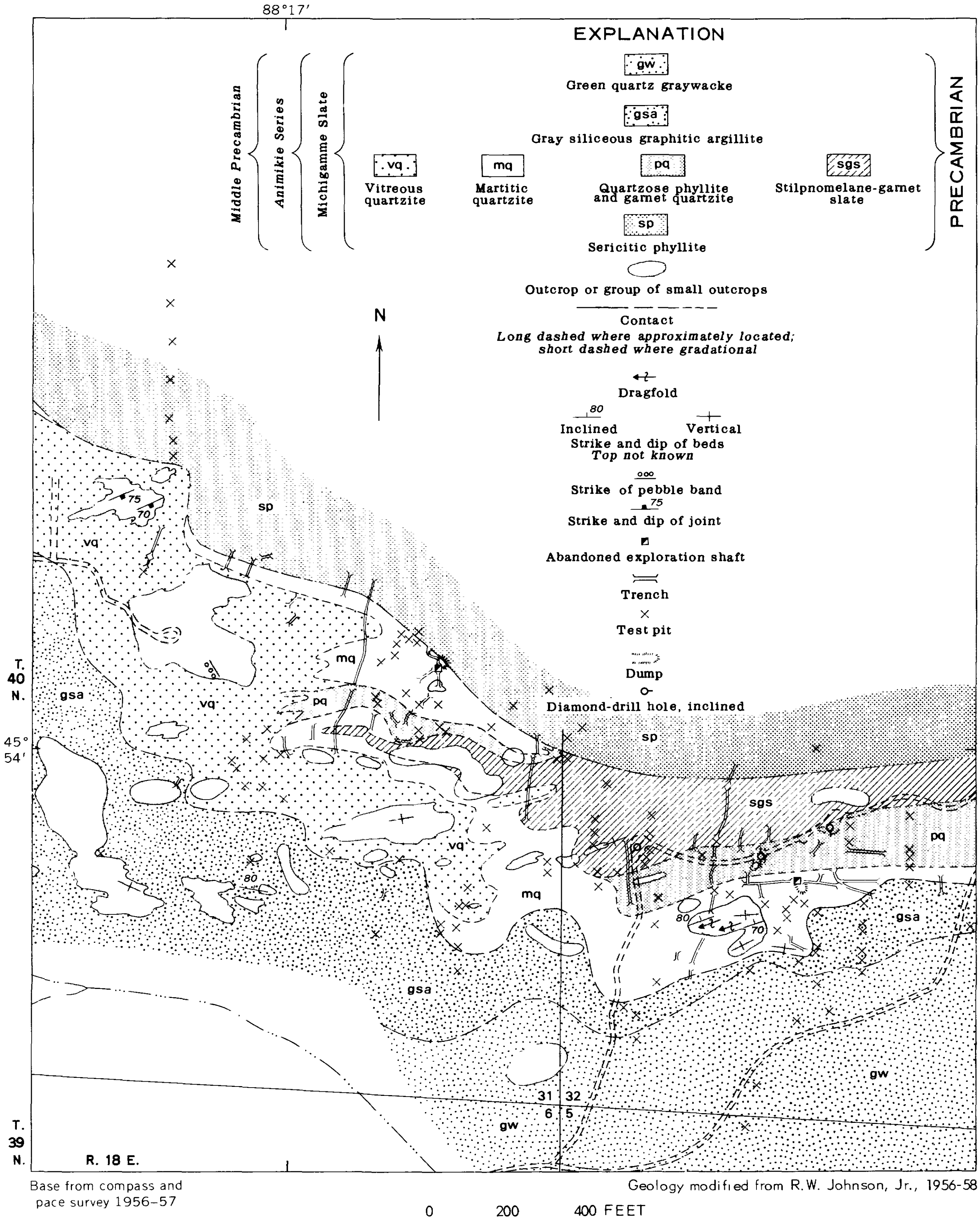

FIGURE 2.—Geologic map showing lithology of the Michigamme Slate at the Little Commonwealth exploration.

stilpnomelane and, rarely, biotite are abundant in some thin beds. Thin stringers of saccharoidal vein quartz transect all structures in the rock.

Stilpnomelane-garnet slate, which is most abundant north of the main road, consists mainly of dark-green to black ferrostilpnomelane and pale-red garnet. Locally, the slate is graphitic and cherty. A fibrous yellow amphibole occurs adjacent to the chert beds. The slate has distinct layers about ½ to 1 inch thick. Weathered outcrops are very soft and friable. The weathered slate is yellow brown to black and in places shows an iridescent coating which is presumably caused by iron or manganese oxides.

Thin sections show a variety of mineral associations and textures. Most commonly the slate is porphyroblastic, showing bands of platy green ferrostilpnomelane and aggregates of red-brown garnet. In some specimens, chlorite and green ferrostilpnomelane are closely intergrown with minor amounts of biotite. Brown ferrostilpnomelane is developed locally as a feathery reaction rim near some chert fragments. Graphite is abundant in some of the slate; where it is present the grain size of the metamorphic minerals is relatively fine, and porphyroblasts are nearly absent. The graphite seems to inhibit the growth of the metamorphic minerals.

A thin belt of a related dark-reddish-brown fibrous slate extends westward some 700 feet beyond the main occurrence and appears to be interbedded and gradational with the martitic quartzite. The slate of the westward extension is less graphitic, and the dominant minerals here are well-developed ferrostilpnomelane and chlorite with some grunerite and chert.

Strata Younger Than Quartzite

Argillite and graywacke, younger than the quartzite near Keyes Lake, are present in small exposures and test pits along the south side of the quartzite throughout its length (pl. 2); the width of the belt within which the outcrops and pits are present is from 100 to 3,500 feet.

The lithology of the strata younger than the quartzite in this area has not previously been described and is much more varied than the common slate-graywacke sequence that characterizes most of the Michigamme Slate. The principal rocks east of Keyes Lake are argillite, quartzite, and a massive garnetiferous chloritic rock; others west of Keyes Lake are phyllite, conglomerate, lean iron-formation, and a rock composed of medium-grained porphyroblastic chlorite.

Thet strata east of Keyes Lake trend northwestward from the south side of sec. 32, T. 40 N., R. 18 E., and vicinity to the center of adjacent section 31, and the area of exposures widens southwestward into the NW¼ sec. 6, T. 39 N., R. 18 E. The succession of rock types southwest of the quartzite seems to be graphitic argillite, graywacke, graphitic argillite, garnetiferous chlorite rock, graphitic argillite, and quartzite. Graphitic argillite in the southwestern part of section 32 is in contact with the martitic quartzite that is a facies previously described (p. 15), and laminated-to-fissile graphitic argillite also occurs near the southwest edge of the quartzite at several places in the SE¼SE¼ and near the center of sec. 31, T. 40 N., R. 18 E. The adjacent graywacke is mainly greenish gray and is massive (SW¼ sec. 32, T. 40 N., R. 18 E.); laminated to phyllitic (SE¼ sec. 31, T. 40 N., R. 18 E.); and massive, locally magnetic, and with or without small fragments of chert or quartzite (near the center of sec. 31). The second occurrence of graphitic argillite contains associated gray to black siliceous argillite. The chlorite rock is massive to poorly bedded, very dark green to black, and composed predominantly of fine-grained iron-rich chlorite and scattered subhedral reddish garnets as much as 2.0 mm in largest dimension. The graphitic argillite and associated phyllite in the third occurrence are dark gray to black, very fine grained, siliceous, and slightly garnetiferous. The adjacent quartzite is massive, medium to fine grained, and brownish gray to light red. These recurrences of similar lithologies may be a simple south-facing homoclinal sequence, but the repetition of graphitic and clastic rocks also suggest the possibility of three folds. If the graywacke is a facies change between the quartzite occurrences to the north and south, it is along an anticlinal axis. The northern occurrence of graphitic slate is along the axis of a syncline, and the chloritic rock is in another syncline. The problem has not been resolved because adequate structural data were not found.

The sequence of Michigamme strata above the quartzite northwest of Keyes Lake could not be worked out in detail even though test pits are locally abundant and small exposures are scattered along its known length. The maximum width of the area indicated by test pit data to be underlain by these strata is approximately 2,000 feet in the NW¼ sec. 25 and the SW¼ sec. 24, T. 40 N., R. 17 E., but further discussion of the sequence refers to lower and upper parts because a median strip that is mainly from 500 to 1,000 feet wide is generally lacking in both exposures and test pits.

The lower part of the sequence contains mostly meta-argillite, lesser amounts of fine-grained to very fine grained metagraywacke, and a little phyllite. The amounts of very fine grained chlorite, graphite, quartz, and locally small garnets range widely.

The oldest of four local units in the lower part of the sequence is a discontinuous conglomerate that lies adjacent to the south side of the most southeastern quartzite outcrop in sec. 25, T. 40 N., R. 17 E., and is also exposed approximately 200 feet northwest, at the Dunkel exploration, where it was penetrated by a test shaft and short adit. The rock is composed of pebbles of quartz (recrystallized chert or quartzite or both) in a matrix of rounded quartz grains, euhedral magnetite, and fine chlorite. The first mentioned occurrence of conglomerate extends for as much as 6 feet from the quartzite and is gradational into the second unit, which is a magnetite-bearing chloritic silty argillite that is about 4 feet thick. Graphic argillite, the third unit, extends from 10 to 20 feet south from the quartzite and contains porphyroblasts of chlorite; this rock also occurs on the crest of the ridge where it contains garnets about 0.50 mm in diameter. Highly contorted iron-formation, the fourth unit and from 20 to 30 feet south of the quartzite, is composed of chert layers about 1 to 2 inches thick and almost equal amounts of interbedded magnetite-grunerite containing some garnets. The iron-formation strikes northwest and can be followed for about 150 feet across part of the south end of the hill. This is the only known occurrence of magnetite-grunerite iron-formation in the Michigamme in the northern part of the Florence area. Massive magnetite, interlayed magnetite and quartz that is probably metachert, and brown-weathering carbonate with associated magnetite and pyritic chert are present in the dump at the Dunkel exploration. This small area of iron-formation causes a very local magnetic anomaly of about 15,000 gammas (pl. 6), which indicates the local concentration of magnetite. Iron-formation containing stilpnomelane, chert, and locally small amounts of magnetite was also penetrated by a few test pits along the trend of the quartzite, about 900 feet north of the Dunkel test shaft and adit.

Another distinctive rock of unknown position in the sequence above the quartzite is composed almost exclusively of intergrown dark-green to black chlorite flakes as much as 1.0 mm in average dimension. Small euhedral garnets in the chlorite are common at some localities. Partings, generally coated with graphite, occur at intervals of ¼ to 1 inch. The decussate chloritic rock is generally underlain by argillite but locally, along the line between secs. 24 and 25, T. 40 N., R. 17 E., is adjacent to the quartzite. Chlorite porphyroblasts about 1.0 mm in average dimension are also common to abundant in some laminated argillite, and fine graywacke contains much chlorite, graphite, or both. A small amount of siderite containing scattered porphyroblasts of chlorite, with or without small fragments of chert, is exposed at the northwest corner of sec. 24, T. 40 N., R. 17 E.

The highest part of the Michigamme strata for which data are available in the area northwest of Keyes Lake is known almost exclusively from the dumps of two exploratory shafts, several trenches, and numerous test pits in adjacent parts of secs. 23, 24, and 25, T. 40 N., R. 17 E. The order of abundance of these rocks is quartz graywacke, argillite, and stilpnomelane-bearing iron-formation. The quartz graywacke is medium to fine grained and greenish gray, weathering to various shades of red. The argillite is bedded or fissile and greenish gray or black, weathering to red.

The iron-formation is composed of limonite or hematite, which appears to be pseudomorphous after radiating stilpnomelane; it is associated with chert, probably in layers or lenses. Very minor amounts of martite or magnetite are present locally. Exposures of iron-formation, penetrated during exploration, trend northwestward from the Dickey shaft in the SW¼SW¼ sec. 24, T. 40 N., R. 17 E., for a known distance of about 3,000 feet. The width of the area underlain by the explored iron-formation in section 24 ranges from 50 to 200 feet. A linear magnetic anomaly to the east of the Dickey and St. Clair shafts (pl. 8) may indicate that the iron-formation at the Dunkel shaft continues northwestward beyond the limits of the geologic map.

PINE RIVER BLOCK

The Pine River block contains only sparse outcrops, mainly along the Pine River (pls. 1 and 2), and the available data indicate that the area is probably underlain mainly by sedimentary rocks and some volcanic rocks. These strata are the westward extension of the Michigamme Slate from southern Dickinson County of Michigan since no interruption of continuity has been noted (pls. 1 and 4). Exposures of Michigamme Slate in Dickinson County are not large or numerous, but the dominant rock known is sericitic quartzose slate with minor amounts of gray vitreous quartzite and iron-formation consisting of interbedded siderite and chert (Bayley and others, 1966); the rock in the Pine River area is generally similar but locally is much more varied and has not previously been described.

The Michigamme strata in this block are believed to be limited on the south by a major fault beyond which lies the northward-facing Quinnesec Formation of early Precambrian age. These relations also occur in southern Dickinson County (Bayley and others, 1966). The most common rock unit exposed in this block is quartzitic conglomerate in which crossbedding shows that top is southward (pl. 1), but the sequences of the older and younger rocks are still only partly known (fig. 3). To the north the quartzitic conglomerate is underlain by a distinctive and persistent assemblage that includes slate, dark-gray biotitic quartz graywacke, gruneritic iron-formation, and amphibolite. Farther north in a few widely scattered exposures is a gray well-bedded to

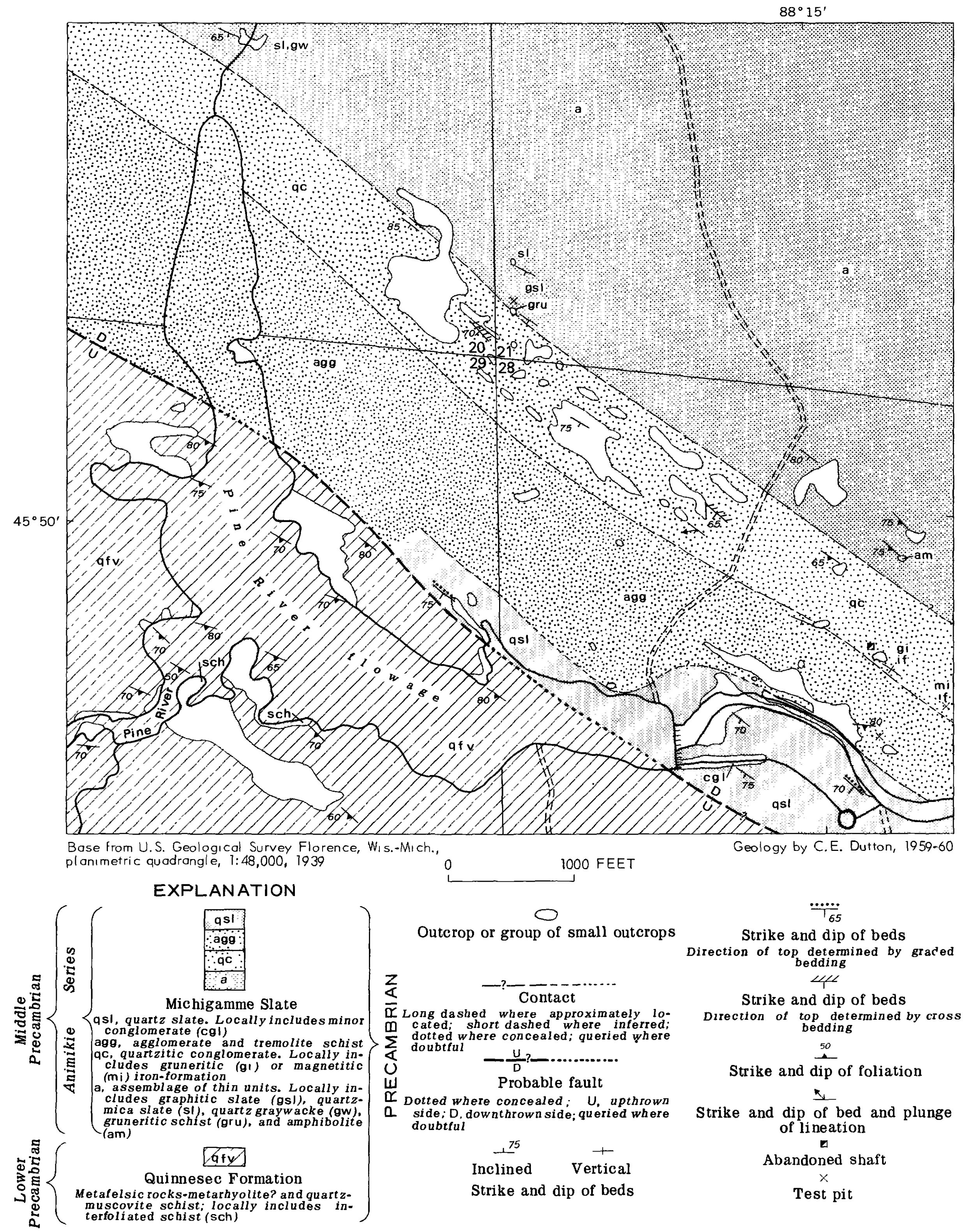

FIGURE 3.—Distribution and relation of the Michigamme Slate and Quinnesec Formation in secs. 20, 21, 28, and 29, T. 39 N., R. 18 E.

laminated sericitic slate or phyllite that probably is the oldest and most extensive unit in this part of the area. The stratigraphic position of iron-formation at and southeast of the quartzitic conglomerate exposures is not known; it is possibly a facies change of the conglomerate but is described separately. To the south the conglomerate is overlain by phyllite and farther south beyond a narrow covered interval by volcanic breccia and then quartz slate with minor beds of conglomerate. The lithology of the informal units in the Michigamme Slate will be described in geographic order from north to south.

SLATE, SCHIST, AND PHYLLITE

Slate along or generally near the Pine River is exposed in sec. 34, T. 40 N., R. 17 E., sec. 3, T. 39 N., R. 17 E. (pl. 2), secs. 27, 28, and 29, T. 39 N., R. 18 E., and secs. 19, 20, and 21, T. 39 N., R. 19 E. (pl. 1). The rock is gray and well bedded in layers approximately one-fourth to one-half inch thick. The percentage of minerals in the rocks is approximated as quartz from 20 to 50; sericite and muscovite from 20 to 70; biotite from 10 to 25; and chlorite, if present, from 5 to 40. Hematite, carbonate, and tourmaline are minor constituents. A little magnetite and pyrrhotite are present locally. The size of the minerals is commonly less than 0.10 mm in diameter, but the micaceous minerals are locally porphyroblastic and are as much as 0.50 mm.

Most schist at these same localities is fine grained and is medium to dark gray and dark green. Chlorite or biotite or both are the principal minerals and are sufficiently abundant and well alined to produce some foliation. Dark red garnets are abundant in the schist near the quartzite; locally they are concentrated in layers and lenses, but they may be minor or absent. Some garnets have been rotated after formation as much as 25°, as shown by the angular discordance between general foliation and the layers of very fine opaque grains within the garnets. Deflected foliation at the boundary surfaces of the garnets also indicates direction but not amount of rotation. Some schist has alternate layers of light and medium gray and is composed chiefly of sericite and quartz. Porphyroblasts of chloritoid as much as 0.40 mm wide and 2.0 mm long have formed across the foliation in schist in the southeastern part of sec. 13, T. 39 N., R. 17 E. Lenticular to equant opaque grains (probably magnetite) about 0.02 mm across are commonly distributed parallel to the foliation in much of the schist.

The phyllite is very fine grained, foliated, and medium to dark gray to dark green. Garnets range from abundant to absent. The composition and relationship of minerals are similar to those in schists, but most grains are about 0.05 mm or less in diameter.

