MAP GQ-1168

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

BEDROCK GEOLOGIC MAP OF THE GREENWOOD QUADRANGLE, MARQUETTE COUNTY, MICHIGAN

By William F. Cannon

Prepared in cooperation with the
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GEOLOGIC QUADRANGLE MAP
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CANNON—BEDROCK, GREENWOOD, MICHIGAN 1:24,000 MAP GQ-1168

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GENERAL GEOLOGY

The Marquette Iron Range is presently (1973) the second largest iron mining district in the United States. Commercial iron deposits, now mostly concentrating-grade ore, are in the Negaunee Iron-formation, which is part of a thick sequence of metasedimentary rocks of Precambrian X age. These rocks are preserved in the west-trending Marquette synclinorium, and are flanked to the north and south by older Precambrian W crystalline rocks (fig. 1).

The Greenwood quadrangle includes part of the central Marquette Range and part of the Precambrian W rocks south of the range. No mines are active in the quadrangle, but appreciable quantities of iron-formation may be future concentrating-grade iron ore reserves.

STRATIGRAPHY AND SEDIMENTATION

Precambrian W rocks, mostly granitic gneiss, were described by Cannon and Simmons (1973). They have a minimum age of about 2.5 b.y. (Woolsey, 1971) and form the basement on which Precambrian X sedimentary rocks were deposited following a very long (about 500 m.y.) period of erosion. Precambrian X rocks of the Marquette Range Supergroup (Cannon and Gair, 1970) were deposited probably about 2.0 b.y. ago (Banks and VanSchmus, 1971). Only the Menominee and Baraga Groups are present in the quadrangle; the Menominee Group lies directly on basement. To the east, these rocks are separated from the basement by the quartzite-carbonate shelf assemblage of the Chocolay Group (Van Hise and Bayley, 1897; Gair and Thaden, 1968) and to the southwest they are overlain by the geosynclinal graywacke-shale-iron-formation assemblage of the Paint River Group (James, 1958). The Menominee Group was deposited as a fining-upward sequence of basal sandstone (Ajibik Quartzite), shale and siltstone (Siamo Slate), and iron-rich chemical precipitates (Negaunee Iron-formation). Deposition was subaqueous in a relatively stable shelflike environment. Uplift followed deposition of the Negaunee and a period of weathering and erosion altered and partly (locally totally) removed the Menominee Group. With ensuing submergence, deposition of the Baraga Group occurred in a progressively less stable environment. Deposition began with a fining-upward sequence, much like that of the Menominee Group, with basal conglomerate overlain by sandstone (Goodrich Quartzite), shale and siltstone (lower argillite member of Michigamme Formation), and iron-rich chemical precipitates (Greenwood Iron-formation Member). An abrupt onset of explosive volcanism produced a thick sequence of pyroclastic rocks (Clarksburg Volcanics Member) which were deposited subaqueously (interbedded argillite and iron-formation). The volcanic rocks were then buried by terrigenous (nonvolcanogenic) graywacke (lower graywacke member) and black shale (lower slate member), probably deposited in deep water. These rocks were probably overlain originally by a great thickness of shale, graywacke, iron-formation, and mafic volcanic rocks preserved to the west and southwest in the upper parts of the Baraga and Paint River Groups.

The section is an interesting example of progressive destabilization of previously long-stable Precambrian W continental crust. Shelflike, miogeosynclinelike, and eugeosynclinelike assemblages are superposed, and all are deposited on deeply buried Precambrian W granitic basement.

STRUCTURE

Precambrian W rocks were intensely deformed about 2.5 b.y. ago. Gneissic foliation generally trends northwest and dips steeply. Foliation in the Bell Creek Gneiss is broadly folded about a west-northwest-trending axis. These rocks were not refolded during the later Penokean orogeny (about 1.9 b.y. ago) despite intense folding of overlying Precambrian X rocks. During the Penokean orogeny, Precambrian W basement rocks moved as rigid fault-bounded blocks (Cannon, 1972, 1973; Cannon and Klasner, 1972). The Marquette synclinorium was formed by relative uplift of Precambrian W rocks along steep faults bounding the synclinorium on the north and south and the Precambrian X Marquette Range Supergroup was passively draped over the marginal blocks; thus the Marquette synclinorium is a fold only with respect to Precambrian X rocks and is a graben with respect to Precambrian W rocks. The synclinorium is west trending in the east half of the quadrangle and northwest trending in the west half. The trend is controlled by the orientation of the basement boundary faults (west-trending Palmer fault and northwest-trending Bell Creek fault). At quadrangle scale the folding is slightly noncylindrical, but all fold axes plunge less than 20°.

