Geology of the Precambrian W (Lower Precambrian) Rocks in Western Gogebic County, Michigan

GEOLOGICAL SURVEY BULLETIN 1407

Work done in cooperation with the Geological Survey Division, Michigan Department of Natural Resources

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By ROBERT GORDON SCHMIDT

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Geologic description of an area of metasedimentary and metavolcanic rocks ("greenstone"), a quartz monzonite pluton, and a variety of granitic gneisses

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METRIC-ENGLISH EQUIVALENTS

Metric unit		English equivalent	
Length			
millimetre (mm)	=	0.03937	inch (in)
metre (m)	=	3.28	feet (ft)
kilometre (km)	=	.62	mile (mi)
Area			
square metre (m^2)	=	10.76	square feet (ft^2)
square kilometre (km^2)	=	.386	square mile (mi^2)
hectare (ha)	=	2.47	acres
Volume			
cubic centimetre (cm^3)	=	0.061	cubic inch (in^3)
litre (l)	=	61.03	cubic inches
cubic metre (m^3)	=	35.31	cubic feet (ft^3)
cubic metre	=	.00081	acre-foot (acre-ft)
cubic hectometre (hm^3)	=	810.7	acre-feet
litre	=	2.113	pints (pt)
litre	=	1.06	quarts (qt)
litre	=	.26	gallon (gal)
cubic metre	=	.00026	million gallons (Mgal or 10^6 gal)
cubic metre	=	6.290	barrels (bbl) (1 bbl=42 gal)
Weight			
gram (g)	=	0.035	ounce, avoirdupois (oz avdp)
gram	=	.0022	pound, avoirdupois (lb avdp)
tonne (t)	=	1.1	tons, short (2,000 lb)
tonne	=	.98	ton, long (2,240 lb)
Specific combinations			
kilogram per square centimetre (kg/cm^2)	=	0.96	atmosphere (atm)
kilogram per square centimetre	=	.98	bar (0.9869 atm)
cubic metre per second (m^3/s)	=	35.3	cubic feet per second (ft^3/s)

Metric unit		English equivalent	
Specific combinations—Continued			
litre per second (l/s)	=	.0353	cubic foot per second
cubic metre per second per square kilometre [$(m^3/s)/km^2$]	=	91.47	cubic feet per second per square mile [$(ft^3/s)/mi^2$]
metre per day (m/d)	=	3.28	feet per day (hydraulic conductivity) (ft/d)
metre per kilometre (m/km)	=	5.28	feet per mile (ft/mi)
kilometre per hour (km/h)	=	.9113	foot per second (ft/s)
metre per second (m/s)	=	3.28	feet per second
metre squared per day (m^2/d)	=	10.764	feet squared per day (ft^2/d) (transmissivity)
cubic metre per second (m^3/s)	=	22.826	million gallons per day (Mgal/d)
cubic metre per minute (m^3/min)	=	264.2	gallons per minute (gal/min)
litre per second (l/s)	=	15.85	gallons per minute
litre per second per metre [(l/s)/m]	=	4.83	gallons per minute per foot [(gal/min)/ft]
kilometre per hour (km/h)	=	.62	mile per hour (mi/h)
metre per second (m/s)	=	2.237	miles per hour
gram per cubic centimetre (g/cm^3)	=	62.43	pounds per cubic foot (lb/ft^3)
gram per square centimetre (g/cm^2)	=	2.048	pounds per square foot (lb/ft^2)
gram per square centimetre	=	.0142	pound per square inch (lb/in^2)
Temperature			
degree Celsius (°C)	=	1.8	degrees Fahrenheit (°F)
degrees Celsius (temperature)	=	[(1.8×°C)+32]	degrees Fahrenheit

GEOLOGY OF THE PRECAMBRIAN W (LOWER PRECAMBRIAN) ROCKS IN WESTERN GOGEBIC COUNTY, MICHIGAN

By ROBERT GORDON SCHMIDT

ABSTRACT

The Precambrian W rocks of western Gogebic County include a sequence of metasedimentary and metavolcanic rocks ("greenstones"), a quartz monzonite pluton, and a variety of gneisses. Some gneisses were derived by metamorphism of the metasedimentary-metavolcanic sequence, but the origin of much of the gneissic rock is not clear. The geology of this area is important to the interpretation of the geology to the east and west because the metamorphic effects of the quartz monzonite pluton extend a few miles into adjacent areas.