QUARTZ GRAYWACKE

Quartz graywacke is commonly massive but locally slightly fissile, mostly fine grained, and medium to dark gray. Some quartz graywacke grades toward or into fine-grained quartz-biotite schist with only slight foliation.

The graywacke is composed predominantly of anhedral to subangular quartz less than 0.10 mm in maximum dimension and some rounded quartz less than 0.50 mm generally, but as much as 2.0 mm in some sections. Associated intergranular minerals are biotite, chlorite, muscovite, and stilpnomelane (?); each is generally less than 0.10 mm. Very poikiloblastic chloritoid is present locally. Irregular to subhedral garnets occur in some sections and are as much as 3.0 mm in maximum dimension.

AMPHIBOLITE

The amphibolite is massive to irregularly layered, dark gray, and fine to medium grained; it is generally found 10 to 50 feet north of the quartzitic conglomerate. In some hand specimens radiating light-greenish-gray hornblende constitutes areas approximately 1.0 mm in diameter and may range in amount from a little to virtually 100 percent. In other specimens only biotite is readily identified with associated light and dark grains that are probably feldspar and hornblende, respectively; or biotite may enclose scattered hornblende porphyroblasts approximately 1.0 mm long.

The weathered surfaces of some amphibolite commonly exhibit irregularly to well-developed, interlayered, lenticular, or diagonally cross-cutting, medium-grained, dark-green material in or with very fine grained light-gray rock, which contains relatively more feldspar. Layers are from 2 to 10 mm thick. Layering is also evident in fresh rock but is not so conspicuous as where weathered. Weathered surfaces of massive rock are uniformly medium to dark gray, mottled gray, or very light gray mottled with green. Foliated amphibolite has abundant chlorite or sericite on the partings.

The amphibolite as seen in thin section is composed predominantly of hornblende and feldspar, but locally biotite predominates. Magnetite and quartz are commonly present, biotite and chlorite less often. Clinozoisite, sphene, and garnet are found in some thin sections.

Blue-green or olive-green hornblende in sheaves or subhedral grains (2.0 mm maximum) is the most abundant mineral present. Slender prisms in radiating or sheaflike bundles are characteristic; single subprismatic grains are more common than irregular ones, and both are generally poikiloblastic. The hornblende in some sections is partly alined, but well-developed lineation is not characteristic. Most feldspar grains are less than 0.50 mm, irregularly anhedral, and untwinned, but determinations from albite and pericline twinning indicate a small amount of oligoclase and andesine with a composition ranging from An_{21} to An_{42} and an average of An_{33} for a total of 25 grains in sections from five localities. Feldspar and hornblende seem to be present in about equal amounts in most thin sections, but the ratio differs greatly even in parts of the same thin sections.

Grunerite Iron-Formation

The grunerite iron-formation is a poorly to well-layered gray rock that weathers brown. It is composed of radiating gray to brown grunerite masses from 1 to 2 mm in diameter, red to brown garnets, very fine grained quartz, and fine-grained magnetite. Some specimens are highly magnetic, but many are only slightly so or are nonmagnetic. Small amounts of limonite or hematite or both are present in weathered and oxidized specimens.

Quartzitic Conglomerate

The most prominent and best exposed unit in the Pine River block was considered a separate formation by Leith, Lund, and Leith (1935, p. 4) and was designated the Breakwater Quartzite. The unit appears, however, to be a lens in the Michigamme Slate and in this report is considered to be a part of that formation.

The quartzitic conglomerate extends northwestward for about 3 miles from scattered exposures near the center of sec. 28, T. 39 N., R. 18 E., to the northeast corner of sec. 24, T. 39 N., R. 17 E. Outcrops are relatively numerous and individually are larger than those of any other sedimentary unit in the Florence area. Because dips are vertical or steeply southward, the 700-foot width of outcrop probably approximates the true thickness of the unit.

Layers and lenses of quartzite containing a few or many flat pebbles generally predominate. The pebbles, and a few sporadic cobbles, are composed mainly of fine-grained colorless quartz, which is mainly recrystallized chert. Some pebbles of iron-formation show laminae composed of very fine grains of specular hematite or magnetite or both, and a few pebbles are exclusively or predominantly composed of fine-grained hematite or magnetite or both. The pebbles and the plates of specular hematite are oriented in the bedding planes of the conglomerate which are also planes of foliation (fig. 5). A few pebbles are grayish-red jasper, and one cobble of jaspilite was found. The matrix of the conglomerate that contains the ferruginous pebbles is medium gray and composed of quartz, specularite, and magnetite. The matrix of other conglomerates generally contains little or no hematite or magnetite, but interstitial hematitic staining is common.

The quartzite beds associated with the conglomerate are fine grained and range from white or pink with very little or no layering to reddish gray with moderately well developed stratification and much crossbedding. Although closely associated locally, the dark-colored quartzite is more abundant in the eastern part of the outcrop belt and the light-colored one in the western part.

Figure 4.—Predominance of quartz pebbles in quartzitic conglomerate near the Pine River, sec. 28, T. 39 N., R. 18 E.

In addition to the distinct pebbles and cobbles, there are lenticular forms that differ from the enclosing material in that they contain larger grains of quartz and very scarce intergranular iron oxide. The quartzitic conglomerate and associated strata in the Pine River area were mapped and described in detail by Nilsen (1965), who believes that these lenticular forms were originally clasts, rather than lenses of sand, inasmuch as (1) lamination within them commonly does not conform to overall stratification in the conglomerate, (2) cross stratification is absent in these forms although associated materials suggest fairly strong currents, (3) most forms are polygonal and angular rather than lenticular, and (4) platy minerals are virtually absent so that boundaries with the matrix are sharply defined.

Nilsen (1965) showed that the quartzitic conglomerate consists of two conglomerate subunits separted by a quartzite and pebbly quartzite subunit. His paleocurrent analysis based on crossbedding shows that the predominant direction of current flow was southeastward, and he inferred deposition in a shallow nearshore basin. In his opinion the quartzitic conglomerate near Pine River and the quartzite near Keyes Lakes are not correlative; however, the two units show many lithologic similarities even to the associated ferruginous rocks, so they may be the same unit. However, their age relations are insoluble on the basis of present knowledge.

Quartzite in the western part of the outcrop belt has a generally massive appearance; but widely spaced

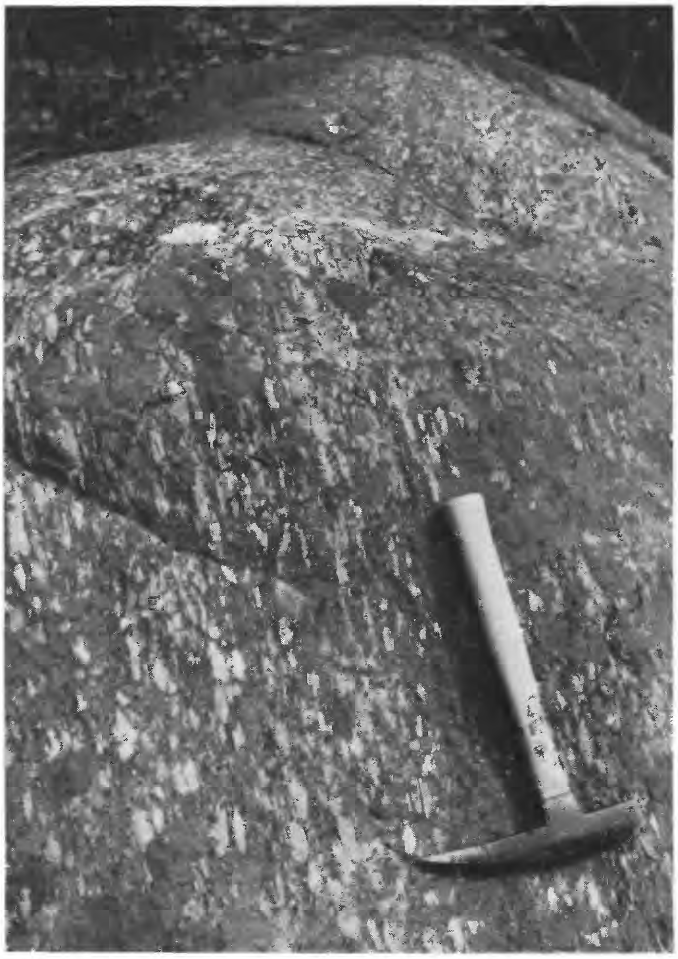

FIGURE 5.—Alinement of pebbles in quartzitic conglomerate, NW¼ sec. 28, T. 39 N., R. 18 E.

partings, which possibly are bedding planes, trend approximately parallel to the base of the unit. Some differences in coloration have a similar trend but are discontinuous. The lower part of the quartzite in sec. 24, T. 39 N., R. 17 E., and sec. 19, T. 39 N., R. 18 E., has a 25-foot pebbly layer that is exceptional in that it contains a garnet-grunerite-magnetite assemblage as the matrix. This association indicates an unexpected contemporaneity of chemical deposition of iron-bearing material and accumulation of the pebbly layer.

The quartzitic conglomerate rests conformably on the underlying strata as observed in sec. 24, T. 39 N., R. 17 E., in the northwestern part of sec. 19, T. 39 N., R. 18 E., and in section 20 of the same township. Strata younger than the quartzitic conglomerate lie conformably above it in sec. 28, T. 39 N., R. 18 E., at the only exposure seen. Another occurrence of younger strata immediately above the conglomerate is reported by Nilsen (1965, pl. 1) to be in sec. 19, T. 39 N., R. 18 E.

IRON-FORMATION

A few outcrops of and test pits in iron-formation in the SW¼NE¼ sec. 28, T. 39 N., R. 18 E. (fig. 3), are 500 to 1,200 feet southeast of the most southeastern exposure of quartzitic conglomerate. The exposed rock appears to be a dense red hematite-quartz iron-formation; but thin sections reveal that the hematite is a secondary weathering product and that the fresh rock is metamorphosed iron-formation composed of grunerite, magnetite, and quartz. Before metamorphism the iron-formation was probably composed of siderite and quartz. Material in the dump of the test pit shown in figure 3 is unweathered and is predominantly magnetite and quartz.

A linear positive magnetic anomaly crests over the occurrences of iron-formation (pl. 7) and, though interrupted at places, appears to extend southeast for 4 miles. Drill holes in the western part of sec. 27, T. 39 N., R. 18 E., passed through Michigamme Slate that locally contained veinlets of pyrrhotite, but the possible relation of the nearby high magnetic values and this mineral occurrence is not known. Exploration by drilling in the NE¼, sec. 34., T. 39 N., R. 18 E., reported penetration of magnetic grunerite schist and associated quartz schist. Another drill hole near the eastern terminus of the anomaly, in the SE¼SE¼, sec. 36, T. 39 N., R. 18 E., cut hematite-magnetite-quartz iron-formation, thus indicating that iron-formation probably causes the magnetic anomaly along much of or all its length. This ferruginous unit is probably cut out to the southeast by the fault that separates the rocks of middle Precambrian age in the Pine River block from rocks of early Precambrian age in the adjacent Popple River block.

The bedding of iron-formation exposed in sec. 28, T. 39 N., R. 18 E. (fig. 3), strikes northwest and, if extended, goes directly to the outcrop of conglomerate overlain by phyllite; and the northwestern continuation of the anomaly just described has similar relations to the outcrop. The probability of the iron-formation being a facies change of the quartzitic conglomerate is suggested by available data. An anomaly in sec. 19, T. 39 N., R. 18 E. (pl. 7), appears to be related to unexposed quartzitic conglomerate and possibly in part to unexposed material south of the contact as shown there and to the southeast in secs. 20 and 29, T. 39 N., R. 19 E. In contrast, however, the anomaly in the northeastern part of sec. 24, T. 39 N., R. 17 E., is related to the basal part of the quartzitic conglomerate that contains magnetite. The value and locally the trend of this anomaly change, but it continues to and beyond the northwest corner of the area shown on pl. 7. The characteristics of the outcrops north and south of the anomaly in secs. 10 and 15, T. 39 N., R. 17 E., are equivalent or identical to those of outcrops in similar positions to the quartzitic conglomerate in its area of exposure. These relations of lithologies and magnetic values to the quartzitic conglomerate unit suggest that iron-formation at, southeast of and possibly northwest of the limit of outcrop may have formed as a facies somewhat comparable to that at the Little Commonwealth area (p. 15) east of Keyes Lake.

Phyllite Above Quartzitic Conglomerate

An exposure of phyllite, about 10 feet wide and 70 feet long, south of and in conformable contact with quartzite containing several pebble bands, occurs near the center of sec. 28, T. 39 N., R. 18 E. (pl. 1 and fig. 3). Most of the rock is laminated, color banded in various shades of gray, and composed chiefly of very fine grained alined flakes of sericite and chlorite and less abundant angular grains of quartz. Tabular masses of chlorite about 0.05 mm wide by 0.20 mm long are common, and a few altered garnets about 1.0 mm in diameter are present in some of the phyllite.

Greenstone Agglomerate

Greenstone agglomerate and associated green schist are exposed in the bluffs north of the Pine River in sec. 28, T. 39 N., R. 18 E., for a strike length of about 1,500 feet and a width of at least 200 feet (fig. 3). Several small exposures occur to the west and northwest in secs. 28 and 29, T. 39 N., R. 18 E. Also, near the north line of sec. 15, T. 39, N., R. 17 E., schistose material is predominant but lenticular fragments are present locally.

The agglomerate is characterized by a predominance of lenticular to subangular greenish-gray fragments from 1 to 12 inches in maximum dimension with material of the same color but finer grain between the fragments. The agglomeratic texture is accentuated on weathered surfaces. Many fragments at this and other localities have small carbonate-filled areas that become pits filled with earthy limonite upon weathering. Much of the rock has been sheared locally, so that the fragmental texture has been partly or entirely destroyed. The principal minerals identified in the agglomerate are actinolite-tremolite, talc, chlorite, and carbonate. The actinolite-tremolite forms radiating clusters in the agglomerate but well-developed prisms in the schist.

Slate and Metagraywacke

Slate and fine-grained quartz graywacke are exposed in the channel and along the banks of the Pine River for about 2,000 feet downstream from the reservoir dam in sec. 28, T. 39 N., R. 18 E. (fig. 3). Most of the rock is well stratified and occurs in layers about 5 to 10 mm thick that differ in shades of gray and in grain size, the darker layers being of finer grain. Only quartz and locally garnet can be identified in hand specimens. Some layers are rich in garnet porphyroblasts that are as much as 6 mm in diameter. Coarse-grained metagraywacke beds a few inches thick occur locally; these contain abundant granules 2 to 4 mm in diameter. A few layers of coarser clastics that contain fine-grained quartzitic material in lenses and also lenticular particles of granule and pebble size were exposed in the canal from the dam to the power plant when the water was diverted in 1959.

The slate contains a few ellipsoidal dark-green masses 1 to 3 inches long and rich in chlorite and amphibole; in thin section chlorite can be seen to fill the space between abundant clusters of colorless amphibole (probably tremolite-actinolite). These ellipsoids are probably metamorphosed concretions that were relatively rich in carbonate. The Michigamme Slate contains such concentrations in several localities in Michigan, for example, in the SE¼ sec. 20, T. 45 N., R. 30 W. (James, 1955, pl. 2).

THICKNESS AND CONDITIONS OF DEPOSITION

The lower and upper contacts of the Michigamme Slate are exposed only in the northern part of the mapped area, where the thickness of the formation is about 5,000 feet or possibly less. Faults bound all other exposures of the formation except at its contact with the Badwater Greenstone in the northeast corner of the southern part of the area. The greatest inferred thickness is about 20,000 feet, in the Pine River block (pls. 1 and 4), where the formation may be least faulted and folded.

The great thickness and the predominance of clastic deposits in the Michigamme Slate indicate probable deposition in a subsiding basin that received an abundance of disintegrated material from which slate, graywacke, and conglomerate formed. Two iron-formation units formed by associated chemical concentration and deposition. Minor vulcanism added fragmental material that is now greenstone agglomerate. The thickness and lithology of the sedimentary rocks and the presence of volcanic rock suggest a general environment of deposition in an orogenically disturbed area.

AGE AND CORRELATION

The Michigamme Slate is of middle Precambrian age and is the most widely distributed sedimentary unit in the Precambrian sequence of northern Michigan and adjacent areas of Wisconsin. From the Florence area the Michigamme extends eastward into Dickinson County, Mich., northward to the Marquette district, and presumably northwestward toward the Gogebic district.

The formation is possibly the correlative of at least part of the Virginia Slate in Minnesota (James, 1958, table 2; Cotter and others, 1965).

BADWATER GREENSTONE

DEFINITION, DISTRIBUTION, AND GENERAL LITHOLOGY

The Badwater Greenstone was named by James (1958, p. 37) for exposures of metabasalt near Badwater Lake in southern Dickinson County, Mich. The greenstone extends northwestward from the type locality across the northern part of the Florence area, with scattered exposures for a length of about 9 miles (pl. 2), and continues northward into Iron County, Mich. The greenstone unit has an apparent thickness that ranges from about 5,000 to 15,000 feet. Outcrops of Badwater Greenstone near the western edge of the northern half of the Florence area represent another part of the formation that trends northwestward for 3 miles beyond the mapped area and continues into Iron County (pl. 4); the western limit and probable thickness of this occurrence are not known. Outcrops of greenstone and associated metasedimentary rocks west of Keyes Lake are believed to belong to the Badwater Greenstone. These outcrops are within an area about 1 mile wide and 1½ miles long.

The only known exposure of the Badwater Greenstone in contact with the underlying Michigamme Slate is in the NE¼SE¼ sec. 18, T. 40 N., R. 19 E.; here the greenstone is conformable with garnetiferous phyllite. No contacts with the overlying Dunn Creek Slate are known in the mapped area, but a conformable relationship between these formations is assumed.

One of the important results of the present investigation of the Florence area was the finding of field evidence which indicated the stratigraphic positions of the Badwater Greenstone and the Paint River Group. The Michigamme slate-graywacke assemblage in the northern part of the mapped area has long been known to extend northwestward and then northeastward to the type locality of the Michigamme Slate at the middle of the west side of Marquette County, Mich. (fig. 1). The stratigraphic relation of the Michigamme Slate and the adjacent Badwater Greenstone was not proved until 1955 when graded bedding in quartz graywacke at or very near the top of the Michigamme was observed by H. L. James, K. L. Wier, and C. E. Dutton. The grading indicates that the tops of the beds are toward the nearby Badwater Greenstone in the SW¼ sec. 12, T. 40 N., R. 18 E., of Wisconsin (pl. 2). Furthermore, ellipsoidal (pillow) structures in the greenstone consistently indicate the tops to face south (as in secs. 14, 22, and 23, T. 40 N., R. 18 E., and sec. 12, T. 40 N., R. 17 E.) toward the Paint River Group in the vicinity of Florence (pl. 2). Thus the relative stratigraphic positions of the Badwater Greenstone and the Paint River Group were also clarified for Iron County, Mich.

The most common rock in the Badwater Greenstone in the Florence area is massive greenish-gray metamorphosed flow basalt. In addition to typical greenstone and also amphibolite, derived from the highest grade of metamorphism of basalt, the formation contains some stratified rocks that are commonly argillaceous to arenaceous but locally are tuffaceous. Thin iron-rich beds are also present.

GREENSTONE

Greenstone, derived through low-grade metamorphism of basalt extrusives, is the most abundant rock type in the Badwater Greenstone. It is exposed in the Brule River block for almost 9 miles northwestward from sec. 20, T. 40 N., R. 19 E. Exposures are most numerous, steep, and rugged along the Menominee and Brule Rivers but are sparse, low, and rounded elsewhere. The maximum width of the outcrop belt is about 3 miles. Other outcrops of greenstone in this block form small scattered knobs in the southeast corner of the area shown on plate 2 and the northeast corner of the area shown on plate 1. Exposures of the greenstone in the Keyes Lake block occur in secs. 21, 27, 28, 35, and 36, T. 40 N., R. 17 E. (pl. 2).