METAMORPHISM

Two episodes of regional metamorphism are evident. Near the close of Precambrian W time metamorphism reached upper almandite-amphibolite facies or perhaps lower granulite facies. Later, during the Penokean orogeny, the Republic metamorphic node developed (James, 1955) (see fig. 1). The Greenwood quadrangle is on the northeast flank of this node; metamorphism ranged from chlorite grade in the northeast corner of the quadrangle to staurolite grade in much of the southwest part of the quadrangle (fig. 1). Mineral assemblages are shown in figure 2. Penokean metamorphism only slightly retrograded the higher grade Precambrian W assemblages, perhaps due to a lack of water which prevented the rehydration of the largely dehydrated Precambrian W rocks. Precambrian X metasedimentary rocks in the quadrangle are in the chlorite, biotite, and garnet zones of the Republic node. The biotite and garnet isograds are drawn to coincide with the first appearance of these minerals in pelitic rocks. Precambrian X metadiabase occurs in all zones. The staurolite isograd projects through the quadrangle approximately as shown by James (1955), but is not shown on this map because Precambrian W rocks of appropriate composition are not present. The boundary of the greenschist and almandite-amphibolite facies is defined by the composition of plagioclase in metadiabase. Albite is typical of the greenschist facies; oligoclase and andesine are typical of the almandite-amphibolite facies.

Continuous changes in metamorphism cannot be observed in the Negaunee Iron-formation because it occurs in three separate geographical areas. On the north limb of the synclinorium it is near the biotite isograd; on the south limb of the synclinorium, near Greenwood mine, it is near the garnet isograd; on the south limb, north of Lake Lory, it is well within the garnet zone.

Within the Greenwood quadrangle, in the Negaunee Iron-formation, the grain size of chert (0.02 mm) is the only indicator of metamorphism in the north limb of the synclinorium. Any other metamorphic changes that might have occurred have been obliterated by post-metamorphic oxidation and leaching. The rock now present is composed of goethite, limonite, and chert, but may have contained abundant siderite and (or) iron silicates after metamorphism.

The Greenwood mine section, near the garnet isograd, shows several metamorhpic changes. The upper units of oxide iron-formation contain specularite, magnetite, martite, and metachert (grain size 0.05 mm). Less oxidized lower horizons consist of magnetite, grunerite, and metachert. The absence of siderite, which is abundant to the east (Van Hise and Bayley, 1897; Gair, 1974; G. C. Simmons, oral commun., 1970), suggests that at least some grunerite may form by a reaction between siderite and chert in the upper biotite zone. Thin clastic seams within the iron-formation are composed of sericite, chlorite, and quartz.

North of Lake Lory, in the garnet zone, the mineralogy of the Negaunee Iron-formation differs little from that at Greenwood mine. The upper oxidized horizons contain specularite, magnetite, martite, and metachert. Grain size of metachert is 0.05–0.1 mm. The increasing grain size of chert with increasing metamorphic grade agrees with values determined by James (1955). Lower, less oxidized, zones consist of grunerite, magnetite, garnet, and metachert. Grunerite commonly forms rims on pods and layers of chert, and clearly has formed partly at the expense of chert. Garnet occurs in thin seams whose dimensions are comparable to clastic sericite-chlorite-quartz seams at Greenwood mine; they may represent similar material that has been more intensely metamorphosed.