The Ramsay Formation, a sequence of metamorphosed argillite, siltstone, minor quartzite, tuff, tuffaceous clastics, and mafic flows, is possibly the oldest rock unit in the study area. It is intruded by coarsely porphyritic Puritan Quartz Monzonite, which produced a fringe of highly modified country rocks. The fringe includes the Whiskers Creek Gneiss, the result of high-grade contact metamorphism of the Ramsay Formation, and the Van Buskirk Gneiss, formed by extensive injection under relatively high temperature and pressure of Puritan Quartz Monzonite neosome into an older layered rock. It is not clear whether this layered rock was also Ramsay Formation, a pre-Ramsay rock, or perhaps a combination of both.

Inclusions of pre-Puritan rocks are present within the Puritan pluton as far as 4 km (about 2.5 mi) north of the Puritan-Van Buskirk boundary, a rather arbitrary boundary line based on the southward appearance of injection gneiss and striped neosome. South of the Whitney Creek-Palms Creek lineament, all single-phase unstriped rock was mapped as Puritan Quartz Monzonite, although all may not have had the same origin.

The style of contact relationships between the Puritan intrusive and the invaded country rock ranges from simple planar contacts in the northern part of the area to broad zones of complex migmatites in the southern part, depending on physical conditions such as depth of burial or perhaps on differences in composition of the original country rock.

All the older crystalline rock units—the Ramsay Formation, Puritan Quartz Monzonite, Whiskers Creek Gneiss, and Van Buskirk Gneiss—are locally invaded by dikes and irregular masses of the leucocratic aplite, granite, and pegmatite Sunset Creek Intrusive Complex. None of these intrusives was found in the narrow strip along the northern edge of the older rocks. The Sunset Creek intrusives occur at least as far as 5 km (3 mi) east and about 8 km (5 mi) west of the mapped area in a variety of country rocks; the northern limit of these intrusives continues east and west into adjacent areas,

crosscutting metamorphic zones related to the Puritan pluton. The Sunset Creek intrusives are interpreted to be distinctly younger than the rocks related to the Puritan event, although at last one group of older pegmatites does occur in the area. Most outcrop areas of the Sunset Creek Intrusive Complex are small, and none are shown as separate map units in this report.

The Precambrian W crystalline rocks are cut by a pervasive latticework of diabasic and gabbroic dikes and sills of diverse mineralogy and age. The oldest of these cut mainly the Van Buskirk Gneiss; younger mafic intrusives cut both Precambrian W- and X-age rocks, and the youngest intrusives cut the rocks of Powder Mill (Precambrian Y) age as well.

Precambrian W rocks in the area have been affected by at least four separate metamorphic events, although the evidence of the earlier events has been blurred by the later ones. This complex metamorphic history has been recorded by the mafic rocks that were intruded between each event.

The main structural events in the Precambrian W rocks were the early folding of the Ramsay Formation before intrusion of the Puritan Quartz Monzonite, three periods of uplift and erosion, and the relatively late northward tilting of a very large block which included all of the Precambrian W and X units and part of the Keweenawan strata.

Zones of sericitic alteration in granitic rocks and sparsely disseminated sulfide in the large mafic dikes contain scant base metal, and there is little evidence that further prospecting would be productive. No sulfide deposits were found in the Ramsay Formation, but so little of this "greenstone" sequence is exposed in the study area that this failure is no basis for evaluation.

INTRODUCTION

GEOGRAPHIC SETTING

The described area includes about 169 km² (65 mi²) in the westernmost part of the northern peninsula of Michigan (fig. 1). It is an irregular area bounded on the east by long 90° W. on the south and west by the Wisconsin boundary, and on the north by the Precambrian X rocks of the Gogebic iron range. It includes parts of the Bessemer and Ironwood 7½′-quadrangles and is entirely within the Ironwood 15′ quadrangle.

The area is one of gently rolling topography with a few scattered steep rocky knobs and hills. Probably 95 percent of the surface is covered by glacial deposits, consisting mostly of outwash and moraine, through which protrude the rock knobs that form the cores of most of the main hills. Several high and relatively steep hills, however, are eskers or kames. Lowest and highest elevations are about 415 and 535 m (1,380 and 1,750 ft). Drainage of the Montreal and Black Rivers and their tributaries is northward to Lake Superior. Swamps are abundant, especially in the south part of the area, because drainage is not well developed.