The greenstone flows are generally massive but locally ellipsoidal (fig. 6) or slightly foliated. Some exposures

FIGURE 6.—Ellipsoidal (pillow) structure in the Badwater Greenstone, SW¼ sec. 27, T. 40 N., R. 17 E.

are agglomeratic. Ellipsoids are commonly 18 to 24 inches long and about 9 inches wide. The rocks are predominantly light greenish gray, but greenish gray or medium gray are local variations. The grain size is normally very fine but ranges to medium.

In thin sections, texture is commonly a fine-grained mosaic that encloses amygdule fillings of quartz, clinozoisite, or carbonate. Actinolite or actinolitic hornblende and clinozoisite-epidote are the most abundant minerals in the mosaic. Twinned subhedral plagioclase, chlorite, sphene, and carbonate occur in subordinate amounts. Leucoxene, quartz, and biotite are minor constituents. The twinned plagioclase is albite with composition range of an_{9-0}.

Phyllitic and slightly schistose rocks that are locally associated with greenstone are composed of alined very fine grained chlorite and quartz and locally also biotite. The phyllites probably represent local thin accumulations of sedimentary or volcanic debris.

AMPHIBOLITE (METABASALT)

The Badwater metabasalts near the confluence of the Brule and Michigamme Rivers show the highest grade of metamorphism in the formation. Exposures are found in the SW¼SW¼ sec. 12, and in the NW¼NW¼ sec. 13, T. 40 N., R. 18 E. The rocks are amphibolite and are medium gray on weathered surfaces, dark gray to black if unweathered. They are fine grained, but granular hornfelsic texture is readily visible. The amphibolite is generally dense and uniform; locally, in sec. 13, it is amygdaloidal.

The principal minerals in the amphibolite are hornblende and plagioclase; associated minerals are clinozoisite, epidote, biotite, quartz, magnetite, and leucoxene. The hornblende is the predominant constituent in the thin sections examined. The characteristic pleochroism is *X*, pale yellowish gray; *Y*, light grayish olive; *Z*, light grayish blue green. Extinctions ($Z \wedge c$) range from 15° to 24°. Slender to stubby prismatic forms (0.5mm) with irregular terminations are prevalent. The plagioclase is andesine and is the second most abudant mineral in the amphibolite. The range in composition of plagioclase in two thin sections is from An_{28} to An_{37}.

Clinozoisite and epidote or only epidote are present in about half the thin sections examined. Biotite is a subordinate or minor constituent in most sections, and in some appears to be an alteration product of hornblende. Quartz is present in minor amounts in most sections and is of anhedral form. Amygdule fillings are most commonly quartz, chlorite, biotite, and carbonate.

IRON-FORMATION

The most distinctive metasedimentary rock in the Badwater Greenstone is the grunerite-magnetite-quartz iron-formation that occurs in at least two discontinuous layered units approximately 10 to 50 feet thick in the western part of the Keyes Lake block. Exposures are few, scattered, and generally less than 10 square feet in area, but the position of the iron-formation at the bedrock surface is indicated by several old test pits and shafts and also by magnetic surveys (pls. 2, 6, and 8). The iron-formation is brown to reddish brown and moderately well stratified in alternate layers that differ in relative amounts of grunerite and quartz. Grunerite and magnetite can readily be seen with a hand lens, but quartz grains are too small to be recognized. Associated minerals seen in thin sections are hematite, garnet, stilpnomelane, carbonate, brown biotite, green biotite, and, rarely, glaucophane.

The grunerite is commonly in randomly oriented irregularly terminated prisms that average 0.10 mm wide and 0.50 mm long. A small amount of grunerite occurs in radiating or sheaflike aggregates that are 1.0 to 3.0 mm. Some grunerite has been partly or completely oxidized and replaced by pseudomorphs of hematite. Subangular quartz grains approximately 0.10 mm in diameter have formed by recrystallization of chert, but other quartz is pseudomorphic after grunerite and is chalcedonic. Magnetite grains are irregular to euhedral and commonly about 0.5 mm. Subhedral garnets, stilpnomelane needles, small subangular carbonate grains, and irregular flakes of brown and green biotite are minor constituents. Some biotite has been partly or completely altered to chlorite. The glaucophane is in blue blades about 0.15 by 0.50 mm long that have normal pleochroism and about 9° extinction ($Z \wedge c$).

The magnetic crestlines shown on plate 2 are based on a magnetometer survey of sec. 36, T. 40 N., R. 17 E., and adjacent areas (see pl. 6 and p. 45 of this report by K. L. Wier and R. A. Solberg. Two approximately parallel magnetic anomalies caused by iron-formation trend northwestward through the western half of sec. 36 into sec. 26, T. 40 N., R. 17 E., and very similar trends occur in sec. 35, T. 40 N., R. 17 E., and sec. 1, T. 39 N., R. 17 E. Thinly stratified quartz-sericite slate crops out at several places between exposures of the iron-formations or the anomalies that result from them. Although the distribution of anomalies suggests possible repetition of iron-formation by simple anticlinal or synclinal folding, such interpretation seems to be contradicted in the southern part of section 26 because the projected trends of the paired anomalies converge as in a southeast-plunging syncline. Further consideration of this subject is given in the general discussion of geologic structure (see p. 39).

Two thin discontinuous grunerite-magnetite-quartz iron-formation units separated by quartz-sericite slate also occur at the line between secs. 27 and 28, T. 40 N., R. 17 E. These units trend southeast, as shown by the magnetic crestlines, and the projection of the southern one converges in section 27 with another crestline that trends southwest (pl. 2 and 8). The structure is interpreted as an anticlinal fold that is plunging southward.

SLATE, METAARGILLITE, AND QUARTZ GRAYWACKE

Most sedimentary rocks associated with the metabasalt of the Badwater Greenstone west and northwest of Keyes Lake consist of gray, very fine grained (less than 0.10 mm) material in which stratification, cleavage, or parallelism of platy and acicular minerals may or may not be present. "Slate" is the designation generally used for the rocks, but it is proper for only a few; most are metaargillite or fine-grained quartz graywacke. Quartz, chlorite, and biotite are commonly the dominant constituents. Sericite, garnet, hornblende, feldspar, pyrite, hematite, magnetite, and graphite range widely in abundance and generally are subordinate to rare.

Most of the minerals have normal characteristics and relationships for rocks of this type, but a few distinctive features are present. Some garnets have been rotated during crystallization as indicated by the S-shaped distribution of inclusions from pre-existing foliation. Poikilitic hornblende porphyroblasts are as much as 1.8 mm wide and 4.5 mm long. The moderate to strong pleochroism of the mineral is *X*, pale straw; *Y*, pale-grayish green; and *Z*, grayish blue. Extinction in various sections ranges from 16° to 25°. The hornblende increases in abundance and grain size with proximity to metagabbro.

One variety of slate has sericite and quartz as the principal constituents with subordinate or minor amounts of chlorite and biotite. This slate crops out in secs. 35 and 36, T. 40 N., R. 17 E., and lies between the two thin iron-formation layers mentioned previously. The slate is light to medium gray, well stratified in beds less than 1 inch thick, and has moderately developed cleavage that is at an angle of about 45° to the stratification. Poorly developed graded bedding is visible in some thin sections.

Hornblende and chloritoid porphyroblasts in slates and slightly schistose rocks commonly have a random orientation, and adjacent foliation has been deflected. Foliation preserved in these minerals, as in the garnets, may be parallel to or rotated from the general trend in the rock.

Another variety of slate examined contains minor to dominant amounts of quartz, amphibole (hornblende?), chlorite, and biotite; magnetite and epidote are minor constituents in a few specimens, and garnet is subordinate to dominant in a few others. The grain size in all sections of this slate ranges mainly from 0.05 to 0.2 mm, but many amphibole grains are 1.0 to 3.0 mm long. Most of the slate of this variety is in contact with or close to metagabbro in secs. 26, 27, 28, 35, and 36, T. 40 N., R. 17 E., and secs. 1 and 2, T. 39 N., R. 17 E. The known distribution of this variety of slate suggests that it is a metamorphic rock rather than a stratigraphic unit, but data are inconclusive. The slate is medium to dark gray and generally exhibits little stratification; locally foliation is moderately developed. In thin sections, amphibole is the most conspicuous component of this variety of slate; it is commonly present as radiating to sheaf-like slender prisms, as poorly to well-developed porphyroblasts, or as irregular and stringy masses. Sieve structure resulting from included quartz is common. Foliation of the slate is interrupted by randomly oriented porphyroblasts and may be bent adjacent to them. Garnets interrupt foliation and deflect it, especially where they have been rotated. Garnets commonly are 0.5 to 1.5 mm in diameter and are subhedral to euhedral.

Thinly bedded gray slate and black graphitic slate containing small garnets are exposed in the SW¼SE¼ sec. 26, the SE¼SW¼ sec. 27, T. 40 N., R. 17 E., and at several places in the NW¼ sec. 1, T. 39 N., R. 17 E.

Quartz metagraywacke is locally present in the Badwater Greenstone and layers as much as several inches thick are interbedded with slate. The metagraywacke is grayish dark green, phyllitic, and contains fine (0.10 to 0.50 mm) grains of quartz that can be readily identified with a hand lens in bright light. In thin sections the metagraywacke is seen to be composed of scattered angular quartz grains and a small amount of rounded twinned and untwinned feldspar as much as 0.20 mm in diameter; but most grains are less than 0.05 mm and are anhedral quartz, biotite, chlorite, and some feldspar.

Some chlorite- and stilpnomelane-bearing rocks, probably metasedimentary, are exposed along the line between secs. 22 and 23, T. 40 N., R. 18 E., and along the Brule River in secs. 7 and 8, T. 40 N., R. 18 E. Chlorite and stilpnomelane(?) are dominant; accessories are feldspar, epidote, leucoxene, and quartz. The rocks are almost phyllitic, but the chlorite and stilpnomelane do not have sufficiently well developed parallel orientation to produce good foliation.

TUFFACEOUS(?) ROCKS

A gray phyllitic rock that probably was originally pyroclastic was found on a test pit dump near the Brule River in the SE¼NW¼ sec. 14, T. 40 N., R. 18 E., Wisconsin. The phyllite is a greenish-gray slightly foliated rock that contains very fine white grains and locally is altered to grayish maroon. In thin section the rock is seen to be composed mostly of very fine grained elongate chlorite less than 0.05 mm in length, angular quartz grains less than 0.10 mm, and scattered untwinned cloudy feldspar grains that are euhedral and anhedral and as much as 0.15 by 0.25 mm. The weathered maroon areas of the phyllite contain spots of hematite as much as 0.20 mm in maximum dimension and hematitic alteration of chlorite.

PAINT RIVER GROUP

The name Paint River Group was used by James (1958, p. 37) to designate the strata of middle Precambrian age that are younger than the Badwater Greenstone in the Iron River–Crystal Falls area, Iron County, Mich. (pl. 4). The group comprises, in ascending order, the Dunn Creek Slate, Riverton Iron-Formation, Hiawatha Graywacke, Stambaugh Slate, and Fortune Lakes Slate. These formations lie within a triangular synclinal basin with apices at Iron River and Crystal Falls, Mich., and at Florence, Wis. The Paint River Group in the Florence area occurs only in the Commonwealth syncline and in a smaller syncline in the Keyes Lake block (pl. 2 and 4).

The Dunn Creek Slate is mainly gray metasiltstone and slate, but the uppermost part is a pyritic graphitic slate. The Riverton Iron-Formation is interbedded siderite and chert where fresh, hematite-limonite chert where oxidized, and grunerite-magnetite chert where metamorphosed. The Hiawatha Graywacke is predominantly massive metagraywacke that commonly contains angular fragments of chert. The Stambaugh Slate is in part, and most characteristically, laminated cherty siderite and magnetite in Iron County, Mich.; this type of rock is absent or very rare in the Florence area. The formation in Michigan also includes chloritic mudstone and slate. Similar rocks in Wisconsin are slightly magnetic and along the projected southeasterly trend of the formation are probably correlative. Rocks in the mapped area that are probably equivalent to part of the Fortune Lakes Slate are slate, associated with thin beds of graywacke, and locally minor amounts of chert-siderite and sideritic slate. The Hiawatha Graywacke, Stambaugh Slate, and Fortune Lakes Slate are not sufficiently well exposed or explored in the Florence area to be mapped separately, except in the northwest corner, and elsewhere constitute a map unit of undifferentiated post-Riverton strata.

On the basis of areal geology, the Paint River Group in the Florence area is estimated to be probably at least 3,000 feet thick. The group locally lies uncomformably on the underlying Badwater Greenstone in the Florence area and is locally unconformable on the Michigamme Slate near Crystal Falls, Mich. The only strata known to overlie the group are two small areas of sandstone of probable Late Cambrian age that occur near Commonwealth but are not shown on the map.

The Paint River Group is composed predominantly of clastic materials (sand and mud) that accumulated in a basin characterized by widespread uniformity for relatively long intervals. Shorter intervals of widespread uniformity were characterized by stagnant and reducing conditions in which carbonaceous mud accumulated. Chert-siderite formed in clear water and a reducing environment of a barred basin or basins in which concentration by precipitation and settling exceeded overflow. Some chert-siderite of the Riverton Iron-Formation was subjected to erosion, probably by wave attack below water level, and fragments of chert were concentrated in place forming a residual breccia or were swept into and embedded in the sandy mud from which the overlying Hiawatha Graywacke formed.

The Paint River Group is of middle Precambrian age and is the youngest group of the Animikie Series known in Michigan. James (1958, table 2, p. 35) considered the Paint River Group to be younger than the Virginia Slate, the youngest formation of the Animikie Group in Minnesota.

DUNN CREEK SLATE

DEFINITION AND DISTRIBUTION

The Dunn Creek Slate is at the base of the Paint River Group and was named for exposures of siltstone and slate near Dunn Creek south of Crystal Falls, Mich. (James, 1958). The Dunn Creek Slate in the Florence area is exposed in a few small outcrops, in open pit mines, and at test pits in four localities.

1. The formation is exposed at and near the Florence mine for at least 1½ miles in secs. 17, 20, and 21, T. 40 N., R. 18 E. (pl. 2 and 3).
2. The next exposures are about 5 miles northwest, in Michigan, in sec. 31, T. 42 N., R. 32 W., which is 6 miles south of the type locality.
3. The Dunn Creek Slate extends southeastward from the Florence mine to exposures southeast of the village of Commonwealth, in secs. 34 and 35, T. 40 N., R. 18 E., near the Badger mine (pl. 2). The formation in this part of the area is in a northwest-plunging syncline. Exposures on the south limb of the syncline were present along county road N in the southwestern part of section 34 prior to widening of the road in 1967.
4. The Dunn Creek Slate is also exposed in parts of secs. 26, 27, 34, and 35, T. 40 N., R. 17 E. (pl. 2), as part of an isolated complexly folded south-plunging syncline. It extends northward into sec. 22, T. 40 N., R. 17 E.

DESCRIPTION

Slate, metasiltstone, and metagraywacke are predominant in the type area of the Dunn Creek Slate and possibly also in the Florence area. The limited data suggest, however, that true slate is present only locally and that classification as argillite and phyllite is appropriate.

Most of the exposures of the Dunn Creek Slate in the Florence area consist of graphitic rock. It forms the uppermost part of the formation close to the contact with the Riverton Iron-Formation and seems to be a direct correlative of the Wauseca Pyritic Member (James, 1958, p. 38) in Iron County, Mich. These graphitic rocks are laminated to thinly bedded, commonly pyritic, and in places complexly folded or contorted. Locally they have well-developed cleavage (fig. 7). The laminated graphitic argillite previously exposed just below Riverton in a cut on the east side of county road N in the SW¼ sec. 34, T. 40 N., R. 18 E., is composed of graphite and limonite (after pyrite) and contains many altered porphyroblasts of chlorite approximately 0.10 by 0.40 mm. Table 3 (lab. No. 14999) shows a chemical analysis of this rock; it is one-half silica with organic carbon and iron oxides as the principal associated constituents.

Laminated graphitic argillite, also not exposed now, on the west side of the cut along county road N is underlain by a massive graphitic breccia in which chips and fragments of graphitic slate or argillite less than one-half inch in maximum dimension are randomly scattered. The fragments commonly break along foliation, and the bright reflection of light from these surfaces contrasts conspicuously with the overall dull appearance of the very fine grained matrix (fig. 8). This breccia is exposed in roadside excavations to the south and west from the northwest corner of sec. 35, T. 40 N., R. 17 E., on the west side of the open pit exploration near that corner, and in a test pit 1,500 feet west and 250 feet north of that corner. This very distinctive breccia occurs throughout the Crystal Falls and Iron River areas to the north and west; its presence in the Florence area adds greatly to its known extent. A chemical analysis of the breccia from the roadcut is given in table 3 (lab. No. 15000); silica makes up slightly over half of the rock, and organic carbon is the only other abundant constituent.

FIGURE 7.—Pencil slate produced by intersection of axial-plane cleavage and bedding-plane parting, Dunn Creek Slate, SW¼ SW¼ sec. 34, T. 40 N., R. 18 E.

The fine-grained clastic rocks in the mapped area are mainly phyllite, but argillite, slate, and metasiltstone are also present. All have approximately the same mineral composition, so only the phyllite is described.

Phyllite is generally some shade of gray or greenish gray and is laminated or thinly bedded. The principal minerals are fine-grained sericite, chlorite, and quartz. Differences in ratios and orientation of these minerals determine the color of the beds and the degree of foliation. The most common type of phyllite has dark-gray layers of very fine alined chlorite and sericite with alternate greenish-gray layers of very fine angular quartz and intergranular chlorite; the quartzose layers are about 2 mm thick, and the micaceous layers range from partings to 2 mm in thickness. Some phyllite is uniformly light gray, well foliated, and composed of very fine chlorite, sericite, and quartz. A third variety is predominantly green and chloritic when fresh but red and hematitic when weathered. Associated with gray phyllite are layers from ⅛ to 1 inch in thickness that

TABLE 3.—*Chemical analyses, in percent, of specimens from the Dunn Creek Slate in Florence, Wis., area*

[Lab. Nos.: 14999, laminated graphitic slate from roadcut, southwestern parts of sec. 34, T. 40 N., R. 18 E.; 15000, graphitic slate breccia from same roadcut as lab. No. 14999; 15005, graywacke from test pit in the SW¼NW¼ sec. 21, T. 40 N., R. 18 E. Analysts: P. L. D. Elmore, S. D. Botts, M. D. Mack. Rapid analysis method used]

	Lab. No.		
	14999	*15000*	*15005*
SiO_2	49. 8	53. 9	61. 7
Al_2O_3	6. 7	8. 3	17. 0
Fe_2O_3	16. 9	. 9	2. 2
FeO[1]	1. 0	. 22	6. 0
MgO	1. 0	. 52	3. 0
CaO	. 10	. 07	. 17
Na_2O	. 10	. 29	. 09
K_2O	2. 1	2. 5	4. 3
TiO_2	. 28	. 51	. 84
P_2O_5	. 02	. 00	. 05
MnO	. 03	. 01	. 04
H_2O	3. 2	1. 6	3. 6
CO_2	<. 05	. 08	. 05
Organic carbon	15. 9	29. 4	--------
Total	97. 18	98. 30	99. 64

[1] FeO values may be in error because of the presence of organic matter in the samples.