AGE AND SEQUENCE OF PRECAMBRIAN X EVENTS

Precambrian X time in the Greenwood quadrangle, as elsewhere in northern Michigan, encompasses a complete cycle of sedimentation and orogeny. The events are summarized in figure 4. The Menominee and Baraga Groups are the oldest Precambrian X sedimentary deposits in the quadrangle. Age determinations (Banks and VanSchmus, 1971) in Dickinson County indicate an age of about 2.1 b.y. for granitic rocks that are interpreted as part of the basement beneath the Marquette Range Supergroup. The Marquette Range Supergroup was metamorphosed about 1.9 b.y. ago (Aldrich and others, 1965; Goldrich and others, 1961). In Dickinson County (fig. 1), volcanic rocks within the Baraga Group (Hemlock Formation) are about 2.0 b.y. old (Banks and VanSchmus, 1971).

The first recognized deformation was associated with geosynclinal subsidence which began at least as early as deposition of the Baraga Group. Sedimentary features in the Baraga Group indicate deposition in an orogenically active environment that produced penecontemporaneous deformation.

Intrusion of large diabase sills was probably associated with early stages of folding (Gair and Simmons, 1970). Many large sill-like and laccolithic masses of diabase occur in the Greenwood quadrangle. They are abundant in units of the Marquette Range Supergroup below the top of the Clarksburg Volcanics Member of the Michigamme Formation.

They have also been found at two localities immediately above the Clarksburg but are apparently absent from younger units both within the quadrangle and to the west where these younger units are extensively exposed. The scarcity of these rocks above the Clarksburg was first recognized by Van Hise and Bayley (1897), but this observation, although not contradicted by any subsequent work in the Marquette or other nearby districts, has been neglected in later work. Van Hise and Bayley proposed that these intrusive rocks were equivalent in age to the Clarksburg Volcanics Member and were not post-"Huronian" as has been generally assumed by more recent workers. In my opinion, this remains a valid, and probably correct, hypothesis.

A few metamorphosed diabase bodies may be younger than the Marquette Range Supergroup, but these are late- or post-kinematic dikes that probably represent a second episode of mafic intrusion. For example, at Greenwood mine nearly vertical dikes are intruded along faults that cut folds; these must be late- or post-kinematic, because they give no indication of being folded, but they are metamorphosed to regional grade.

Precambrian X sedimentation terminated during the culmination of the Penokean orogeny. At this time, basement block faulting controlled folding and faulting of the Marquette Range Supergroup and the Marquette synclinorium was produced by draping of Precambrian X rocks into a fault trough in Precambrian W rocks.

Metamorphism probably began during deformation but culminated after deformation as evidenced by the metamorphism of the set of late- or post-kinematic dikes. Textures in the metamorphic rocks also indicate that metamorphism culminated after deformation (James, 1955).

No granitic rocks associated with the Penokean orogeny have been found in the Greenwood quadrangle although a few pegmatites have been reported in areas immediately to the west.

IRON DEPOSITS

DIRECT-SHIPPING-GRADE ORE

The Negaunee Iron-formation contains small to moderate amounts of direct-shipping-grade ore throughout the quadrangle.

On the north limb of the synclinorium, several underground mines have recovered soft ore. Although no mine openings occur in the north limb in the quadrangle, the workings of several mines in adjacent quadrangles extend into the quadrangle at depth. Drilling indicates that the iron-formation in the subsurface of the Greenwood quadrangle is virtually the same as that near the mine shafts.

On the south limb of the synclinorium a large quantity of direct-shipping-grade hard ore has been mined at Greenwood mine. The mine, operated by Inland Steel Company, produced 2,365,815 tons of ore between 1932 and its closing in 1963 (Inland Steel Company records and Lake Superior Iron Ore Assoc., 1938); peak annual production was 154,034 tons in 1943. The mine workings extend to a depth of about 2100 feet below the surface and follow the strike of the ore body for about ¾ mile. All ore was produced from the upper 100 feet of the Negaunee and most was from the upper 50 feet.

North of Lake Lory the Negaunee contains only small quantities of direct-shipping-grade ore. Small shipments were made from the Conrad (Michigan) mine in 1872–73 which totalled 4,439 tons (Lake Superior Iron Ore Assoc., 1938). The ore was granular magnetite and martite, and specular hematite. The ore body was at the top of the Negaunee Iron-formation and was apparently only 10–20 feet wide and perhaps 500 feet long.