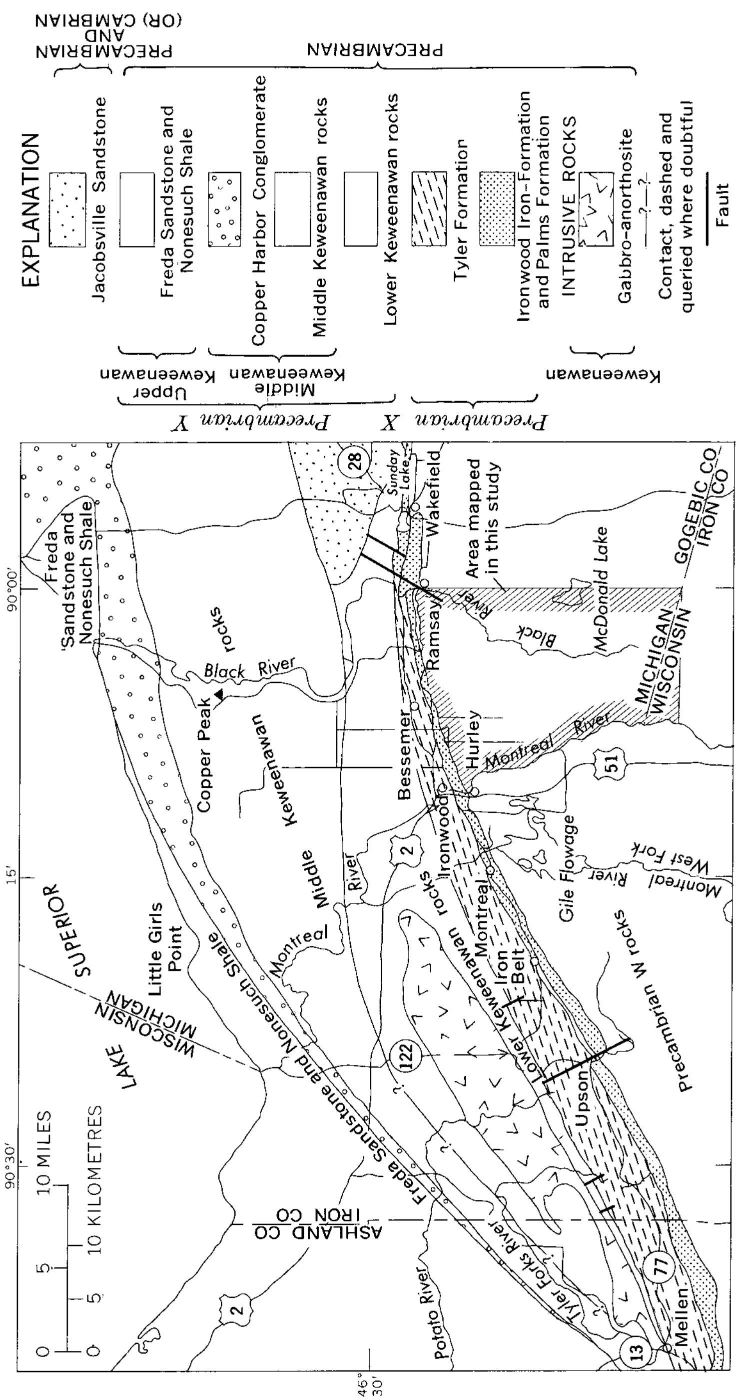


FIGURE 1.—Generalized geologic map of northern Wisconsin and northwestern Michigan showing the area in Gogebic County, Mich., mapped in this study.

PREVIOUS GEOLOGIC WORK

Many papers on the geology of the Precambrian X strata and the iron ores of the Gogebic range have been published, but relatively few treat the older crystalline rocks. The first major paper on the area was that of Irving and Van Hise (1892), which provides a good general description of the iron-formation and iron ores, excellent maps of the area, descriptions based on reconnaissance of the Precambrian W rocks ("Archean"), and an excellent complete résumé of previous publications. Generally, this material was abstracted in Van Hise and Leith (1911).

The most comprehensive study of the stratigraphy of the Precambrian X formations was made by Hotchkiss (1919), but he made scant mention of the older rocks. Aldrich (1929) also dealt mostly with Precambrian X strata of Wisconsin and added little new information to the earlier descriptions of the "Archean" rocks.

Field relations and base-metal content of mafic dikes in this area were described by Schmidt and Trent (1969). The structural history of the region, especially those structural events assigned to the "Penokean Orogeny," was discussed by Schmidt and Hubbard (1972). A map showing the individual outcrop locations and the general bderock subdivisions on which this report is based was released as an open file report (Schmidt, 1972).