FIGURE 8.—Graphitic slate breccia in the Dunn Creek Slate, SW¼SW¼ sec. 34, T. 40 N., R. 18 E.

are minutely porous and predominantly quartz. Thin sections of this material show many angular quartz grains probably cemented by interstitial quartz containing very fine opaque material that is presumably graphite. The reason for the characteristic porosity is not known; it may be caused by the solution of interstitial quartz.

Metagraywacke in the Dunn Creek Slate occurs interbedded with phyllite and is mineralogically the same except that it contains clastic quartz grains as much as 0.5 mm across and sparse altered feldspar grains. The fresh rock is medium gray; the weathered is grayish red to dark red. Locally, thin beds of quartzite not more than 1 inch thick are interbedded with the phyllite and metagraywacke. A chemical analysis of graywacke from north of the Florence mine is given in table 3 (lab. No. 15005); silica is the main constituent and alumina the principal associate.

The Dunn Creek Slate in secs. 26, 27, 34, and 35, T. 40 N., R. 17 E., is more metamorphosed than at Commonwealth and Florence. Biotite is commonly present instead of sericite and chlorite and makes up 5 to 50 percent of the thin sections. Subrounded garnets are as much as 0.25 mm across, and irregular garnet areas that include biotite and quartz are as much as 0.5 by 1.0 mm. One specimen contained abundant hornblende, with many inclusions, in a wide range of sizes reaching 1.0 by 1.0 mm in maximum dimensions.

The Dunn Creek Slate is exposed in the northwest corner of the mapped area (pl. 2). Most of the outcrops consist of gray to black slate with locally some chert. The northernmost outcrops are laminated graphitic slate.

THICKNESS AND RELATIONS TO ADJACENT FORMATIONS

The thickness of the Dunn Creek Slate can only be estimated from the areal pattern. The width of the formation northeast of Commonwealth is shown on the maps as 2,500 feet, which may approximate or exceed its average thickness. Increased width shown southeastward is probably due to repetition of beds caused by folding related to the major synclinal axis. The forma-

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tion apparently thins northwestward from Commonwealth and does not extend to the Brule River in sec. 12, T. 40 N., R. 17 E., but reappears in Michigan and is exposed in the northwest part of the mapped area. The limits of the formation south of sec. 34, T. 40 N., R. 18 E., and of its extension west of that section are not known.

No contact of the Dunn Creek Slate and the underlying Badwater Greenstone was found in the Florence area. Gray phyllite occurs in a test pit 500 feet northwest of the greenstone outcrop in the northeast part of sec. 20, T. 40 N., R. 18 E. (pl. 3). This is the closest the two formations are known to come together.

The Dunn Creek Slate is generally overlain conformably by the Riverton Iron-Formation, but northwest of Florence the Riverton is missing, and therefore post-Riverton strata rest unconformably on the Dunn Creek Slate.

CONDITIONS OF DEPOSITION

The Dunn Creek Slate marks the return to deposition of fine-grained clastic sediments after the volcanic eruptions that formed the Badwater Greenstone. The conditions of deposition further changed during Dunn Creek time as land-derived detritus decreased, circulation of water in the depositional basin decreased, and accumulation of pyritic black mud increased. Then either a very widespread submarine slump (James, 1958, p. 38), a turbidity flow, or a roiling by an earthquake tremor occurred. This disturbance formed the graphitic breccia with its chaotic character, wide extent, and absence of extraneous material. A return to quiescent conditions is indicated by subsequent deposition of laminated graphitic slate (argillite).

AGE AND CORRELATION

The stratigraphic unit that lies between the greenstone and the iron-formation in the Florence area is believed to be of the same age as the Dunn Creek Slate to the northwest in Iron County, Mich., because the stratigraphic position is similar to that in the type area. Furthermore, the pyritic graphitic slate and the distinctive graphitic breccia subunit in the sequences in the Florence area and the Crystal Falls and Iron River, Mich., areas are lithologically equivalent.

RIVERTON IRON-FORMATION

DEFINITION AND DISTRIBUTION

The Riverton Iron-Formation was named (James, 1958) for the abandoned Riverton mine where the first mining in the Iron River area began in 1882. The Riverton Iron-Formation occurs in a major northwest-plunging syncline near Florence and Commonwealth, in an irregular southeast-plunging syncline 5 miles west of Commonwealth, and possibly in a few scattered outcrops to the north of this locality (pl. 2). From the Florence mine in secs. 20 and 21, T. 40 N., R. 18 E. (pl. 3), the iron-formation extends northwestward for only a short distance into the SW¼ sec. 17, T. 40 N., R. 18 E., where the formation above the Riverton apparently lies directly on the Dunn Creek Slate. The Riverton Iron-Formation reappears northwestward in and beyond the northwest part of the mapped area (pl. 2.). Southeastward from the Florence mine the formation extends to the southeast corner of sec. 34, T. 40 N., R. 18 E., turns westward at the axis of a northwest-plunging major syncline, and then continues to a faulted and indefinite termination in the northern part of sec. 4, T. 39 N., R. 18 E. The westernmost exposures occur in parts of secs. 26, 27, 34, and 35, T. 40 N., R. 17 E.; this area is approximately 4 miles southwest of the Florence mine and the same distance west of the termination in section 4 (pl. 2). A small isolated occurrence of Riverton is found in the northwest corner of sec. 26, T. 40 N., R. 17 E., and the adjacent part of section 23. Smaller isolated exposures of iron-formation in the east-central part of secs. 22 and 27, T. 40 N., R. 35 W., are probably also part of the Riverton.

DESCRIPTION

James (1954) recognized four facies in the sedimentary iron-formations of the Lake Superior region: Sulfide, carbonate, oxide, and silicate. The carbonate facies consists of interbedded siderite and chert, and is known to be present at least locally in the Florence area (pl. 3). Alteration of this facies has produced three secondary types—oxidized iron-formation, iron ore, and grunerite-magnetite-quartz iron-formation. Chert in the primary and secondary types of iron-formation occurs generally as layers but may occur locally as lenses or rarely as fragments.

In the carbonate facies, siderite and chert occur in approximately equal amounts, each being predominant in alternate layers that generally range in thickness from ½ to 3 inches. Siderite is fine grained and banded in shades of gray that mark the stratification. Chert is mottled gray, lighter than the siderite, and has a fine-grained sugary texture. This type of iron-formation is in a few very small exposures and test pits northwest of the Florence mine (pl. 3), in small amounts in the dumps of the Ernst mine and Welch exploration (pl. 2), and was very sparingly in the east side of a former excavation along county road N in the southwestern part of sec. 34, T. 40 N., R. 18 E. A chemical analysis of siderite-chert iron-formation from the Riverton Iron-Formation at the Welch exploration is given in table 4. The metallic iron content is 22.3 percent, and a common average for siderite-chert iron-formation in the Iron River–Crystal Falls area is 25 percent.

The examination of thin sections of siderite-chert iron-formation indicates that siderite ranges from 0.02 to 0.05 mm across and chert from 0.05 to 0.10 mm; both are commonly subangular. Some sections contain scattered rectangular areas of chlorite as much as 0.15 by 0.07 mm in size. Scattered siderite areas in chert are about 0.15 by 0.10 mm.

Hematite or limonite or both, with interbedded chert, have formed from the siderite-chert iron-formation by oxidation of the siderite. The iron oxides are generally fine grained, dull, soft, and compact; but locally they are relatively hard, somewhat glossy, and break with a conchoidal fracture. As in the unaltered iron-formation, the iron-rich and silica-rich layers occur in approximately equal amounts. This oxidized iron-formation averages about 35 percent iron. Siliceous limonitic or hematitic material with embedded angular chert fragments is in the upper part of the Riverton or basal part of the Hiawatha in small exposures across the southern part of sec. 27, T. 40 N., R. 17 E., and in the northeastern part of sec. 4, T. 39 N., R. 18 E.

Iron ore has formed locally from siderite-chert iron-formation by oxidation of siderite and by leaching of chert, or by a much more extensive replacement than took place when the hematite-limonite-chert iron-formation was formed. Iron ore shipped from mines in the Florence area ranged from 48 to almost 51 percent metallic iron as mined, and 52.5 to 56.5 percent if dried. The iron content of limonite is 60 percent and of hematite 70 percent, but admixtures of chert and argillaceous rock with the ore minerals lower the grade.

Regional metamorphism of siderite-chert iron-formation has produced grunerite-magnetite-quartz iron-formation in secs. 26, 27, 34, and 35, T. 40 N., R. 17 E. The metamorphosed iron-formation is an aggregate of abundant grunerite and scattered red to brown garnets as much as 2.0 mm in size and euhedral magnetite as much as 1.0 mm. Metachert is generally present as layers or lenses but is not as distinctly separated as in other types of iron-formation because of the growth of grunerite at the interfaces. Metachert that ranges from scattered fragments to concentrations of randomly oriented pieces as much as 1 inch thick and 6 inches long is present locally. Gruneritic iron-formation in the northwestern part of sec. 35, T. 40 N., R. 17 E., has been altered and sufficient soft hematite and limonite formed to warrant exploration and shipment of some material from a small open pit. Grunerite is in small light-golden to brown blades that are commonly arranged radially in clusters about 2.0 mm in average diameter or randomly in decussate manner. The recrystallized quartz forms a mosaic of grains about 0.05 to 0.10 mm in diameter with smooth boundaries. Quartz at the margins of former chert layers and fragments is commonly elongate and divergent as if pseudomorphous after grunerite but has irregular extinction as in chalcedony.

TABLE 4.—*Chemical analysis, in percent, of interbedded siderite-chert from the Riverton Iron-Formation, Florence, Wis., area*

[Location: Welch exploration, NW¼ sec. 34, T. 40 N., R. 18 E. Analysts: P. L. D. Elmore, S. D. Botts, M. D. Mack. Rapid analysis method used. Lab. No.: 15004]

SiO_2	45.4	TiO_2	.05
Al_2O_3	1.8	P_2O_5	.41
Fe_2O_3	8.4	MnO	1.7
FeO[1]	21.1	H_2O	.50
MgO	1.9	CO_2	16.7
CaO	1.1		
Na_2O	.05	Total	99.18
K_2O	.07		

[1] FeO values may be in error because of the presence of organic matter in the sample.

The silicate facies of iron-formation is probably represented by laminated to thinly bedded green-gray to dark-green layers composed of quartz, moderately iron-rich chlorite, chamosite, and some $2M_1$ muscovite (S. W. Bailey, written commun., 1961). The layers range from dull argillitic to slightly phyllitic and are generally less than 1 inch thick. Lenses and interbedded layers of chert from one-quarter to one-half inch thick are commonly present. The only silicate facies seen has been in several of the open pit mines (the Florence, Badger, and Davidson open pits, pl. 2) and was as fresh or altered as the chert-siderite or oxidized iron-formation with which it was interbedded. Oxidation of the silicate facies has converted the silicate layers to very fine grained, compact, maroon to dark-gray-blue hematite. The silicate facies was not specifically recognized in the area of metamorphosed iron-formation. Data are too limited to determine satisfactorily the proportion of the Riverton that is silicate facies. However, because of the general similarity of the Florence area to the Iron River–Crystal Falls area, it seems likely that the probable silicate facies constitutes the upper part of the Riverton Iron-Formation or at least is more common in that part.

Black partings and thin layers interbedded in the chert-siderite iron-formation and derivatives from it are pyritic and graphitic, may range from minor to locally abundant, and are generally near the base of the Riverton.

THICKNESS AND RELATIONS TO ADJACENT FORMATIONS

The normal thickness of the Riverton Iron-Formation can be only approximately but is believed to be about 600 feet.

So far as is known, this formation is conformable with the Dunn Creek Slate as in Iron County, and interbedding is present at least locally. The Riverton is generally overlain, probably conformably, by younger strata of the Paint River Group except northwest of the Florence mine as previously mentioned. Local absence of the Riverton may be due to one or more of the following conditions: nondeposition, erosion, onlap of younger strata, facies change resulting from a much greater ratio of argillaceous material, or faulting. No field data specifically supported any one of these possibilities.

CONDITIONS OF DEPOSITION

The unaltered Riverton Iron-Formation consists mainly of interbedded siderite and chert. It was presumably deposited in a marine basin under conditions of restricted circulation when available oxygen was sufficient to yield carbonate but insufficient to produce ferric iron. James (1954) suggested that deposition occurred in a marginal basin developed by broad offshore buckles during the change from earlier shelf environment to later geosynclinal conditions. The iron and silica were probably derived from deep weathering on land of low relief. The possibly argillaceous ("slaty") nature of the upper part of the Riverton indicates an influx of very fine detritus, a change in the character of chemical reactions, and a transition to dominantly clastic deposition.

AGE AND CORRELATION

The iron-formation from which ore was formerly mined in the vicinity of the communities of Florence and Commonwealth occupies the same stratigraphic position, relative to the distinctive widespread graphitic slate breccia of the Dunn Creek, as the Riverton Iron-Formation in Michigan and is doubtless correlative. It is therefore in the Paint River Group of middle Precambrian age.

POST-RIVERTON STRATA

DISTRIBUTION

The normal sequence of formations younger than the Riverton Iron-Formation can be identified only in the northwest corner of the mapped area (pl. 2) and is, from oldest to youngest, Hiawatha Graywacke, Stambaugh Slate, and Fortune Lakes Slate. The Hiawatha Graywacke is massive, dark gray, and thin to locally absent. The Stambaugh Slate is mostly green to greenish-gray fissile slate with a few layers of graywacke, chert, siderite, or cherty siderite iron-formation; some parts are magnetic. The Fortune Lakes Slate is mainly gray slate with interlayered graywacke. These formations are fully described in the report on the Iron River-Crystal Falls area (James and others, 1968).

Post-Riverton strata in other parts of the area cannot be individually recognized but are exposed in small outcrops and were penetrated by test pits along the south slope of the prominent ridge that extends southeastward from the Brule River in sec. 12, T. 40 N., R. 17 E., to the village of Florence. The strata have also been seen near and south of the village of Commonwealth, Wis., at numerous test pits and small outcrops and in several open pit mines. The strata possibly occur at a third locality that includes small parts of secs. 27, 34, and 35, T. 40 N., R. 17 E.; exposures are so small that these occurrences are not shown separately from the Riverton Iron-Formation on the geologic map. The inferred area of post-Riverton strata at this location is based on an assumed average width of outcrop of the Riverton.

DESCRIPTION

Most of the post-Riverton rocks in the area are argillite. They are mainly laminated to thinly bedded and composed of grains of sericite, chlorite, stilpnomelane, and quartz less than 0.05 mm in average dimension. They lack slaty cleavage but are locally phyllitic or fissile. The common color is green to grayish green, locally olive drab, olive green, gray, and black where graphite is the principal constituent. Many specimens weather to maroon, and many others have a dark-bluish coating on all weathered surfaces. Minor amounts of pyrite may be present. Interbedded chert is common in the argillite near the Brule River but decreases southeastward.

Identification of the principal constituents and determination of their relative abundance is difficult, but some approximations are informative. Quartz is commonly present and may be as much as 50 percent of a thin section. Sericite is found in about half of the sections and ranges from 50 to 85 percent. Stilpnomelane is present in most of the other sections and commonly ranges from 25 to 50 percent. Chlorite is in fewer sections than sericite or stilpnomelane and ranges mostly from 35 to 50 percent.

Magnetite was not observed in any thin sections, but in some localities many small loose chips of fissile argillite are attracted by a magnet. Magnetite-bearing chips are present on the hill south of the Florence mine and other localities along the ridge to the Brule River in sec. 12, T. 40 N., R. 17 E. Magnetic surveying northwest of Florence (pl. 8; J. E. Gair, unpub. data, 1955) indicates a well-defined anomaly trending northwestward to outcrops of the typical Stambaugh Slate in Iron County, Mich., and suggests correlation. Magnetite-bearing argillite is also present at a few localities to the south and west of the village of Commonwealth but is not mapped separately.

The second most abundant post-Riverton rock type is quartz metagraywacke. It is poorly bedded to massive, green to greenish gray, and commonly weathers to maroon. Chert fragments are easily seen in most specimens of graywacke and are present in all thin sections. The size of fragments ranges greatly and may exceed several centimeters. Grains less than 0.05 mm in size constitute about 75 percent of the rock; the principal associated minerals are stilpnomelane (as much as 50 percent), quartz (35 percent), chlorite (30 percent), and hematite (50 percent). Quartz grains are easily visible to the unaided eye or with a hand lens; grains larger than 0.05 mm constitute about 15 to 20 percent of typical thin sections. The shapes of most quartz grains are elliptical to subangular, and irregular grains are relatively uncommon. The ends of many elliptical grains are not sharply limited but are penetrated by blades of stilpnomelane. Slides commonly contain about twice as much quartz as chert, but the opposite relation was also observed. Growth of stilpnomelane into chert is generally much more extensive than into quartz. The chemical analysis of Hiawatha Graywacke from near Commonwealth is shown in table 5. The rock is predominantly siliceous and ferruginous. The iron-bearing minerals are stilpnomelane, hematite, and chlorite.

The graywacke described is lithologically similar to the Hiawatha Graywacke of the Paint River Group in Iron County, Mich. It commonly has a chert breccia at the base, but the only known occurrence of basal breccia between the Riverton Iron-Formation and magnetite-bearing slate in the Florence area, is in outcrops in the NW¼NE¼ sec. 4, T. 39 N., R. 18 E. Most occurrences of Hiawatha Graywacke with chert fragments are, as stated previously, at open pit mines and outcrops in the vincinity of the village of Commonwealth and are adjacent to the Riverton Iron-Formation, but it has not been feasible to map the rock as a separate unit.

Material that is probably also correlative with the basal brecchia of the Hiawatha Graywacke is exposed at a small open pit exploration in the northwestern part of sec. 35, T. 40 N., R. 17 E. Chert fragments as much as ½ by 2 inches in maximum dimensions are common locally in a garnetiferous dark-green matrix that becomes very limonitic or hematitic where weathered Quartz grains are generally rare to absent. This rock unit is associated with and is believed to overlie the Riverton, which at that place is weathered magnetite-grunerite iron-formation. The breccia is not shown separately on the geologic map.

TABLE 5.—*Chemical analysis, in percent, of the Hiawatha Graywacke, Florence, Wis., area*

[Location: South wall of small open pit in the NW¼SE¼ sec. 34, T. 40 N., R. 18 E Analysts: P. L. D. Elmore, S. D. Botts, M. D. Mack. Rapid analysis method used. Lab. No.: 15002]

SiO_2	50.2	TiO_2	.49
Al_2O_3	10.1	P_2O_5	.45
Fe_2O_3	3.5	MnO	1.6
FeO[1]	17.9	H_2O	5.6
MgO	5.3	CO_2	3.4
CaO	.80		
Na_2O	.06	Total	99.48
K_2O	.08		

[1] FeO values may be in error because of the presence of organic matter in the sample.

Graywacke occurs in small exposures on both sides of the highway in sec. 12, T. 40 N., R. 17 E. It lies south of and stratigraphically above magnetite-bearing fissile argillite, possibly Stambaugh Slate, and may be correlative with part of the type Fortune Lakes Slate in Iron County, Mich. Graywacke with chert fragments, found at a test pit near the west side of sec. 21, T. 40 N., R. 18 E., has a similar stratigraphic position. Graywacke at the test pit in the northwestern part of sec. 20, T. 40 N., R. 18 E., and graywacke and argillite at the eastern pit in the southeastern part of sec. 19, T. 40 N., R. 18 E., are probably also correlative with the Fortune Lakes Slate.

Several other types of rock are statigraphically younger than the Riverton Iron-Formation. Beds of buff to pink chert or porous silica-rich material in layers from one-eighth to one-fourth inch thick are locally interbedded with thinly bedded green-gray argillite. Massive to poorly laminated rocks composed of fine-grained iron-rich chlorite are exposed or were penetrated by test pits at several places in secs. 33 and 34, T. 40 N., R. 18 E. A small amount of thinly interbedded siderite and chert was found in a few localities.