CONCENTRATING-GRADE ORE

Because the definition of concentrating grade ore is complex and involves many considerations beyond the scope of this report, the following are only general recommendations based solely on the mineralogy and texture of the Negaunee Iron-formation and its accessibility to recovery from open pits.

On the north limb of the synclinorium, the Negaunee is entirely chert, and iron oxides (goethite and massive hematite) were penetrated by drill holes. With recent advances in the processing of very fine grained nonmagnetic taconite, this material might be considered as concentrating-grade ore. Secondary enrichment is widespread and the rock ranges from negligibly enriched to nearly pure iron oxide; in terms of iron content it is probably well within the limits for concentrating ore. Although the dip is steep (70°–80°) the unit is 800–1000 feet thick and has a seemingly adequate surface area for open pit development, but a 60–80 foot overburden of glacial material is a hindrance to development.

Near Greenwood mine, the Negaunee is mostly cherty magnetite-specularite iron-formation. A limited amount of drilling shows a stratigraphic thickness of about 500 feet of iron-formation whose iron content is probably sufficient to make concentrating grade especially in the upper 100 feet where secondary concentration has greatly enhanced the iron content. The steep dip (70°) combined with the relative thinness of the unit, and as much as 100 feet of glacial overburden are hindrances to development.

The Negaunee north of Lake Lory is largely cherty grunerite-magnetite iron-formation. Although large amounts of concentrating-grade oxide iron-formation are found just west of the quadrangle, these units extend into the quadrangle only as thin and probably discontinuous units at the top of the formation. The silicate iron-formation nowhere appears suitable for concentrating-grade ore. Although the iron content is high, most iron is contained in grunerite; the magnetite content is generally 10–20 percent.

GREENWOOD IRON-FORMATION MEMBER

The Greenwood Iron-formation Member of the Michigamme Formation has been explored by test pits at several localities. None of these show appreciable concentrations of ore minerals. The present study found no areas where secondary concentration, such as that which formed direct-shipping-grade ore in the Negaunee, has occurred. Although the member is characterized by its magnetism, magnetite is nowhere sufficiently abundant to yield concentrating-grade ore by present standards. The highest grade of iron is probably in sec. 16 and 20, T. 47 N., R. 28 W., but even there magnetite comprises only 10–15 percent of the rock.