PRESENT INVESTIGATION

Mapping in western Gogebic County was undertaken in 1965 in cooperation with the Geological Survey Division, Michigan Department of Natural Resources. Fieldwork was done from 1965 to 1969 by Robert G. Schmidt, assisted in 1967 by George C. Stephens. Although much of the study was directed to the Precambrian X strata enclosing the Ironwood Iron-formation and the iron ores, early reconnaissance of the southern area indicated that detailed mapping there would probably be productive. Relationships between the "greenstone" sequence and younger plutonic rocks are well developed, perhaps better than in adjacent areas to the east and west; recent renewed interest in prospecting greenstone-type rocks in Precambrian areas encouraged this aspect of the study.

MAPPING METHODS USED

An attempt was made to visit all areas of outcrop in the mapped area, but it seemed unjustified to visit each individual outcrop in the places of abundant exposures. Aerial photographs were used to select the field traverses most likely to locate rock exposures or

to intersect contacts or other critical data points. The photographs were also used for location in the field and data points were recorded directly on them.

Much of the bedrock of the study area consists of granitic mixed-rock complexes, in many of which separate rock types can be recognized (pl. 1). For these I have used the term "migmatite" as it was originally used by Sederholm (1907, p. 88–89) to describe a mixed gneissic rock in which part of the rock appears to be intrusive and therefore relatively younger than the other. These genetic implications of Sederholm's original usage are appropriate here, for the mixed rocks ordinarily consist of an older rock type, or paleosome, invaded or engulfed by a newer one, or neosome.

Many of the structural features described and named in classical migmatite areas, such as agmatites, merismites, injection gneisses, and nebulites, are common in this area. Many rock outcrops contain two migmatite phases, and outcrops containing three are fairly common. Phase contacts showing distinct age relationships were specifically sought in the field but occurred rather rarely. The scale of some of the migmatite features is so large that interpretations must be made by synthesizing data from many outcrops.

All of the granitic rocks of the area contain the same general mineral suite; field classification was made according to colors, macroscopic texture, structural relationships, and radioactivity. Modal anlaysis showed that some, but not all, megascopically different rock types were also somewhat different in mineral composition, though not enough so to be a usable criterion for discrimination in the field.

Total gamma radiation measurements were systematically made on the different mixed-rock phases as a routine part of field mapping; it was hoped the measurements might be helpful in distingushing some of the visually similar neosome phases. The ranges of total gamma radiation from the different neosome phases overlap so much, however, that the method was not very helpful for discriminating among them. It was useful, though, in distinguishing areas of granodioritic paleosome and quartz monzonitic neosome on poorly exposed rock surfaces, as in the Van Buskirk Gneiss or in the Puritan Quartz Monzonite-Whiskers Creek Gneiss border zone. Average results of radiation measurements and analyses of potash, uranium, and thorium, for the different types of lower Precambrian rocks are given in table 1.

The geologic relationships of the lower Precambrian rocks are very complex in this region. The study area is a key location which

TABLE 1.—*Total gamma radiation and potassium, uranium, and thorium content of lower Precambrian rocks in the study area*

Rock type	Gamma radiation measured on outcrop surface (microroentgens/hour)			Laboratory analyses			
	Normal range	Minimum	Maximum	Number of analyses	K_2O* (percent)	Uranium † (ppm)	Thorium ‡ (ppm)
Ramsay Formation	3–7	3	7	--	--	--	--
Puritan Quartz Monzonite	9–16	7	29	3	5.4	5.8	40
Van Buskirk Gneiss, quartz monzonite neosome	7–20	6	66	1	5.0	4.8	21
Whiskers Creek Gneiss	4–11	4	13	4	3.1	5.0	9
Sunset Creek Intrusives	7–18	5	90	3	5.1	4.8	21
Mafic dikes and sills (includes some of Precambrian X and Y age)	4–5	--	--	9	.7	--	--

* Rapid rock analyses performed by the U. S. Geological Survey.
† Fused pellet fluorometric analyses by Joseph Budensky and Roosevelt Moore, U.S. Geological Survey.
‡ Instrumental neutron activation analyses by Jesse J. Warr, Jr., and Fred O. Simon, U.S. Geological Survey.

provides information on geologic relationships that probably apply over a much larger area of western Michigan and northeastern Wisconsin. Although it is hoped that relationships proposed here will be found to be valid in areas to the east and west, interpretations made in this report are not the only ones that fit the field data: detailed studies of adjacent areas are almost sure to provide new pertinent information to justify modifications of these interpretations.

RAMSAY FORMATION AND WHISKERS CREEK GNEISS

The oldest known stratified rock unit in the region is named the Ramsay Formation in this report. It consists of metamorphosed and generally somewhat schistose siliceous arkosic argillite, micaceous and arkosic siltstone, and volcanic tuff and breccia. The Ramsay Formation grades through bedded schist into the granodioritic Whiskers Creek Gneiss as the metamorphic intensity increases close to the intrusive Puritan Quartz Monzonite.