CONDITIONS OF DEPOSITION

Post-Riverton strata that were originally mainly mud and sandy mud indicate a marked change in the depositional environment from the quiet water in which the Riverton Iron-Formation accumulated. Probable elevation of land near the site of accumulation for post-Riverton strata greatly increased the available amount of clastic materials, but iron and silica continued to concentrate in the depositional basin as is indicated by the presence of magnetite, stilpnomelane and chlorite, and bedded chert.

The conditions preceding or during deposition of the early post-Riverton strata brought disturbance of the underlying Riverton Iron-Formation and at least locally broke up the chert layers into slabs or small fragments. Some slabs, as much as 2 by 18 inches and seen only in cross sections (fig. 9), were only slightly rearranged and buried in ferruginous mud, but more commonly small fragments were transported farther and incorporated in ferruginous sandy mud. Subaerial

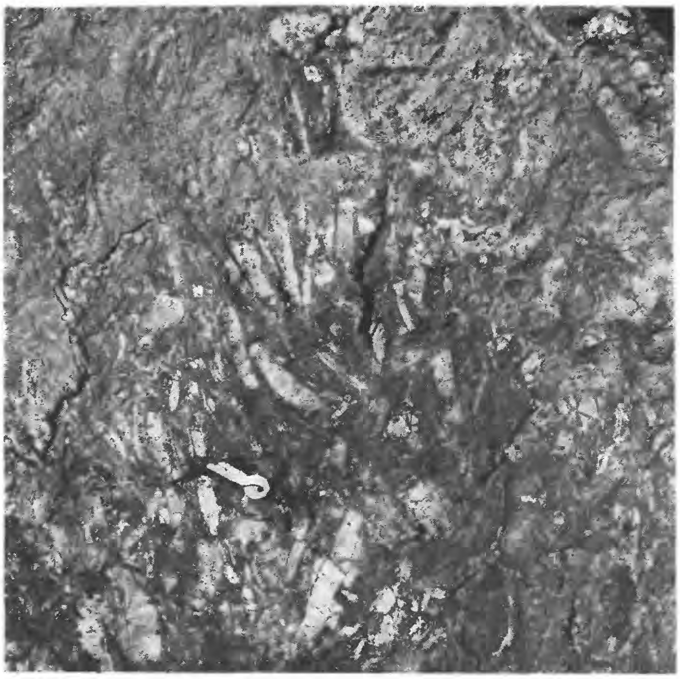

FIGURE 9.—Chert breccia in Riverton or post-Riverton strata, sec. 27, T. 40 N., R. 17 E.

erosion of the iron-formation is not necessarily indicated. Erosion to form the breccia could have taken place below sea level but above wave base, as on shelves, or in deeper water by slump. Subsequently, relative stability in the area of accumulation gave rise to deposition of mud with only small and local amounts of sand.

THICKNESS AND RELATIONS TO ADJACENT FORMATIONS

The thickness of the post-Riverton strata is believed to be several thousand feet. These strata generally overlie the Riverton Iron-Formation disconformably, and the contact exposed for short distances at several abandoned open pits near the village of Commonwealth presumably marks similar relations. The Riverton is, however, not present at the bedrock surface northwest of sec. 17, T. 40 N., R. 18 E., near the village of Florence; and post-Riverton strata are believed to lie unconformably on the Dunn Creek Slate as far as sec. 12, T. 40 N., R. 17 E., and then on Badwater Greenstone to beyond the Brule River. Insofar as known, the post-Riverton strata are not overlain by rocks of Precambrian age.

AGE AND CORRELATION

The post-Riverton strata in most of the Florence area are considered to be of middle Precambrian age on the basis of their stratigraphic relation to the Riverton Iron-Formation. Furthermore, the lithology and probable stratigraphic sequence of these strata are similar to individually recognized formations of the Paint River Group in the northwest corner of the mapped area from which they can be traced to the type area near Crystal Falls, Mich.

CAMBRIAN(?) ROCKS

Two small areas underlain by sandstone that is of probable Cambrian age are not shown on the map. Test pits along the west side of sec. 35, T. 40 N., R. 18 E., penetrated rock composed of well-rounded quartz, 0.25 to 0.75 mm in diameter, cemented by fine-grained bluish hematite. Angular blocks composed of well-rounded quartz about 0.25 mm in diameter cemented by fine-grained dull limonite are abundant in an area 100 feet east and west by 25 feet north and south, on the south-facing slope in the NE¼ sec. 4, T. 39 N., R. 18 E.

INTRUSIVE ROCKS

Metagabbro and granite are the principal intrusive rocks in the Florence area, mostly in the Popple River structural block. Each intrudes the Quinnesec Formation but was not seen in contact with the other. Metadiabase occurs with metagabbro locally. A few pegmatites of quartz, feldspar, muscovite, and generally some tourmaline are present. Metagabbro and associated metadiabase are also found in the Keyes Lake and the Brule River structural blocks and very sparingly in the Pine River block.

METAGABBRO

Metagabbro is exposed in the southeastern part of the Florence area, especially in two large masses that presumably have generally sill-like relations to the Quinnesec Formation (pl. 1). The northern mass is exposed locally over a length of approximately 2½ miles and width of half a mile through secs. 4, 5, and 6, T. 38 N., R. 19 E. The other mass is about 3 miles long, as much as 1 mile wide, and extends from secs. 13 and 24, T. 38 N., R. 18 E., through secs. 18, 19, 20, and into sec. 21, T. 38 N., R. 19 E. The metagabbro in sec. 9, T. 38 N., R. 19 E., represents the west end of a third sill about 2½ miles long by as much as 1 mile wide and mainly east of the Florence area (Bayley and others, 1966). Small scattered occurrences of metagabbro in the Quinnesec Formation are present elsewhere, as indicated on the map. Isolated outcrops of metagabbro in areas believed to be underlain by Michigamme Slate occur in secs. 19 and 36, T. 39 N., R. 18 E., and sec. 19, T. 39 N., R. 19 E.

Metagabbro commonly crops out as knobs that differ greatly in height, outline, and size. The outcrop areas indicated on the map represent groups of individual exposures that could be readily distinguished both on air photos and in field mapping. Some metagabbro areas in the Quinnesec Formation probably include small masses of Quinnesec, inasmuch as hornblende schist and amphibolite derived from basalt are not readily distinguishable from similar rocks that were once gabbro. The contacts of metagabbro with associated formations are not commonly exposed, so most limits and relations are inferred.

The weathered surfaces of metagabbro are commonly dark green and rough, owing to the abundance, large size, and stability of the hornblende. The recessed areas are plagioclase that produces a gray mottling in the dark green (fig. 10).

The metagabbro in the two sill-like masses in the southeastern part of the mapped area is medium to coarse grained and is generally composed of about equal amounts of plagioclase and hornblende, but the latter is as much as 75 percent in some specimens. The plagioclase is mainly labradorite (An_{50-66}) and bytownite (An_{70-85}) with minor andesine (An_{40-47}). The relative abundance of andesine is less in the south sill (two of 26 determinations) than in the north (eight of 28 determinations). This difference is interpreted as indicating that regional metamorphism of the southern mass was possibly less effective within the thermal aureole of the adjacent Hoskin Lake Granite. The hornblende has characteristic bluish-green pleochroism along *Z*, poikiloblastic texture, and an extinction angle of about 24°. Accessory minerals are mostly small anhedral grains of chlorite, clinozoisite, epidote, untwinned feldspar mosaic, quartz, sericite, and sphene. The metagabbro in the small scattered exposures in the southern part of the area is similar to that in the large masses except that bytownite is generally absent and andesine is more abundant than labradorite.

Metagabbro and metadiabase in the vicinity of Keyes Lake occur mainly in the Badwater Greenstone (pl. 2). Plagioclase in most of the rocks is andesine (An_{30-37}), as in secs. 26, 27, and 36, T. 40 N., R. 17 E., and sec. 1, T. 39 N., R. 17 E. Texture and accessory minerals are similar to those described in the southern part of the area. Metagabbro just west and southwest of the quartzite and conglomerate in the Michigamme Slate in sec. 24, T. 40 N., R. 17 E., and sec. 31, T. 40 N., R. 18 E., occurs as small altered exposures that contain albite (An_{3-8}) and the greenstone minerals commonly associated with this type of plagioclase. Metagabbro exposed in the northern parts of secs. 9 and 16, T. 40 N., R. 17 E., but just west of the mapped area, contains albite (An_{3-5}). Some of the large outcrops of metamorphosed mafic intrusives in secs. 27 and 35, T. 40 N., R. 17 E., show a marked transition in grain size from metagabbro to metadiabase, but no systematic relationships were evident. An outcrop 3,200 feet west and 350 feet north of the southeast corner of sec. 27, T. 40 N., R. 17 E., is mostly metagabbro but locally has vesiclelike cavities filled with calcite and a few small fragments similar to those in agglomerate. Another occurrence of agglomerate associated with metagabbro is 1,550 feet west and 1,900 feet south of the northeast corner of sec. 35, T. 40 N., R. 17 E. The amygdaloidallike and agglomeratelike rocks are probably masses of Badwater that are in, or at the margins of, the metagabbro.

FIGURE 10.—Small sills of metagabbro in hornblende schist of the Quinnesec Formation, sec. 26, T. 38 N., R. 18 E. Note tabular form and rough surface that results from differential weathering of hornblende and plagioclase.

The area underlain by Badwater Greenstone along the Brule and Menominee Rivers (pl. 2) contains a few outcrops of mafic intrusive rock, but its relationship to adjacent rocks in Wisconsin was seen only in a small area in the northeast corner of sec. 13, T. 40 N., R. 18 E. Intrusive contacts are well exposed at this locality, but amygdaloidlike areas are also present. The texture and relation of hornblende and feldspar in other outcrops suggest derivation from diabase or gabbro.

The intrusive rock near the northeast corner of sec. 13, T. 40 N., R. 18 E., cuts across and also follows the bedding of graywacke. The rock is massive and generally fine grained but has a few dark-gray feldspar laths. The principal mineral in a thin section is blue-green hornblende, in a mosaic of anhedral feldspar. Examination of six feldspar laths indicates a range in composition from An_{29} to An_{39}. Minor minerals are chlorite, biotite, quartz, and magnetite.

Rocks with ophitic texture in thin section are known only in two localities in this part of the area. The rock at the Brule River in sec. 12, T. 40 N., R. 17 E. (pl. 2), is massive, medium gray, generally fine grained but some amphibole grains are as much as 1.0 mm across; it is not visibly ophitic in hand specimen. The principal minerals identified in thin section are actinolitic hornblende, clinozoisite, and chlorite. A few altered feldspars are present. Saussurite pseudomorphs of feldspar prisms and sphene with cores of opaque material are common.

Metadiabase in sec. 12, T. 40 N., R. 18 E., is massive, fine grained ophitic, and dark gray. The principal minerals in a thin section are blue-green hornblende and albite (An_{0-9}) in approximately equal amounts. Minor constituents are epidote, biotite, quartz, and magnetite(?). Much of the plagioclase is lathlike, and albitic twinning is common.

Metagabbro is also exposed in Michigan along and adjacent to the Brule River; in sec. 17, T. 41 N., R. 31 W., it forms an irregular sill-like body in the Badwater Greenstone. The texture is that of a medium-grained gabbro, but the rock is now an epidote amphibolite, characterized by pale-green hornblende (after pyroxene) and abundant epidote and sphene. The plagioclase is mainly oligoclase gradationally zoned to cores of andesine or labradorite.

A narrow sill of amphibolitic metagabbro is exposed in sec. 6, T. 41 N., R. 31 W.; it is closely associated with amphibolite derived from the Hemlock(?) Formation and distinguished from it chiefly by the local gabbroic texture. The metagabbro and metadiabase in the Florence area are of post-Animikie age.

HOSKIN LAKE GRANITE

Prinz (1959, 1965) gave the name Hoskin Lake Granite to a coarse-grained porphyritic rock for which the type locality is about 2 miles east of the southeast corner of the Florence area. The area of granite exposures does not extend from the type locality into the adjacent part of the Florence area, but a short western boundary is shown in sec. 21, T. 38 N., R. 19 E., because there are outcrops within 100 feet to the east and extending for 1,000 feet north of the southeast corner of the area (pl. 1). Exposures south of the area in secs. 28, 29, and 31, T. 38 N., R. 19 E., indicate a continuation of the granite southwestward for an undetermined distance. Additional less porphyritic granite outcrops scattered in an area 3 miles wide that extends approximately 5 miles northwest in the southwest part of the area shown on plate 1 are considered to be part of the Hoskin Lake Granite.

Granite and pegmatite dikes in the Quinnesec Formation in the northwestern part of the area shown on plate 1 are present in secs. 15, 22, 26, and 27, T. 39 N., R. 17 E. Granite west of the Florence area (not shown on the map) occurs as dikes in sec. 16, T. 39 N., R. 17 E., but as low scattered knobs of the only bedrock seen in an area about 1,300 feet long and 600 feet wide in the SE¼ SW¼ and SW¼SE¼ sec. 20, T. 39 N., R. 17 E. These occurrences are also believed to be part of, or closely related to, the Hoskin Lake Granite.

Granite in the southwest part of the area shown on plate 1 generally forms prominent rounded knobs that have well-developed joints and irregular outline. The granite is pink, gray, white, or mottled. The texture is coarse grained with at least a few, or locally many, feldspar phenocrysts. Other outcrops are fine grained and approach an aplitic appearance, especially in sec. 27, T. 39 N., R. 17 E. Structure is generally massive but may be locally streaked. The alinement of feldspar phenocrysts and the trend of slightly biotitic concentrations are due north in secs. 13 and 14, T. 38 N., R. 17 E. Similar features are found in the exposures in sec. 20, T. 39 N., R. 17 E., just west of the mapped area; however, the outcrops are smaller, less prominent, and less jointed. The coarse-grained texture also occurs in most of the granite dikes.

Two-thirds of the measured strikes of joint systems are northwestward; approximately half of these trend N. 10° to 20° W., and 60 percent of them are vertical. Half of the northeast-trending joints strike N. 60° to 70° E., and dip from 70° S. to vertical.

The granite is locally crossed by tourmaline-coated fractures, tourmaline-bearing pegmatites and quartz veins, and aplitic dikes. A pegmatite in the NE¼ sec. 22, T. 39 N., R. 17 E. (pl. 1) is mainly coarse gray to white feldspar and quartz but locally has up to 2-inch veins of quartz with pink tourmaline crystals mostly about 1 inch in length and 0.15 inch in diameter. Laths of striated feldspar and anhedral grains of unstriated feldspar can be readily distinquished in hand specimens of pegmatite; either type may be the more abundant in thin sections. The plagioclase is commonly albite (An_{0-8}) or andesine (An_{43-53}).

The granite in the Florence area is about 75 percent very light buff to orange-pink feldspar for which the maximum size is generally about 1 cm; phenocrysts are 2 to 4 cm long. Quartz is commonly light gray and less than 0.5 cm in maximum dimension. Biotite is about 1 mm across and uniformly scattered except for some local very thin discontinuous aggregates. Thin sections of nonporphyritic specimens consist mainly of anhedral to subprismatic twinned and untwinned feldspar and anhedral quartz with accessory biotite, chlorite, and sericite. Microcline is the common feldspar; untwinned feldspar is mainly oligoclase and some orthoclase. Plagioclase is generally less common than other feldspar but is equally or more abundant in some sections, which indicates that parts of the intrusive are quartz monozonite. Composition of plagioclase ranges from An_0 to An_{43}. Perthite and myrmekite are present. Some feldspar is cloudy and contains scattered sericite. Quartz has wavy extinction, and a cataclastic texture is common. Some parts show virtually a mortar structure. A few grains of epidote and clinozoisite are present.

No contact of the granite with adjacent rock was seen in the Florence area, and location of a boundary is inferred almost entirely from the aeromagnetic data (pl. 7). A small outcrop of hornblende schist occurs within the granite in the SE¼NE¼ sec. 3, T. 38 N., R. 17 E., but no contact is exposed. Dikes in the northwestern part of the area shown on plate 1 generally have sharp contacts with enclosing hornblende schist or amphibolite of the Quinnesec Formation, but some dikes have transitional gneissic boundaries like those in sec. 20, T. 39 N., R. 17 E., just west of the mapped area.

The granite is not known to intrude rocks younger than the Quinnesec Formation; it is probably younger than the metagabbro yet older than the regional metamorphism that affected the Animikie Series and the gabbro (except locally as mentioned on p. 35). Lead-alpha and isotopic lead methods placed the geologic age of zircons from the granite as 1,650 million years (Bayley and others, 1966, p. 75). This suggests a relation to the post-Animikie deformation and metamorphism in Michigan of 1,700 million years ago (Goldich and others, 1957, p. 550).

PEAVY POND COMPLEX

Exposures of metagabbro, in secs. 33 and 34, T. 42 N., R. 31 W., are part of the Peavy Pond Complex (Bayley, 1959), which occupies an irregular area of about 5 square miles in the adjacent Lake Mary quadrangle. The Peavy Pond Complex is composed mainly of metagabbro and metadiorite; but the northwest quarter has areas of predominantly metatonalite, granodiorite, and granite arranged in order of decreasing basicity from the mafic area. Most of the complex is hornblende metagabbro that is described (Bayley, 1959, p. 78) as composed of 55 to 80 percent labradorite (An_{50-70}), 16 to 45 percent hornblende in a variety of colors, trace amounts of biotite and iron ore, and a few other associated minerals.

Granitic rock in metasediments and in part of the complex in the Florence area is in thin lenslike bodies, few of which are more than 5 feet wide and tens of feet long. The rock, which ranges in texture from granitic to pegmatitic, is composed of quartz, microcline, sericitized oligoclase, and muscovite. Most of the bodies are parellel to foliation in the enclosing rock, but a few cross the regional trend. In at least one occurrence, in the NE¼ sec. 33, T. 42 N., R. 31 W., a cross-cutting pegmatitic granite has been sheared after emplacement and has a crude foliation parallel to that of the country rock.

STRUCTURAL GEOLOGY

The Florence area has four major structural units formed by three northwest-trending faults along which the blocks to the south have been relatively uplifted (pl. 4). Only major faults that caused profound dislocation of the normal stratigraphic succession have been shown; none of the fault surfaces have been seen in the field. The three faults appear to be the westward continuation of inferred faults in southern Dickinson County, Mich. (Bayley and others, 1966). These structural units, which will be described in sequence from north to south, are the Brule River block, the Keyes Lake block, the Pine River block, and the Popple River block.

Inasmuch as outcrops are scarce, structures within the blocks can rarely be defined solely on the basis of inclination of bedding top directions, especially as indicated by graded beds and crossbedding in the Michigamme Slate and ellipsoids in the Badwater Greenstone, help to decipher the fold patterns.

Beds dip steeply throughout the Florence area, being vertical in many places and overturned locally. Minor folds are abundant. Foliation is generally nearly parallel to the bedding except at fold axes. Lineation is present in some places.

BRULE RIVER BLOCK

The Brule River block includes most of the area shown on plate 2. It is underlain by a sequence ranging from the Hemlock(?) Formation to post-Piverton strata. These strata have been folded and form the Commonwealth syncline along the southern edge of the block, which is believed to be a fault because most of the southwest limb of the syncline is missing. More evidence of this fault is given in the discussion of the adjacent Keyes Lake block. The Brule River block extends northwestward into Iron County, Mich., southeastward into Dickinson County, Mich., and northward without limit in each of them.