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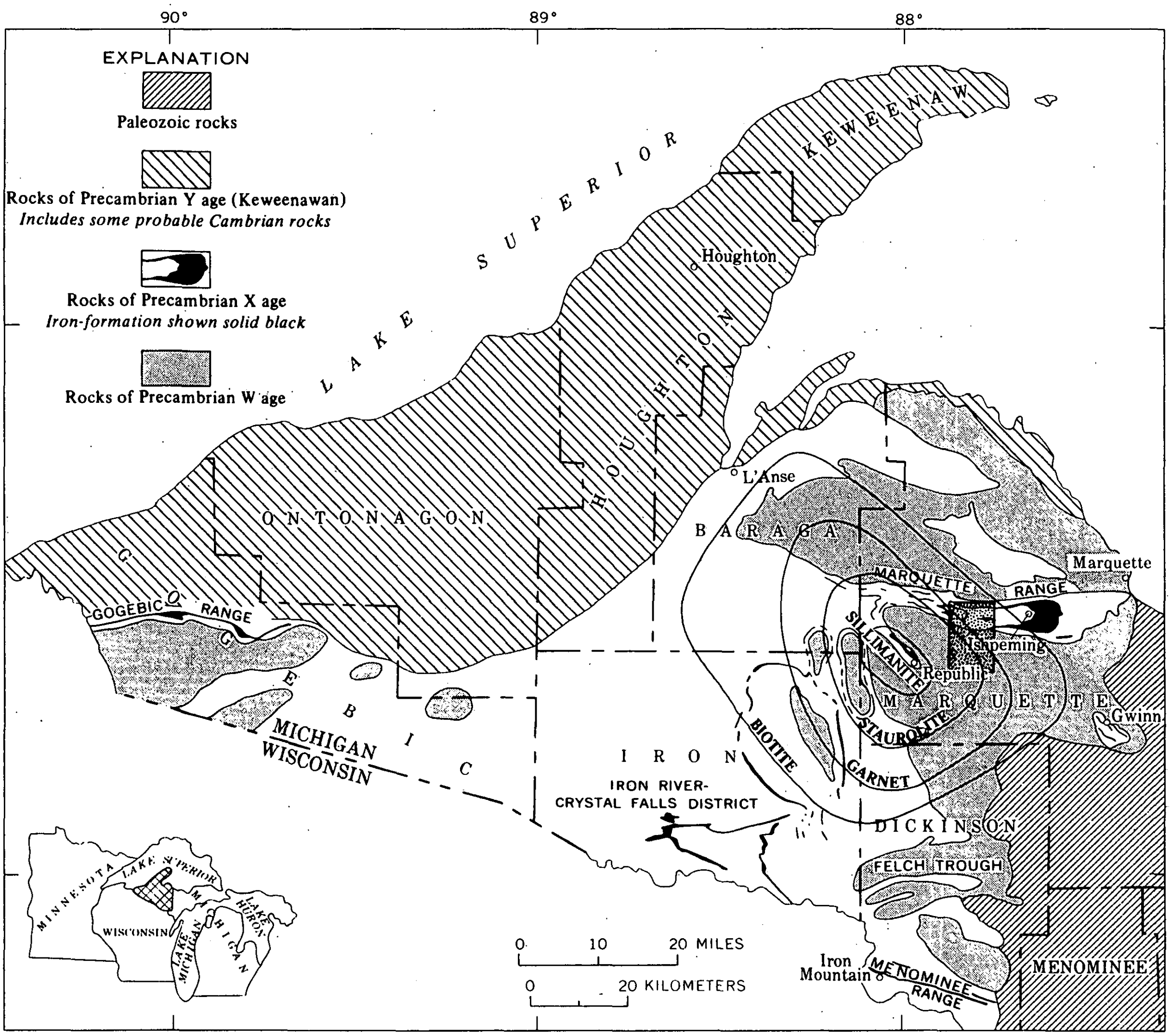
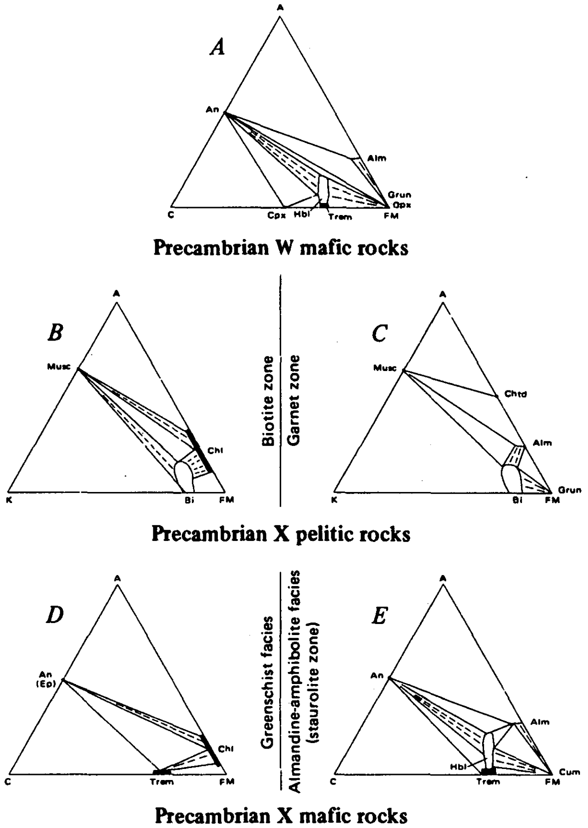


FIGURE 1.—Geologic sketch map of part of the northern peninsula of Michigan showing the location of the Greenwood quadrangle in relationship to the Marquette Range and other principal features. Isograds are shown for the Republic metamorphic node as mapped by James (1955).