COMMONWEALTH SYNCLINE

Commonwealth syncline is the name here proposed for the northwest-plunging fold in the Brule River block. This syncline forms one apex of a large triangular basin whose other apices are at Crystal Falls and Iron River in adjacent Iron County, Mich. (pl. 4).

The general stratigraphic sequence in the group of northwest-trending formations is indicated by the following features:

1. Graded bedding in an outcrop of the Michigamme Slate in the SW¼ sec. 12, T. 40 N., R. 18 E., shows that the stratigraphic top of the beds very near the Badwater Greenstone is toward that formation.

2. The shape and arrangement of ellipsoids in the Badwater Greenstone (in sec. 12, T. 40 N., R. 17 E.; secs. 14, 22, and 23, T. 40 N., R. 18 E.; and sec. 18, T 40 N., R. 19 E.) indicate that younger rocks are toward the south.

These data are important because they have been the principal basis for recognition of not only the local position of the Paint River Group, but also the regional stratigraphic position. In the Florence area this group includes three units—Dunn Creek Slate, Riverton Iron-Formation, and post-Riverton strata.

The Badwater Greenstone forms an outcrop belt that trends southeastward across the Florence area and continues into Dickinson County, Mich. Here the strike of the formation changes to westward, and the top of the beds is northward (Bayley and others, 1966).

The areal distribution of the Riverton and associated formations also indicates a syncline (pl. 2). The strike of the beds trends from the northwest corner of the Florence area southeastward through the villages of Florence and Commonwealth to the pit of the Badger mine in sec. 34, T. 40 N., R. 18 E., turns sharply, and then trends generally westward for about a mile, to where the structure is believed to be interrupted by a major northwest-trending fault.

Minor folding in which the predominant plunge is steeply to the northwest is common in the Riverton. The areal pattern shown for the Riverton northwest of Florence and at the southeast end of the syncline is indicated by the outcrops, but elsewhere the pattern is based on a general structural interpretation.

OTHER FOLDS

A series of five folds, all within Michigan, was noted in the northern part of the Brule River block. The main folds in the eastern half of the area shown on plate 2 are an overturned syncline, the axis of which lies immediately north of the Peavy Falls Dam, and a parallel anticline in which the Hemlock(?) Formation is exposed a little more than a mile to the south. The axes of these folds form broad south-facing convex arcs that are rudely symmetrical with the border of the Peavy Pond Complex to the north. This may represent an actual deformation of the fold axes, but more likely the structural trends resulted from the syntectonic emplacement of the igneous complex (Bayley, 1959). The fold axes plunge westward at an angle of about 20°, as estimated from measured values of lineation and minor folds. Three folds in the western half of the area shown on plate 2 extend for a short distance but do not seem to continue into the eastern half. In fact, it seems likely that none of the folds extend for more than a few miles, and that as a group they are arranged in an en echelon pattern that in some way is related to emplacement of the Peavy Pond Complex. One further aspect, probably also related to emplacement of the complex is that in the northern part of the quadrangle, beds are overturned to the north, whereas in the southern part they are overturned to the south.

Doubtless many folds in the northern part of the Brule River block are intermediate in size between the two main structures and the small crumples that can be seen in outcrop. A minor synclinal axis certainly must be present a short distance north of the Michigamme Falls Dam because tops of beds are opposite each other. This in turn requires a second reversal between the outcrops at the dam and the Michigamme-Badwater contact. In a reconnaissance traverse of the Michigamme River below the damsite prior to construction of the dam, H. L. James and R. W. Bayley noted that tops of beds were toward the south; it has not been possible to reexamine the outcrops in order to verify these observations.

Minor crumpling of beds is common, particularly near axes of major folds. Good examples may be seen in outcrops of staurolite schist in the SE¼ sec. 31, T. 42 N., R. 31 W., and in the SW¼ sec. 15, T. 41 N., R. 31 W.

The pattern of the Michigamme-Badwater contact along the Brule and Menominee Rivers indicates a series of complex minor folds, and almost certainly the great range in outcrop width of an uppermost unit of the Michigamme Slate (not shown on the map) is due to folding. Outcrops of graywacke and slate along the Menominee River show much evidence of tight folding along axes that plunge southwestward at angles of 25° to 50°.

KEYES LAKE BLOCK

Geologic structure in the Keyes Lake block is known only in the southwest part of the area shown on plate 2, where geologic data are virtually restricted to within a few miles of Keyes Lake. It is inferred, however, that the block continues eastward across the north part of the area shown on plate 1. In sequence from east to west, structures near Keyes Lake are a homocline of south-dipping Michigamme Slate, a southeast-plunging syncline of Badwater Greenstone, a fault trending north-northwest, a south-plunging syncline of Dunn Creek to post-Riverton strata, and a south-plunging anticline of Badwater Greenstone and Dunn Creek Slate.

The best exposed part of the Michigamme Formation in this block is the quartzite near Keyes Lake; here crossbedding is common and uniformly indicates stratigraphic top to be toward the southwest. Consequently, so far as is known, the Michigamme strata constitute a vertically or steeply dipping homocline. Furthermore, the structural and geographic relations of this quartzite to the Riverton Iron-Formation in the Brule River block are especially significant. The general trends at the east end of the quartzite and the west end of the iron-formation are approximately toward each other. Because the formations structurally face in opposite directions and appear to be terminated in approximately the same locality (pl. 2), a fault is inferred to lie between them. The area south of the fault was raised relative to the area north of it. A fault of similar relative motion in Dickinson County, Mich. (Bayley and others, 1966) has a northwesterly trend and presumably continues into northeastern Florence County, Wis. (pls. 2 and 4).

The northwest end of the quartzite is marked by a progressive decrease in the number and size of exposures in sec. 14, T. 40 N., R. 17 E. The quartzite is shown on the map as continuing toward the same inferred fault that terminates its easterly extent, but it may simply lens out.

One of the major structures in the Keyes Lake block is a southeast-plunging syncline of Badwater Greenstone west of Keyes Lake. As previously stated (p. 25), a fold is suggested by the arcuate areal distribution of two thin iron-formation units separated by a gray slate unit. A similar arcuate pattern of magnetic crests was indicated by a magnetometer survey (see pl. 6). The synclinal character of the fold is indicated by well-developed ellipsoids in metabasalt in the northeast limb that show that the top of the beds is to the southwest (pl. 2); no data to indicate top were observed in the southwest limb. Toward the southeast the structure is uncertain because of the absence of exposures beyond Keyes Lake and Loon Lake. It is likely, however, that the fold is cut off by the fault at the south edge of the Keyes Lake block. Another fault trending north-northwesterly is believed to extend along the west side of the southwest limb of the syncline because the adjacent structure to the west is another south-plunging syncline, and the normally intervening anticline seems to be absent.

Two more folds in the southwest part of the Keyes Lake block lie between the two faults just described. One fold is a south-plunging syncline of Riverton Iron-Formation and Dunn Creek Slate. The other, which is mainly a mass of Badwater Greenstone to the northwest, is a plunging structure indicated by the southward convergence of magnetic crests. The anticlinal form is shown by the arrangement of ellipsoids indicating that the tops of the beds are to the northeast in sec. 21, T. 40 N., R. 17 E., and to the southwest in sec. 27, T. 40 N., R. 17 E. (fig. 6).

Folds and faults in the southwestern part of the area shown on plate 2 are believed to be related to the major fault along the southwest side of the Iron River-Crystal Falls-Florence synclinal basis. The sections and map on plate 4 illustrate a suggested interpretation of the development of the structure in this area. The Riverton Iron-Formation at this locality was part of a continuous layer that once extended along the side of the major basin (see reconstructed areal geology), but its present distribution resulted from faulting and subsequent erosion of the former anticlinal connections (sections on pl. 4).

Termination of the three southeast-plunging folds in the Keyes Lake block relative to nearby exposures of Michigamme Slate along the Pine River to the southwest is interpreted to be the result of a northwest-trending fault with relative uplift on the south—a continuation of a fault in Dickinson County, Mich. This fault is a second one of major significance in Florence and Dickinson Counties.

PINE RIVER BLOCK

The Pine River block includes a small area shown in the southwestern corner on plate 2 and the continuing elongate area shown across the northern part of plate 1. This block is underlain almost exclusively by Michigamme Slate and extends westward and northward from Dickinson County, Mich. The scattered exposures are insufficient to determine the structure of all the Michigamme. However, the tops of the beds are toward the south in the crossbedded quartzitic conglomerate in sec. 24, T. 39 N., R. 17 E., to sec. 28, T. 39 N., R. 18 E., and in graded beds of graywacke in sec. 29, T. 39 N., R. 18 E. The uplift of this block is relatively higher than the Keyes Lake block but is relatively lower than the Popple River block to the south.

POPPLE RIVER BLOCK

The Popple River block includes slightly more than the southern half of the area shown on plate 1 and extends for undetermined distances to the east, south, and west. It is underlain by metavolcanic rocks of the Quinnesec Formation of early Precambrian age and by intrusive rocks of late middle Precambrian age. A fault along the north side is inferred because ellipsoids in the metabasalt of the Quinnesec Formation indicate a north-facing sequence, whereas the Michigamme Slate in the Pine River block faces south. The exact location of the fault is unknown except where the south-dipping graywacke in the Michigamme Slate is within 50 feet of the felsic metavolcanic rock that overlies the metabasalt in the Quinnesec Formation (fig. 3). The Popple River block has been uplifted at least several thousand feet relative to the Pine River block. The fault continues into southern Dickinson County, Mich., where the formations and relations are similar to those in the Florence area.

FOLIATION AND LINEATION

Argillaceous units within the Michigamme Slate and the Paint River Group show a well-developed foliation that typically is nearly parallel to the bedding except at fold axes. Foliation is also present locally in the Hemlock(?) Formation and Badwater Greenstone. This foliation is due to parallel orientation of platy metamorphic minerals, notably mica and hornblende. Lineation due to mineral alinement is evident locally in schistose rocks and amphibolite but generally is not an obvious feature; the lineation is shown best by the axes of minor crumples. Both the major foliation and the lineation are clearly related to the principal west-trending axis of structural deformation. The strike of lineation in the northern part of the area also seems to be related to the northward arc of the major structures.

Foliation is common in metarhyolite and metabasalt of the Quinnesec Formation. The strike is predominantly northwest, and the dip is steeply southwest.

Only one outcrop of the Quinnesec Formation near the inferred contact with the Hoskin Lake Granite is known; foliation in the Quinnesec strikes northwest and is parallel to the contact, but this general direction is so common that it probably has no special significance. Only minor foliation was observed in the Hoskin Lake Granite.

TIME OF FOLDING AND FAULTING

The youngest strata—the post-Riverton beds—are folded and faulted, and the general parallelism of folds and faults in the Florence area presumably indicates early and late phases of a single deformation of post-middle Precambrian time. Some metagabbro has foliation locally. The Hoskin Lake Granite has mortar structure locally, and cataclastic texture of quartz is common.

METAMORPHISM

The Florence area lies on the south side of the Peavy node and on the north side of the Florence County node of regional metamorphism (James, 1955). The metamorphic grade decreases from sillimanite at the north edge of the area to chlorite along the Commonwealth syncline and then rises to garnet in the southern part of the area. The pattern (pl. 5) is generally similar to that shown by James, whose data included only a few localities in Wisconsin. As in Michigan, the grades in Wisconsin were determined on the basis of mineralogic changes in argillaceous rocks, mafic igneous rocks, and iron-formation. About 100 thin sections of specimens from 75 widely distributed localities were examined. A general systematic arrangement of grades is evident if a few local differences are minimized.

CHLORITE ZONE

The chlorite zone or equivalent grade of metamorphism is largely restricted to the Commonwealth syncline in the Brule River block but also extends into the adjacent part of the Keyes Lake block on the south. Chlorite and sericite are prevalent in the argillaceous rocks of the Paint River Group in the Brule River block; the ferruginous rocks are sideritic, hematitic, or limonitic. Much chlorite and saussurite are present in the metabasalt of the Badwater Greenstone at the locations shown on plate 5.

Chlorite and sericite are also prevalent in argillaceous rocks of the Michigamme Slate in the Keyes Lake block, and albite-oligoclase (An_{2-13}) is found in the metagabbro that intrudes the Michigamme in sec. 24, T. 40 N., R. 17 E., and sec. 31, T. 40 N., R. 18 E. (pl. 2) in the same block. A small area of quartz-magnetite iron-formation is exposed in secs. 31 and 32, T. 40 N., R. 18 E., and associated rocks have much chlorite and stilpnomelane and locally garnets. These rocks, however, are not considered an index to metamorphism because biotite is rare and much manganese is indicated by X-ray spectrograph (S. W. Bailey, written commun., 1961). Quartz-magnetite iron-formation is also exposed in a small area in the SE¼SE¼ sec. 25, T. 40 N., R. 17 E., associated with garnetiferous graphitic argillite and garnet-magnetite-grunerite with interbedded chert; this locality is an exception to the general low-grade metamorphism of the Michigamme here. Biotite is found in the exposure of Michigamme in the northwest corner of sec. 6, T. 39 N., R. 18 E., and delineates the limit of the chlorite zone in this part of the area.

BIOTITE ZONE

Information on the biotite zone or equivalent grade of metamorphism in the Brule River block is based on a few exposures at locations shown on plate 5. Most of the rocks are greenstone, but some are slate and metagabbro. All contain biotite, and the metaigneous ones, albite. Metabasalt at the north edge of the Badwater in the northeast part of T. 40 N., R. 18 E., contains oligoclase-andesine (An_{28-37}), which is equivalent to normal garnet grade, and metadiabase 500 feet south has albite (An_{0-9}) accompanied by biotite. These characteristic differences establish the northern limit of the biotite zone at this locality.

Biotite in metamorphosed argillaceous rocks of the Michigamme indicates the location of the biotite zone in other parts of the Florence area. The boundary between it and the garnet zone in the western part of the Florence area may be drawn to show alternative interpretations. For example, the biotite zone might be considered to be a single unit that narrows sharply northwestward, and the two biotite localities near the north limit of T. 39 N., R. 17 E., would be either just local anomalies or a very small enclave in the garnet zone. In the interpretation shown on plate 5, however, the wide biotite zone in the eastern part of the area is believed to bifurcate toward the northwest, and the two apparently isolated biotite localities represent a southern branch. The biotite-bearing rocks in T. 39 N., R. 18 and 19 E., are predominantly slates composed of quartz and sericite in widely ranging proportions, whereas rocks in the adjacent part of the garnet zone are gruneritic iron-formation and schist. Similar lithologic, stratigraphic, and structural relations are found in T. 39 N., R. 17 E.

GARNET ZONE

The northern garnet zone is in the Brule River block and is of small extent. The present study shows that the garnet and staurolite isograds must be approximately half a mile south of the positions shown by James (1955, pl. 1). Garnetiferous phyllite is present in the Michigamme Slate as far south as the contact with the Badwater Greenstone. Within the garnet zone, the typical graywacke and slate of the Michigamme, such as that exposed at the Michigamme Falls Dam, is nongarnetiferous; the graywacke, however, contains abundant epidote. At the north side of the zone, staurolite-bearing schist is exposed as far south as the center of sec. 8, T. 41 N., R. 31 W.

The principal garnet zone extends across the southwest half of the mapped area and through each of the known formations from the Quinnesec to the Riverton and younger metagabbro. The garnet zone in the Pine River and Keyes Lake blocks appears either to have divided or narrowed the biotite zone in the western part of the area. The data for each formation are discussed in stratigraphic sequence.

The mafic rocks of the Quinnesec Formation are predominantly amphibolite, with minor amounts of hornblende schist; garnet-grunerite schist occurs in at least two localities. The feldspars in the amphibolite and hornblende schist are mostly andesine, but compositions range from An_{26} to An_{43}. These rocks are part of an andesine-amphibolite facies that continues eastward beyond the mapped area (Bayley and others, 1966). The facies apparently also continues westward beyond the mapped area, and near the center of the west side on plate 1, biotite and garnet occur in a small area of metasedimentary rocks. This occurrence indicates that the andesine-amphibolite facies in mafic extrusive rocks is generally equivalent to the garnet grade in argillaceous rocks. The intensity of metamorphism in the felsic rocks of the Quinnesec is not indicated specifically but may be inferred by the composition of associated metagabbro.

Rocks indicative of the garnet zone in the Michigamme Slate are garnet-magnetite-grunerite rock, garnetiferous quartz graywacke, and amphibolite containing oligoclase-andesine (An_{23-42}). These rocks extend from the southeast corner of T. 39 N., R. 18 E., northwestward beyond the mapped area.

Two thin discontinuous layers of grunerite with garnets and magnetite are in the Badwater Greenstone in T. 40 N., R. 17 E. Garnets are also present in some associated argillaceous strata.

Interbedded garnet-magnetite-grunerite layers and sugary quartz (recrystallized chert) layers make up most of the Riverton Iron-Formation in the western part of the Keyes Lake block.

The predominance of andesine (An_{30-50}) and locally some bytownite (An_{85}) in the gabbroic rocks that intruded all formations from the Quinnesec to the Dunn Creek indicates that most occurrences are within the limits of the garnet zone. The high anorthite content of plagioclase in the metagabbro near the Hoskin Lake Granite in the southeastern part of the area suggests that the granite intrusion occurred at nearly the same time as the regional metamorphism and locally retarded the widespread conversion that took place elsewhere in the metagabbro and metabasalt. Apparently no such relationship exists in the vicinity of Hoskin Lake Granite in the southwest part of the area, but very few data are available.

STAUROLITE ZONE

The graywacke-shale suite, iron-formation, and basic igneous rocks in the staurolite zone of regional metamorphism of northern Michigan are described by James (1955). His description is generally applicable to the rocks on the south side of the Peavy node along the eastern part of the northern edge of the mapped area and is quoted below.

GRAYWACKE-SHALE SUITE

[James, 1955, p. 1465–1466]

The bulk compositional requirements necessary for formation of staurolite are such that this index mineral is found only in a few argillaceous rocks in northern Michigan. It is abundant in some beds, however, and not uncommonly it is present in the originally finer-grained upper parts of graded beds, thus increasing the contrast in grain size with the granulitic lower parts. * * *

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The similarity in composition between staurolite and chloritoid would suggest that the latter mineral would be equally common in a lower zone of metamorphism and that there might be a paragenetic relationship between the two minerals. Such, however, is not the case; chloritoid is a rare mineral in the region, and no evidence of development of staurolite from chloritoid has been seen in any of the sections studied.

* * * * *

Garnet is present in most rocks within the staurolite zone, and is exceedingly abundant in some layers * * *. The garnet commonly is a more deeply colored variety than that within the garnet zone proper but is similar in habit. Some of the biotite is molded around the garnets, but there is little or no evidence to indicate thrusting aside during growth, or rotation. Biotite is the predominant mica, though some muscovite is generally present.

As in the garnet zone, the original graywacke layers are not notably different in appearance from those in the lower zones of metamorphism. The rock is massive, gray, and fine- to medium-grained, without schistose or gneissose structure. Original textures are entirely lost, however, and in thin section the quartz and feldspar (generally oligoclase) form an interlocking mosaic; the rock is a granulite, as that term is used by the British petrologists. * * *

IRON-FORMATION

Iron-formation in the staurolite zone consists of granular quartz, magnetite, and lesser grunerite, in layers one-fourth to one-half inch thick; but locally it is a skarnlike aggregate of grunerite, green pyroxene, garnet, quartz, and magnetite in various proportions.

BASIC IGNEOUS ROCKS

[James, 1955, p. 1472]

Metamorphosed basic intrusive [and extrusive] rock within what is believed to be the staurolite zone is exposed at many places. It is now amphibolite. * * *

Differences between the amphibolite of the staurolite zone and the epidote amphibolite of the main part of the garnet zone are not marked in outcrop but are clearly evident in thin section. The most obvious differences are the absence of epidote (except as a retrograde product) and the increase in anorthite content of the plagioclase. This transition from epidote amphibolite probably occurs within the upper part of the garnet zone. Texturally, most of the specimens studied are dominated by large hornblende plates, generally with irregular outline, which are set in a matrix of equigranular plagioclase and quartz with some biotite and sphene. The plagioclase typically is well twinned and of a composition varying from An_{35} to An_{45}. The change from the sodic oligoclase of the garnet zone to intermediate or calcic andesine is abrupt and doubtless is related to the absence of epidote in the higher zone of metamorphism; in the sections studied, no plagioclase was found with a composition in the range An_{20}–An_{30}. The hornblende plates are typically larger than associated grains; green is the dominant color, with strong pleochroism (X—yellowish; Y—green; Z—green, faintly bluish). Biotite is common as clear plates ranging in color from yellowish brown to reddish brown, the latter more common in the higher part of the zone. Other constituents of the rock are quartz, muscovite, sphene, and magnetite. * * *

SILLIMANITE ZONE

Rocks in the sillimanite zone were also described by James (1955), and some are present along the eastern part of the northern edge of the mapped area.

GRAYWACKE-SHALE SUITE

[James, 1955, p. 1466–1467]

The only area in which sillimanite-bearing rocks are known to be exposed is at Peavy dam, in the southeastern part of Iron County. Most of the rock in the vicinity of the damsite is massive biotite granulite (graywacke) with interbedded micaceous sillimanite-staurolite schists; stratigraphically these beds are part of the Michigamme slate * * *.

Three analyses of the Peavy dam rocks are given in Table 3 [table 6 of this report]. The modes of two thin sections for each of these analyzed rocks are tabulated in Table 4 [table 6 of this report]. The quartz and feldspar that form the groundmass mosaic are equidimensional and about 0.2 mm in diameter. The feldspar is oligoclase (approximately An_{15}) and only a few grains show twinning; in some slides, the plagioclase shows a slight but definite gradational zoning to a more albitic rim. The biotite is brown, forms large flakes about 0.5 mm in length with marked preferred orientation, and most grains show numerous dark haloes around tiny grains of zircon. The muscovite occurs as large clear flakes, 1 mm or more in length, that typically lie athwart the cleavage direction defined by the biotite. The garnet and staurolite form porphyroblasts of typical form and appearance; the garnets are rarely more than 0.5 mm in diameter, but the staurolite forms grains up to 10 mm in length. The sillimanite is most abundant in the more micaceous beds in association with staurolite. On cleavage surfaces it forms thin rods and lenses commonly oriented parallel to the regional linear structure. In thin section it appears as clusters of fine needles * * * The sillimanite bears no systematic paragenetic relationship to other minerals in the rock.

* * * * *

The rocks retain much of the outward appearance of the graywacke and slate in zones of lower grade. Bedding is well preserved and some layers show original gradational grain (now reversed, with staurolite in the originally finer-grained, more argillaceous "tops" of some layers). Originally calcareous concretions are visible in some beds; at this particular locality they are strongly drawn out, with axial ratios of 10:2:1. The concretions are considerably different in mineralogy from the matrix, most notably in the composition of the plagioclase, which is labradorite (approximately An_{53}), as compared with oligoclase in the enclosing rock. Apatite is abundant as small grains. The texture, however, is much similar to that of the enclosing rock, and the boundaries are indistinct in thin section.

BASIC IGNEOUS ROCKS

[James, 1955, p. 1472]

Few specimens of basic igneous rock from the sillimanite zone have been studied. Most are similar to the amphibolite from the staurolite zone—chiefly green hornblende and andesine. However, some specimens from the Peavy node in southeastern Iron County contain brownish hornblende, and some contain abundant pyroxene adjacent to gabbroic intrusive bodies (R. W.

TABLE 6.—*Chemical analyses, in percent, and modes of three samples from the Michigamme Slate*

[From James (1955, tables 3 and 4). Locality: SE¼ sec. 32, T. 42 N., R. 31 W., Iron County, Mich. Analyst: Lucille M. Kehl]

Analysis:			
SiO_2	66. 51	55. 90	60. 56
Al_2O_3	15. 31	19. 31	18. 43
Fe_2O_3	. 50	. 95	2. 14
FeO	5. 22	7. 83	6. 40
MgO	2. 45	4. 01	3. 39
CaO	2. 00	1. 17	1. 33
Na_2O	3. 08	1. 73	1. 99
K_2O	2. 72	4. 91	3. 09
H_2O-	. 03	. 19	. 06
H_2O+	1. 21	2. 77	1. 48
TiO_2	. 66	. 85	. 82
CO_2	. 01	None	. 01
P_2O_5	. 15	. 18	. 18
MnO	. 06	. 04	. 04
Total	99. 91	99. 84	99. 92
Mode, in volume percent:			
Quartz	62. 8	35. 9	46. 3
Biotite	21. 5	40. 7	33. 0
Muscovite	5. 6	7. 6	2. 0
Plagioclase (An_{15})	8. 5	9. 4	4. 3
Garnet	1. 6	3. 0	1. 0
Staurolite	------	. 3	13. 3
Sillimanite	Tr.	3. 1	Tr.

Bayley, personal communication). The pyroxene-bearing rock is granoblastic, with irregular anhedra of nearly colorless diopside and scarce hypersthene in a matrix of andesine grains. Hornblende occurs as discrete grains or as replacements of the pyroxenes, and the rock apparently is a hornfels modified by regional metamorphism.

PEAVY NODE

The Peavy metamorphic node centers approximately on the Peavy Pond Complex described by Bayley (1959) as a syntectonic intrusion. The earliest, and quantitatively the major part of the complex presently exposed, is gabbroic in character. The gabbro was succeeded by later intermediate and granitic rocks. Locally rocks of the Hemlock Formation (in the Lake Mary quadrangle) were metamorphosed by the gabbro to the hornfels facies. Subsequently, both the gabbro and hornfels were metamorphosed to amphibolite in the same cycle. It is evident, therefore, that although the node of the thermal activity, as reflected by the zonation, is approximately centered on the complex, the source of metamorphic heat was not derived from that body at its present level of erosion. The now-metamorphosed gabbro may have formed a hood for a larger subjacent and possibly convecting body of magma; the relatively small bodies of granitic rock possibly represent offshoots from this deeper source.

TIME OF METAMORPHISM AND RELATION TO DEFORMATION

Metamorphism was regional in scope and possibly took place before the deformation. Several occurrences of rotated garnets indicate that some deformation was contemporaneous with, and possibly subsequent to, metamorphism. More positive evidence of possible pretectonic metamorphism, at least locally, consists of wrinkled foliation in schistose Michigamme Slate (fig. 11) in sec. 3, T. 39 N., R. 17 E. (pl. 2), in the Quinnesec Formation in secs. 4 and 9, T. 38 N., R. 18 E. (pl. 1), and especially in sec. 28, T. 39 N., R. 17 E., west of the mapped area, along the east side of State Route 101 (fig. 12). In the specimen shown in figure 11, stratification results from differences in the amount of biotite, and foliation results from parallel orientation of fine-grained muscovite. Biotite flakes tend to be slightly elongate along the wrinkles of foliation. Examination of another thin section of the Michigamme Slate from the same location shows that biotite flakes, as much as 0.15 by 0.30 mm in size, are unaffected by and independent of the foliation of the muscovite and tend to be elongate parallel to the wrinkles in the foliation. Foliation and wrinkles are at angles of about 30° and 60°, respectively, to the bedding.

The cataclastic texture of quartz and the mortar structure in the Hoskin Lake Granite are evidence that

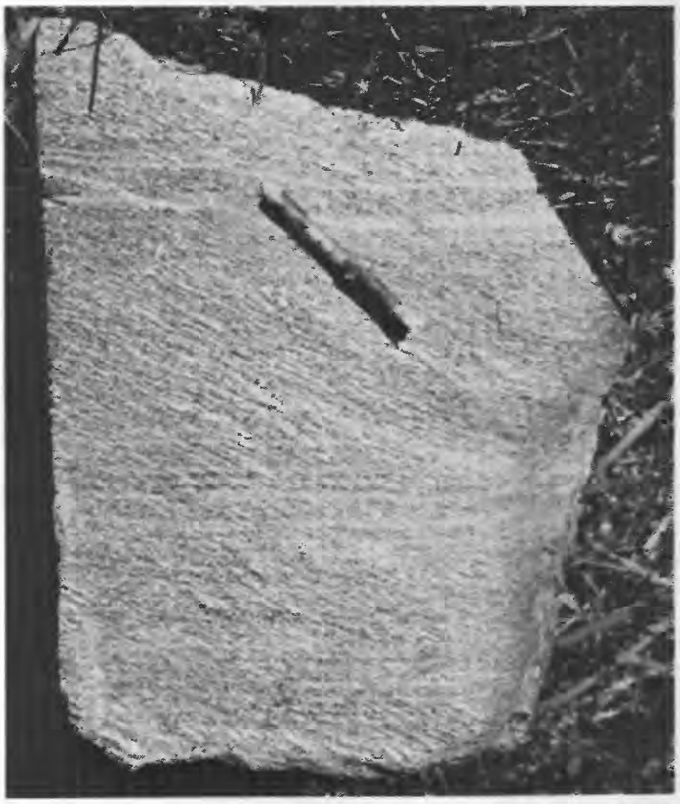

FIGURE 11.—Michigamme Slate in sec. 3, T. 39 N., R. 17 E. Foliation parallel to surface of photograph. Bedding represented by horizontal differences in color. Wrinkled foliation inclined to right. Piece of twig is 1 inch long.

FIGURE 12.—Folded foliation in the Quinnesec Formation, sec. 28, T. 39 N., R. 17 E. Knife is 3½ inches long.

crystallization of the granite was accompanied or followed by some deformation.

The isograds on plate 5 are drawn in accordance with the concept that metamorphism preceded deformation. Although alternative interpretations are possible, they do not seem to be especially more advantageous.

MAGNETIC SURVEYS

GROUND MAGNETIC SURVEY

In 1958–59 an area of about 4 square miles near Keyes Lake in the southwestern part of plate 2 was surveyed by K. L. Wier and R. A. Solberg with vertical-intensity magnetometers. The instruments were temperature compensated and had sensitivities of about 30 gammas per scale division.

Magnetic determinations were generally made at paced intervals of 100 feet along traverse lines generally 300 feet apart, but intermediate lines and stations were added in a few places. The traverse lines were controlled by the use of sundial compasses.

Magnetic values above an arbitrary zero base are shown in tens of gammas on plate 6. The zero base has an approximate absolute vertical intensity value of 57,500 gammas, as established from magnetic base stations in southeastern Iron County, Mich., by the U.S. Bureau of Mines (Bath, 1951).

The most prominent feature shown by the magnetic data is a concentration of high values in two pairs of discontinuous northwesterly trends that converge and join (pl. 6) like a plunging fold. Ellipsoidal structures in greenstone indicate that the top of lava flows associated with the northeast pair of anomalies is now toward the southwest, so the structure is interpreted as the northeast limb of a syncline plunging southeastward even though no data concerning the sequence in the southwest limb were found.

Magnetic gruneritic iron-formation is exposed or was penetrated by test pits or shallow shafts at several places along each of the paired anomalies, except in the southeastern part of sec. 35, T. 40 N., R. 17 E., and the northwestern part of sec. 1, T. 39 N., R. 17 E. Discontinuity of the anomalies may indicate that the layers may be long lenses or that the magnetite content of layers is locally less because of the original composition or subsequent oxidation. Gray slate crops out at several places between the two magnetitic units and apparently separates them throughout the structure; this relationship nullifies the possibility that the paired anomalies represent the limbs of a simple anticline or syncline.

The abrupt termination of the anomalies toward the southeast is probably related to faulting. Termination of the greenstone outcrops is presumably due to deep preglacial erosion and subsequent extensive and thick accumulations of glacial deposits.

Other features of the magnetic data appear to be less structurally significant. The anomaly in sec. 25, T. 40 N., R. 17 E., at the Dunkel exploration is caused by a local concentration of magnetite just above the upper part of a vitreous quartzite in the Michigamme Slate. The rocks underlying the anomaly near the center of sec. 31, T. 40 N., R. 18 E., are not especially magnetic, but their gross effect may have influenced the magnetometer; furthermore, these rocks are possibly the lithologic equivalent of those penetrated by the St. Clair-Dickey explorations in sec. 24, T. 40 N., R. 17 E. (pls. 2 and 8). Here small amounts of martite occur in radiating blades of limonite that is probably pseudomorphous after stilpnomelane or grunerite.

The southward trend of a conspicuous anomaly outlined by the 1,000-gamma line near the southwest corner of Keyes Lake is possibly related to a dike of metagabbro. Most exposures of metagabbro are not noticeably magnetic, but some fracture surfaces in the outcrop northwest of the outlet of Keyes Lake contain scattered magnetite crystals as large as one-quarter of an inch.

An anomaly with a northeast trend in the southwestern part of sec. 26, T. 40 N., R. 17 E., is not parallel either to the strike in the nearby outcrop of the Riverton Iron-Formation or to the areal pattern shown on plate 2. It may indicate a northeast extension of the small syncline of Riverton in the northwest corner of adjacent section 35 toward the outcrop mentioned above. However, a magnetometer traverse over the Riverton in a shallow syncline in the northwestern part of section 26 showed no anomalous magnetic values.

A magnetic survey of the area without exposed bedrock in the northeast part of the mapped area (pl. 2) and the adjacent area eastward for 1 mile into Dickinson County, Mich., was made by Wier in 1954. Several anomalies were located, but the geology of the area remains largely unknown. A 2,000-gamma positive anomaly trending west-southwest crosses the north half of sec. 34, T. 42 N., R. 31 W., and is flanked on the south by a 600-gamma negative anomaly. A pair of closely spaced anomalies resemble each other: in the S½SW¼ sec. 35, T. 42 N., R. 31 W., the ground plan is circular and about 1,300 feet in diameter, and the relief is 5,000 gammas; in the NW¼NW¼ sec. 2, T. 41 N., R. 31 W., the ground plan is elliptical with dimensions of 1,300 by 900 feet, and the relief is 6,000 gammas. An anomaly in the NW¼ sec. 12, T. 41 N., R. 31 W., and extending a short distance westward into the adjacent section 11, has an area of about a square mile and relief of 3,000 gammas. Magnetic values just east of the mapped area increase rapidly in the eastern quarter of sec. 12, T. 41 N., R. 31 W., and the western part of sec. 7, T. 41 N., R. 30 W. An anomaly there is 3,600 feet wide, has 13,000-gamma relief, and is apparently related to the Felch Formation of the Felch trough in Dickinson County, Mich. (James and others, 1961).

AEROMAGNETIC SURVEY

The aeromagnetic maps (pls. 7 and 8) not only show a close relation to most of the areal geology based entirely on field data (pls. 1 and 2) but also show several significant features that would not have otherwise been apparent. The magnetic pattern generally agrees with the location and trend of the inferred faults that separate the structural blocks. The principal magnetic and geologic relations will be considered in each of the structural blocks.

BRULE RIVER BLOCK

The areas of high magnetic values related to the Michigamme Slate and the Paint River Group and low values for the Badwater Greenstone in the northeast limb of the Commonwealth syncline are well delineated by the magnetic pattern (pls. 2 and 8). The anomaly at the northwest corner of the mapped area is of special significance inasmuch as it is caused by the magnetite-bearing Stambaugh Slate. This slate is younger than the Riverton Iron-Formation and has been traced magnetically and by outcrops in the Crystal Falls and Iron River areas. It is, however, not a recognizable unit elsewhere in the Florence area, even though the southeastward continuation of the anomaly suggests that similar material is present in the lower part of the post-Riverton sequence.

A prominent circular anomaly in the south-central part of plate 8 is centered above the axis of the Commonwealth syncline. Apparently it is caused by strata in the lower part of the post-Riverton sequence that are probably equivalent to the Stambaugh Slate. It is presumed that a steep northwestward plunge and extreme plication of magnetic strata are at this structural position.

KEYES LAKE BLOCK

The magnetic anomalies of the Keyes Lake block are a series of northwest-trending elongate areas (pls. 7 and 8). The anomalies on plate 8 are clearly related to the lithology and to a homoclinal structure in the Michigamme Slate, to a syncline and anticline in the Badwater Greenstone, and less clearly to a syncline in the Riverton Iron-Formation, as shown on plate 2. The cause of the anomaly near the north edge on plate 7 is not known. Drilling in that area (pl. 1) penetrated a variety of slates.

PINE RIVER BLOCK

The magnetic pattern and related geology in the Pine River block are shown on plates 1, 2, 7, and 8. The area is underlain by the Michigamme Slate, and the cause of most of the anomalies is not known. However, some are due to the magnetite-grunerite rocks exposed in sec. 2, T. 39 N., R. 17 E. (pl. 2), and penetrated by drilling in secs. 34 and 36, T. 39 N., R. 18 E. (pl. 1 and p. 22). The anomaly adjacent to the fault in the southwest corner on plate 8 continues across most of the area shown on plate 7 and possibly farther. The drilling in secs. 30 and 31, T. 39 N., R. 19 E., was reported to have penetrated gray slate in section 30 but graphite slate in the northern part of section 31 and greenstone in the two southernmost holes.

A prominent anomaly along the southwestern part of the block (pls. 7 and 8) appears to be closely related to exposed magnetite-bearing quartzitic conglomerate but extends northwestward and southeastward into areas where there are no exposures. Drilling in sec. 27, T. 39 N., R. 18 E., near the maximum magnetic value (pl. 1) penetrated Michigamme Slate that contained some small veinlets and disseminations of pyrrhotite, but the possible relation of the anomaly and this mineral is not known. Drilling in secs. 34 and 36, T. 39 N., R. 18 E., cut magnetic grunerite schist and iron-formation, respectively.

A prominent west-facing broadly convex anomaly shown along the eastern side on plate 7 constitutes the western end of a major anomaly that extends southeastward into Dickinson County, Mich., and is caused by the Vulcan Iron-Formation that is exposed there and was formerly mined for iron ore. The Michigamme Slate overlies the Vulcan in Michigan, but no Vulcan is known to crop out or to have been penetrated by drilling in Wisconsin. The western termination of the Vulcan is believed to be a steeply west-plunging anticline cut off just north of the axis by the fault that separates the Pine River and Keyes Lake blocks.

POPPLE RIVER BLOCK

The most striking feature in the magnetic pattern of the Popple River block (the southwest half on pl. 7) is its contrast and abrupt change from the well-defined northwestward trends in the Pine River block to few short, much less well defined trends, varied directions, and lower magnetic values.

A large area of low values in the southwestern part of the block is presumably underlain by the Hoskin Lake Granite that crops out in a few places. The irregular contact between this rock and the surrounding Quinnesec Formation (as shown on pl. 1) is based on the magnetic pattern.

More than half of the area underlain by the felsic metavolcanic rock of the Quinnesec Formation is characterized by low magnetic values.

The "bird's-eye maple" pattern in the remainder of the Popple River block probably indicates variations in the mineral composition of metabasalt and metagabbro that were not recognized during the geologic mapping.

ECONOMIC GEOLOGY

The possibilities of renewed mining in the area under present economic and technologic conditions do not appear to be favorable. The available iron-bearing material is not currently competitive in quality or quantity either as direct-shipping ore or as material amenable to beneficiation. The ore bodies that have been mined were all small, and geologic features that might have been conducive to the formation of large ore bodies do not appear to be present. The amount of low-grade magnetic or nonmagnetic ore that is readily available is believed to be very limited.

Almost 8,000,000 tons of direct-shipping iron ore was mined locally from the Riverton Iron-Formation in the period from 1880 to 1960. The ore was predominantly soft hematite and limonite with a high phosphorus content, non-Bessemer grade; hard hematite with a conchoidal fracture was present locally but was not separated in mining. The composition of ore marketed prior to 1938 is given in table 7, but ore of similar grade is not known to be available in significant amount.