EXPLANATION

Alm – almandite
An – anorthite
Bi – biotite
Chl – chlorite
Chtd – chloritoid
Cpx – clinopyroxene
Cum – cummingtonite
Ep – epidote
Grun – grunerite
Hbl – hornblende
Opx – orthopyroxene
Trem – tremolite
Musc – muscovite

===== Inferred tie lines in two phase fields

FIGURE 2.—Metamorphic mineral assemblages. *A*, Mineral assemblages in Precambrian W mafic rocks and iron-formation developed during Precambrian W metamorphism. All observed assemblages shown, except for the distinction between grunerite and iron-rich orthopyroxene which occur either singly or together in iron-formations, and for the common presence of biotite which does not lie in the ACFM plane. Retrograde minerals are not shown. *B* and *C*, Mineralogic changes in Precambrian X pelitic rocks crossing the garnet isograd. Garnet apparently forms mostly at the expense of chlorite. *D* and *E*, Mineralogic changes in Precambrian X metadiabase occurring near the boundary of the greenschist facies and almandine-amphibolite facies. The boundary is defined by changes in the An content of plagioclase, which cannot be shown on the ACFM plane. The mineralogic changes illustrated occur within about 1 mile on either side of the boundary.

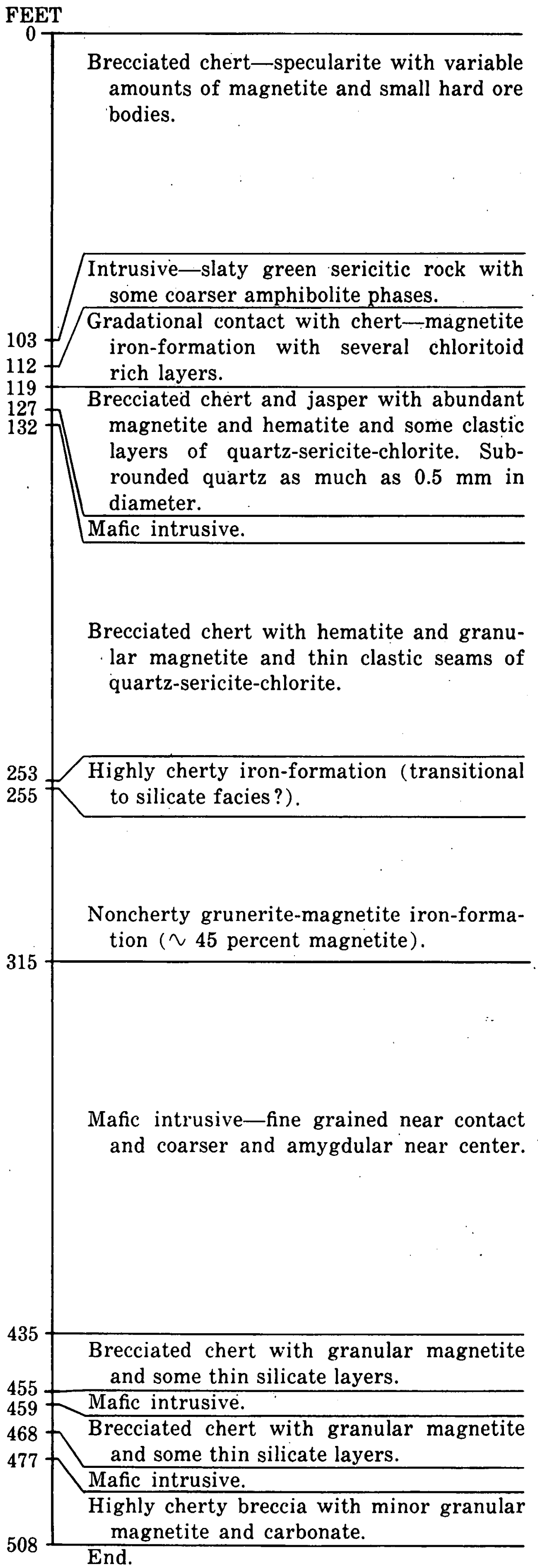


FIGURE 3.—Log of diamond drill hole drilled from workings of Greenwood mine. Hole begins about 50 feet stratigraphically beneath the top of the Neguanee Iron-formation and is horizontal, crossing bedding at about 70°. Core was made available for author's examination by Inland Steel Company.

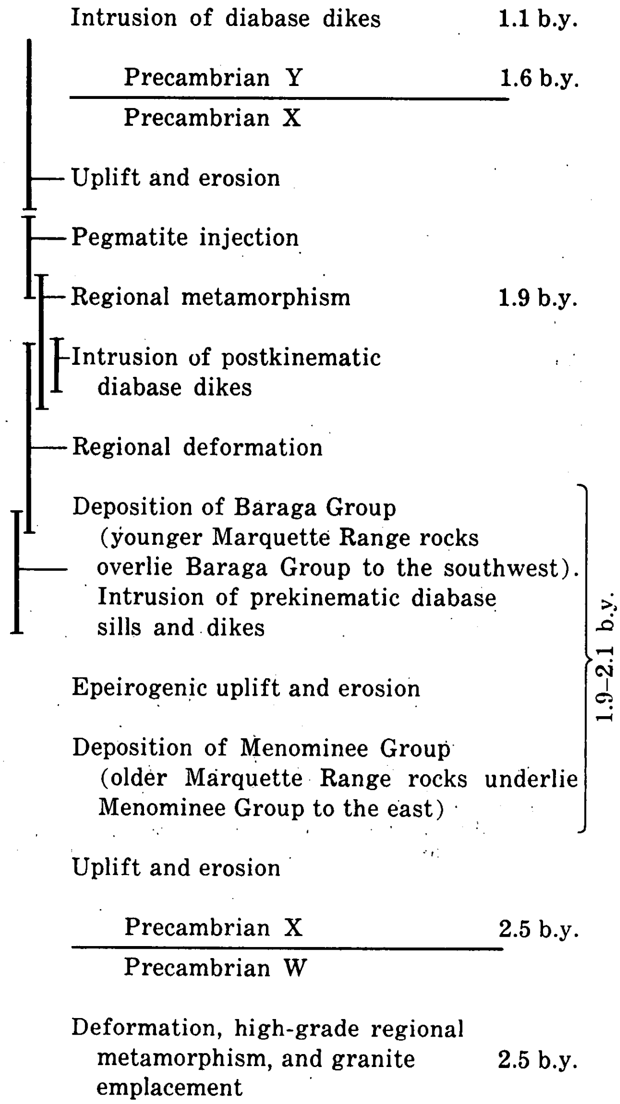


FIGURE 4.—Sequence of Precambrian events in the Greenwood quadrangle with overlap of events shown by vertical lines. No attempt is made to show relative duration of events.

TABLE 1.—*Chemical analyses and modes of selected rocks from the Greenwood quadrangle, Michigan.*

[Standard rock analyses similar to methods described by Peck (1964); analyst, S. M. Berthold, U.S. Geological Survey. Tr = observed but < 0.1 percent of rock; N.o. = not observed]