Small nonmagnetic iron-bearing deposits associated with other formations have also been explored for direct-shipping ore but apparently have not been found to be of economic importance. Parts of the Riverton, Badwater, and Michigamme are magnetic, but neither the quantity nor quality of the iron-bearing rock appears to be suitable for possible beneficiation at this time.

Deposits of sand and gravel have been, and intermittently still are being, utilized for construction.

IRON-ORE MINES

The inaccessibility of all underground mines in the Florence area and the sparsity of critical geologic data on available mine maps make a detailed interpretation of the principal ore occurrences difficult. Data show that interbedded chert and siderite were associated with the ore and presumably were the source from which the ore was formed by oxidation of siderite and removal of much of or all the chert by leaching, replacement, or some combination of these processes.

FLORENCE MINE

The Florence mine is in secs. 20 and 21, T. 40 N., R. 18 E. (pl. 3). Production of ore began from a small open pit, but most mining was underground. Shipments of ore during the period of 1880 to 1931 totaled 3,680,000 tons.

Trend of the ore bodies was N. 45° W.; their general dip of 70° NE. indicates that the Riverton and associated strata are overturned. Ten levels were developed within a total depth of approximately 650 feet. Three ore bodies at the first level, about 132 feet deep, ranged from 400 to 750 feet long and from 70 to 250 feet wide. A fourth ore body, which was not distinct at the first level, was about 1,100 feet long and 150 feet wide at the third level. The four ore bodies were arranged in pairs; a small ore body was southeast of a large one on each side of a center line that trended N. 45° W. The southeast ore bodies did not extend below the seventh level (a depth of 425 ft), and the others had decreased considerably in size at this depth but extended to the tenth level.

The southeast ore bodies were separated by pyritic black slate, according to the descriptions on available mine maps. This is presumably Dunn Creek Slate and forms the core of an anticlinal fold plunging northwestward. The northwest convergence of the north-

TABLE 7.—*Partial analyses, in percent, of iron ores from Florence, Wis., area*

[From Lake Superior Iron Ore Association (1938, p. 149, 152)]

Mine	Sample	Chemical composition									
		Iron	Phosphorus	Silica	Manganese	Alumina	Lime	Magnesia	Sulfur	Loss	Moisture
Commonwealth group [1]	Dried at 212°F	52.50	0.400	10.00	0.13	2.80	2.75	2.72	0.500	5.00	------
	Natural [2]	48.04	.366	9.15	.12	2.56	2.57	2.54	.458	4.58	8.50
Ernst	Dried at 212°F	56.52	.353	5.73	.26	2.56	3.06	2.90	.213	3.67	------
	Natural [2]	50.65	.316	5.14	.23	2.29	2.74	2.60	.191	3.29	10.39
Florence	Dried at 212°F	55.37	.267	6.95	.22	4.43	1.63	2.79	.138	4.40	------
	Natural [2]	50.06	.241	6.28	.20	4.01	1.47	2.52	.125	3.98	9.60

[1] Commonwealth, Badger, Buckeye, and Davidson mines.
[2] Basis for sale and use; recalculated from analyses of dried sample.

west ore bodies is further evidence of the plunging anticline that must be accompanied on the north by a syncline or fault from which the Riverton continues along the general northwest trend. Other reported occurrences of pyritic black slate with iron-formation on each side indicate other anticlines, and a few occurrences of graywacke (classified as tuff in some places) flanked by iron-formation indicate synclines. However, no general pattern of folding was shown on the mine maps. Occurrences of tuff or black slate and tuff immediately northeast of the Riverton are mentioned in records of underground drilling and suggest the possibility that some faulting has locally cut out part of the normal sequence of Dunn Creek Slate.

BADGER MINE

The Badger mine is in the SE¼SE¼ sec. 34, T. 40 N., R. 18 E., and is at the southeast apex of the Riverton Iron-Formation in the Commonwealth syncline (pl. 2). This mine opened in 1891 and probably closed in 1901; approximately 700,000 tons of ore were shipped. Operations began as an open pit, which is now 600 feet in a west-northwest direction and 300 feet wide. Five levels, the lowest at a depth of 630 feet, were developed to mine an area about the same size as the open pit. It was reported that the ore body dips 70° N. and plunges westward. Graphitic phyllite of the Dunn Creek Slate is exposed in the northeast corner of the pit and was observed in the southeast end when the pit was partly dewatered in 1959. Fine-grained graywacke and argillaceous rock, also of the Dunn Creek Slate, crop out in several places east of the pit. A shallow northwestward extension of the pit exposes several thin lenses or wedges of graywacke containing a few chert fragments; these occurrences are believed to be Hiawatha Graywacke in small synclines.

BUCKEYE MINE

The Buckeye mine, in the southern limb of the Commonwealth syncline, is in the SW¼SE¼ sec. 33, T. 40 N., R. 18 E. (pl. 2); it was opened in 1909 as an underground operation and was closed in 1911. No record of the amount of ore produced was found.

Eight levels were developed within a total depth of 825 feet. Drifts and crosscuts extended beneath an area approximately 1,400 feet north to south and 600 feet east to west, within which the ore-bearing area was about 560 feet north to south and 330 feet east to west. Mine maps show that two main ore bodies near the shaft were generally elliptical in horizontal section, elongate east and west, and vertical. The north one was 200 feet by 70 feet with a vertical extent from the third to the eighth levels. The south one had maximum measurements of 220 feet by 80 feet and extended from the first to the eighth levels. A small ore body 350 feet south of the shaft was 170 feet by 40 feet and extended vertically from the first to the fourth levels.

The geology of the mine was mapped by W. O. Hotchkiss in 1910–11, and his maps are in the files of the Wisconsin Geological and Natural History Survey. A suite of 45 specimens is also available for examination. Strikes, dips, and some folds are shown on the maps; general lithologic descriptions for numerous localities are recorded, but no stratigraphic units or contacts are indicated. Prevalent strikes are east-west, and dips are steep, both north and south. Minor folds do not indicate the type of larger fold to which they are related. Graphitic slate, possibly the Dunn Creek, occurs east of the shaft and a few other localities. Much oxidized iron-formation lies adjacent to the ore bodies but some cherty carbonate occurs in the northern part of the fourth, fifth, and sixth levels. North of the oxidized iron-formation, the mottled green and red, massive, bedded argillite with chert lenses is possibly the upper part of the Riverton. West and south of the iron-formation is a generally fine grained quartz graywacke that is graphitic throughout or has graphitic partings and is probably a part of the Hiawatha Graywacke. The distribution of these rocks and their strikes and dips suggest that the Buckeye ore bodies probably occurred mainly in the north flank of an anticline that plunges westward (pl. 2).

COMMONWEALTH MINE

The Commonwealth mine, in the NE¼SW¼ sec. 34, T. 40 N., R. 18 E. (pl. 2), was opened in 1880 and closed in 1896. About 700,000 tons of ore were shipped. Mining began as an open pit operation, but later six levels within a total depth of 610 feet provided access for mining in an area 450 feet southeast to northwest and 400 feet across. Only the Riverton Iron-Formation is exposed in the open pit; no geology is shown or available mine maps. Field data in the vicinity of the pit indicate that this ore body was in the northeast limb of a major syncline and was possibly related to a local synclinal drag fold.

DAVIDSON MINE

The Davidson mine is in and also slightly east of the NE¼SW¼ sec. 34, T. 40 N., R. 18 E. (pl. 2); it was opened in 1889 and was probably operated until 1906 and again from 1953 to 1960. Approximately 800,000 tons of ore were shipped.

Information concerning this mine is restricted mainly to the latest operation, by the Zontelli Mining Co., which produced a northwest-trending open pit 600 feet long, 350 feet wide, and about 100 feet deep. The south wall of the pit is pyrite-bearing graphitic rock of the Dunn Creek Slate, but elsewhere the opening exposes only Riverton Iron-Formation in which many minor folds are present, especially at the east end. This mine is in the north limb of an anticline in which Dunn Creek Slate is exposed. The south limb extends eastward through the small Field mine pit in which the Dunn Creek is exposed in the north wall, the Riverton is only about 100 feet thick, and the Hiawatha forms the south wall.

ERNST MINE

The Ernst mine is in the SW¼SW¼ sec. 27, T. 40 N., R. 18 E. (pl. 2). The mine was operated from 1912 to 1929, and 670,000 tons of ore was mined from six levels developed within a total depth of 500 feet. Main drifts extended N. 60°–75° W. for distances that ranged from 350 to 500 feet from the shaft. Width of the areas penetrated by crosscuts ranged from 170 to 240 feet. The single ore body began about 280 to 370 feet from the shaft, and horizontal sections at various levels ranged from circular at 75 feet in diameter to rectangular at 130 feet by 130 feet.

No maps showing the geology of the mine are known to be available, and the structural setting of the ore is not known. Exploratory drill-hole data indicate that the ore was in an extensive area of oxidized iron-formation and interbedded chert-siderite. The record of one drill hole east and another north of the ore reported gray tuffaceous slate—probably graywacke in the Dunn Creek Slate. The ore occurrence at the Ernst mine is interpreted as being in a segment of the Riverton Iron-Formation on the northeast limb of the Commonwealth syncline.

Exploratory drilling in the Ernst area in 1911–12 consisted of nine holes from the surface and four to possibly nine holes from underground locations. Holes from the surface were inclined from 60° to 80°, and drilled depths ranged from 175 to 679 feet. Most of the material penetrated by the holes from the surface was reported as some variation of iron-formation—ore, oxidized iron-formation, or cherty carbonate. Small amounts of gray slate, graphitic slate, and ferruginous slate were also reported. A vertical hole from the sixth level was recorded as being in hard blue and soft red ore of 50 to 65 percent iron for 500 feet, but the amount of sulfur generally exceeded 0.20 percent and locally 1.0 percent.

EXPLORATIONS

NONMAGNETIC IRON-FORMATION

A few localities have been explored by shafts with limited underground workings or by test pits, and brief descriptions are given. Classification of materials in or from the shafts and test pits was a part of the field study, and information is recorded on a set of data sheets at the scale of 1:12,000 on file at the Wisconsin Geological and Natural History Survey.

WELCH

The Welch exploration in the NW¼ sec. 34, T. 40 N., R. 18 E. (pl. 2), had three levels. The deepest drift was at the 400-foot level, but the most extensive was at 300 feet, where crosscuts extended 250 feet southwestward, to a main northwest-southeast drift that was 600 feet long. No records of the geology at this exploration were found. The dump material is predominantly very fine grained hematite, limonite, or both, with interbedded chert. A very small amount of interbedded siderite and chert is also present. Oxidized quartz graywacke in the dump of a test shaft about 300 feet northeast of the Welch shaft is believed to be a part of the Dunn Creek Slate.

POLDERMAN

The Polderman exploration in the NW¼SW¼ sec. 33, T. 40 N., R. 18 E. (pl. 2), had only 120 feet of crosscut and 110 feet of drift at an unrecorded depth. The dump material is believed to be predominantly oxidized Hiawatha Graywacke. There are a few test pits in the vicinity of the shaft.

SPREAD EAGLE

The Spread Eagle explorations were in the N½ sec. 8 and near the center of the W¼ sec. 9, T. 39 N., R. 19 E. (pl. 1). A shaft in the SE¼NW¼ sec. 8 had workings designated as the 50-foot and 100-foot levels. The upper level had 165 feet of drift and 200 feet of crosscuts; recorded iron content of samples from the drift and from a zone 10 to 60 feet wide in the crosscuts ranged from 25 to 51 percent and averaged 40 percent. The lower level had 100 feet of drift and 170 feet of crosscuts; the iron content for 70 feet of the drift and 50 feet of a crosscut ranged from 27 to 47 percent and averaged about 41 percent. Rock associated with the iron-bearing material was designated as slate. A shaft near the center of the W¼ sec. 9 was 57 feet deep, and a crosscut northward for 85 feet penetrated two ferruginous zones that totaled 29 feet in thickness. The iron content ranged from 25 to 57 percent and averaged 36 percent. Associated material is recorded as greenstone. Drilling nearby is reported to have also penetrated satiny slates, tuffaceous slates, and tuffs. Numerous test pits and two additional shafts or cribbed test pits are also present. Exposures of Badwater Greenstone just north of this area of explorations indicate that the ferruginous material is probably part of the Michigamme Slate and near its upper limit—a part of the Michigamme that is transitional with the Badwater. Ferruginous material in the upper part of the Michigamme is present at the Wausau exploration in sec. 17, T. 41 N., R. 31 W., Iron County, Mich. (pl. 2 and p. 14), and at several localities in Dickinson County, Mich.

Many other nonmagnetic localities have been explored by diamond drilling; the geologic data and other information are in the files of the Wisconsin Geological and Natural History Survey and have been compiled on the data sheets previously mentioned. Descriptions of materials penetrated were generally not helpful for determining the lithology, stratigraphy, or structure. However, reported occurrences of cherty carbonate or carbonate slate, which presumably was unoxidized Riverton Iron-Formation, were used locally in interpreting the areal geology.

MAGNETITIC IRON-FORMATION

In the southwestern part of the area shown on plate 2, magnetitic iron-formation is found in several types of occurrence. The localities have been known since at least 1879 and have been examined repeatedly.

The Riverton Iron-Formation in secs. 26, 27, 34, and 35, T. 40 N., R. 17 E., consists of alternate layers of garnet-magnetite-grunerite and chert that are complexly folded and presumably faulted. Oxidation in the NW¼ sec. 35 has produced soft limonitic and hematitic material that has been explored by several companies; a small amount of material from an open pit was shipped in 1948. The amount of magnetite is small as indicated by magnet tests, magnetic surveys, and visual inspection. A small concentration of fine-grained bluish hematite in the NW¼ sec. 35 was explored prior to 1910.

The Badwater Greenstone in this group of sections and in several adjacent ones is predominantly metamorphosed basaltic rock with two thin discontinuous layers of garnet-magnetite-grunerite and interbedded chert. Magnetic values determined by an aeromagnetic survey (pl. 8) are as high as, and locally higher than, those of adjacent Riverton; but the amount of magnetite and quantity of rock containing it are small. Several small areas have been explored by test pits or trenches.

The St. Clair exploration shaft was in the SW¼ NW¼ sec. 24, T. 40, N., R. 17 E. (pl. 2). A drift and a crosscut at an unrecorded depth were each 240 feet long. The Dickey exploration, in the SW¼SW¼ sec. 24, was was just a shaft of unrecorded depth, so far as indicated by data in files. These explorations were in a thin oxidized layer of garnet-magnetite-silicate in the Michigamme. Limonite is more common than hematite, but both occur locally in radiating patterns and presumably were derived from stilpnomelane or, less likely, from grunerite. This area also was explored by many test pits.

The Michigamme Slate in and just west of SW¼ sec. 32, T. 40 N., R. 18 E., contains a concentration of hematitic-magnetitic material at the Little Commonwealth exploration (p. 15 and fig. 2). A small deposit of magnetitic material in the Michigamme Slate in the SE¼ sec. 25, T. 40 N., R. 17 E., occurs at the Dunkel exploration (p. 18 and pls. 2 and 6). This deposit was explored with two shallow shafts prior to 1910 and has been of recurrent interest to mining companies.

Several explorations in the Michigamme Slate in secs. 27, 28, and 34, T. 39 N., R. 18 E., near the center of the area shown on plate 1, are along a prominent northwest-trending anomaly (pl. 7). The dump of a shallow test pit or shaft opened prior to 1910 in the SW¼NE¼ sec. 28, T. 39 N., R. 18 E. (fig. 3), contains predominantly iron-bearing rock that crops out nearby. In thin section the materials are translucent to opaque hematite, minor magnetite, garnets as much as 1 mm across, and quartz. The hematite is commonly arranged in a radiating pattern, as if pseudomorphous after grunerite or stilpnomelane, and spreads through adjacent areas of quartz. The quartz may be either approximately equigranular with unsutured boundaries and normal extinction or irregularly elongate with sutured contacts and wavy extinction. No definitely clastic quartz was recognized, so it is likely that the material is recrystallized chert. The dump of a shallow shaft, also in the SW¼NE¼ sec. 28, T. 39 N., R. 18 E., contains mainly somewhat quartzose but very magnetic iron-formation and some associated magnetic grunerite schist with a small amount of chert. The amount of magnetite-bearing rock is indeterminate from present data, but the highest known magnetic value in this area (6,750 gammas) is about 2,000 feet southeast along the prominent anomaly, and the area enclosed by the 3,000-gamma contour is 1 mile long and almost half a mile wide.

The southwestern part of sec. 27, T. 39 N., R. 18 E., was explored in 1908 by two drill holes that were inclined 60° to the southwest and penetrated to depths of 605 and 833 feet. The core is quartz-sericite slate that presumably is part of the Michigamme Slate. Locally the core contains pyrite, magnetite, and pyrrhotite. Holes drilled in 1911 in the northeast part of sec. 34, T. 39 N., R. 18 E., were reported to have penetrated magnetite-grunerite iron-formation.

A small magnetic crest indicated in the SE¼ sec. 36, T. 39 N., R. 18 E., by the work in 1910–11 (pl. 7), created enough interest in 1958 so that a 265-foot hole was drilled. The material penetrated was opaque irregular hematite and minor amounts of magnetite interlayered with quartz. The quartz was irregular to bladelike in form, as if pseudomorphous after grunerite, and characterized by wavy extinction, as in chalcedony.

In summary, the possibility of utilizing the known magnetitic iron-formation in the Florence area is very remote because the deposits are small, thin, few in number, and of very low grade.

GUIDES TO FURTHER EXPLORATION

If renewed interest in direct-shipping ore should develop, several considerations should be taken into account. Previously, ore bodies were discovered at the bedrock surface and were then followed along strike and downdip as far as they were economically profitable, but today new procedures must be followed.

1. Some tightly folded structures such as those at the east end of the Riverton Iron-Formation in the Commonwealth syncline may have ore that lies deep on the flanks of and along the axes of folds. To test this possibility will require additonal test pitting, trenching, and drilling in order to study the possible relations between structure and areas of enrichment.
2. The prominent circular magnetic anomaly near the community of Commonwealth is another area that warrants further study. The anomaly is probably due to the presence of complexly folded Stambaugh Slate at depth (p. 46); the Riverton Iron-Formation and associated post-Riverton formations exposed here are generally only very slightly magnetic. The Michigamme Slate at the Little Commonwealth exploration and the Vulcan Iron-Formation, which is older than the Michigamme and in adjacent Dickinson County, Mich., contain ferruginous facies that are magnetic; but neither is likely to be present at this site. Nevertheless, further detailed magnetic and geologic work may indicate that exploration is warranted.
3. Although the Riverton Iron-Formation is locally absent at the surface northwest of Florence, it may be present at depth and may have been enriched.

Other sites to be considered for further geologic work and some exploraton to evaluate the possibilities of finding magnetic iron-formation are the iron-rich facies of the Michigamme Slate in the Little Commonwealth and Dunkel areas and the metamorphosed Riverton Iron-Formation in the Larsen exploration area (NW¼ NW¼ sec. 35, T. 40 N., R. 17 E.).

If future circumstances cause increased interest in the carbonate facies of the Riverton Iron-Formation, places that should be investigated are the Ernst and Welch mines near Commonwealth, the Buckeye mine area south of Commonwealth, and the rock-cored ridge that extends northwest from the Florence mine. It seems likely, however, that the amount of carbonate iron-formation in the mapped area is small. If there is an increased interest in the oxidized iron-formation, studies should probably begin at the sites of inactive mines and extend along the strike and down the dip of the Riverton Iron-Formation.

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