	Negaunee Iron-formation		Michigamme Formation: Greenwood-Iron-formation Member					Michigamme Formation: Clarksburg Volcanics Member				Metadiabase	
	1	2	3	4	5	6	7	8	9	10	11	12	13
Chemical analyses (Weight percent)													
SiO_2	42.65	35.33	61.15	67.59	60.88	59.75	54.27	42.14	47.80	57.91	43.11	46.63	45.48
Al_2O_3	1.70	3.06	3.58	4.66	9.89	8.45	14.75	15.06	15.62	13.26	14.80	13.21	15.61
Fe_2O_3	3.87	25.99	7.77	3.33	8.37	5.39	2.69	.86	2.16	1.64	1.89	1.64	2.05
FeO	35.22	28.34	19.30	16.95	10.24	16.53	10.82	9.52	10.40	5.75	13.76	9.01	10.82
MgO	7.12	3.79	2.32	1.83	1.84	3.22	5.94	3.98	7.85	5.54	11.62	4.60	9.72
CaO	1.77	.70	.77	2.25	1.61	.41	2.44	9.34	5.23	3.50	1.34	8.95	9.03
Na_2O	.05	.02	.01	.04	1.45	.06	2.25	4.99	3.99	.52	2.15	2.41	1.82
K_2O	.77	.17	.81	.08	2.83	1.39	2.13	.77	2.28	2.83	2.15	.77	.65
H_2O^+	2.14	1.06	1.29	1.57	1.05	3.37	2.45	1.66	3.15	4.12	5.01	3.00	2.29
H_2O^-	.02	.02	.09	.11	.03	.03	.01	.02	.05	.18	.07	.00	.07
TiO_2	.43	.19	.52	.32	.60	.43	1.21	2.52	1.40	1.54	3.08	1.44	1.30
P_2O_5	.06	.09	.30	.20	.16	.20	.17	.34	.24	.26	.41	.23	.20
MnO	2.58	.85	.82	.30	.48	.36	.48	.25	.22	.10	.34	.24	.23
CO_2	.34	.03	.01	.06	.11	.08	.09	6.84	.12	2.46	.08	7.30	.07
Total	98.72	99.64	98.74	99.29	99.54	99.67	99.78	98.29	100.51	99.61	99.80	99.43	99.34
Modes (Volume percent)													
Quartz	—	—	21.0	25.6	42.0	31.6	28.0	Tr	8.4	(1)	[2] 16.4	10.6	Tr
Plagioclase	—	—	N.o.	N.o.	1.0	N.o.	N.o.	43.2	18.0		.4	37.6	23.6
Hornblende	—	—	N.o.	27.4	N.o.	Tr	12.8	N.o.	49.6		8.4	N.o.	66.0
Tremolite	—	—	—	—	—	—	—	N.o.	N.o.		6.4	—	—
Biotite	Tr	N.o.	10.0	N.o.	44.2	67.8	49.8	Tr	22.0		31.8	3.2	2.2
Chlorite	N.o.	N.o.	—	—	—	—	—	30.0	Tr		30.0	23.2	Tr
Chert	N.o.	1.8	—	—	—	—	—	—	—		—	—	—
Epidote	—	—	—	—	—	—	—	—	—		—	N.o.	4.6
Garnet	15	N.o.	13.4	7.2	1.6	Tr	N.o.	—	—		—	—	—
Carbonate	2	N.o.	N.o.	N.o.	N.o.	N.o.	Tr	—	—		—	—	—
Calcite	—	—	—	—	—	—	—	20.6	Tr		Tr	20.8	N.o.
Grunerite	3	48.6	41.0	39.4	N.o.	N.o.	N.o.	—	—		—	—	—
Ilmenite	—	—	—	—	—	—	—	2.2	2.0		6.6	3.8	1.8
Magnetite	Tr	49.6	14.6	.4	11.2	.6	9.4	—	—		—	.8	N.o.
Apatite	—	—	—	—	—	—	—	—	—		—	Tr	N.o.
Sphene	—	—	—	—	—	—	—	—	—		—	N.o.	1.8

[1] Mode not determined; abundant fine-grained alteration products.
[2] May include some plagioclase.

1. Grunerite-garnet schist, SW¼NE¼ sec. 12, T. 47 N., R. 29 W.
2. Grunerite-magnetite iron-formation, NE¼SE¼ sec. 12, T. 47 N., R. 29 W.
3. Iron-formation, SE¼NW¼ sec. 20, T. 47 N., R. 28 W.
4. Iron-formation, NW¼SW¼ sec. 17, T. 47 N., R. 28 W.
5. Iron-formation, NW¼SE¼ sec. 16, T. 47 N., R. 28 W.
6. Iron-formation, SW¼SE¼ sec. 6, T. 47 N., R. 28 W.
7. Iron-rich argillite, NW¼NE¼ sec. 17, T. 47 N., R. 28 W.
8. Amygdular metabasalt, NE¼NE¼ sec. 14, T. 47 N., R. 28 W.
9. Amygdular metabasalt, SE¼SE¼ sec. 9, T. 47 N., R. 28 W.
10. Agglomerate, SE¼SE¼ sec. 9, T. 47 N., R. 28 W.
11. Tuff, SE¼SE¼ sec. 1, T. 47 N., R. 29 W.
12. Metadiabase from biotite zone, NW¼SE¼ sec. 14, T. 47 N., R. 28 W.
13. Metadiabase from garnet zone, NE¼NW¼ sec. 21, T. 47 N., R. 28 W.

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