RAMSAY FORMATION

The several outcrops from which the Ramsay Formation is described extend southward from the edge of the village of Ramsay along the west side of the Black River in the SW¼ sec. 13, in the NW¼ sec. 24, and within the area 330 m (1,000 ft) south and west of the NE cor. sec. 23, all in T. 47 N., R. 46 W.

Some of the Ramsay Formation is thinly laminated, some appears to be in beds several centimetres thick, and part of the rock, especially fine-grained dark amphibolitic material, is not stratified

at all. Coarse fragmental textures are interpreted as derived from metamorphism of volcanic breccias. The dips of the strata are generally southward and commonly about 55°. These beds are assumed to be right side up because many attitude determinations a few miles to the east show the tops to be southward and the strata to be right side up (W. C. Prinz, oral commun., 1973), but no data for determining stratigraphic tops were noted in the study area. Though neither base nor top of the Ramsay Formation is known, the total thickness of the unit is at least a few thousand feet and could be much greater.

Fine-grained amphibolitic tuffaceous rocks are common near Ramsay, and the strata, probably younger, farther south contain more argillite, metasiltstone, and quartzite. Most of the rocks in both areas are feldspathic. The tuffaceous rocks contain as much as 10 percent quartz, 15–33 percent plagioclase, as much as 3 percent microcline, 50–60 percent hornblende, and as much as 10 percent chlorite. The metasediments to the south contain 20–60 percent feldspar (mostly plagioclase) and 10–40 percent quartz; biotite is the major dark mineral. Thus, if the assumption of stratigraphic top is correct, the younger strata tend to be more siliceous.

All of the outcrops studied are within the metamorphic aureole of the Puritan Quartz Monzonite. The metamorphism was mostly to the amphibolite facies or equivalent, which has since been partly modified by later and lower grade metamorphic events. The least metamorphosed Ramsay Formation in the mapped area is in a small area south of Ramsay. Similar rock trends eastward of here and has been traced in that direction for several miles; westward, it grades through micaceous and amphibolitic gneisses into the granodioritic Whiskers Creek Gneiss.

The Ramsay Formation is presently defined in only the western part of the easternmost of two large lenses of "green schists" in Michigan and Wisconsin (Irving and Van Hise, 1892, p. 104–105). The lenses were described as bounded by granitic gneisses on the south and by the unconformity at the base of the Penokee Series, as used by Irving and Van Hise, Precambrian X rocks on the north. The eastern area includes mafic flows at several localities east of Ramsay. Additional work may show these flows to be part of the Ramsay Formation or may justify dividing the "greenstones" into additional formational units. Detailed mapping of the western "greenschist" area may show that the Ramsay Formation is present there also.

LOCAL VARIATIONS IN THE RAMSAY FORMATION

The Ramsay Formation is cut by the Black River Fault, and right-lateral displacement has offset the areas of exposure of the amphibolitic tuffaceous phase and the siliceous phase of the formaation. West of the fault, the main area of amphibolitic metatuffs and tuffaceous argillites is close to the north-south section line between the W½SW¼ sec. 13 and E½SE¼ sec. 14, and between the NW¼NW¼ sec. 24 and the NE¼NE¼ sec. 23, all in T. 47 N., R. 46 W. Mostly argillite and arkosic metasiltstone are present farther south close to the same section line between the SW¼-NW¼ sec. 24 and the SE¼NE¼ sec. 23.

A good example of the siliceous clastic phase is the well-bedded schistose metasiltstone in a small streambed near the south end of a large Sunset Creek pegmatite knob, about 90 m (300 ft) northwest of the E¼ cor. sec. 23, T. 47 N., R. 46 W.

East of the Black River Fault, dark feldspathic metatuffs occur west of the center of sec. 24, and biotitic argillite and metasiltstone are present in outcrops near the SW cor. NW¼SW¼ sec. 24.

WHISKERS CREEK GNEISS

The Whiskers Creek Gneiss is a generally foliated granodioritic rock (fig. 2) derived by granitization from the Ramsay Formation and perhaps other similar strata. It forms a rather simple envelope around the Puritan Quartz Monzonite and is thickest where the Puritan is coarsest, poorly developed where the Puritan is relatively fine grained, and gradational northeastward and westward away from the intrusive contact to the surrounding metamorphosed sedimentary rocks. This interpretation was perhaps first suggested by M. C. Lake in 1915 (Aldrich, 1929, p. 77). Because of much current emphasis on the search for sulfide ores in greenstone belts in this region, the identification of this type of foliated gneiss as the metamorphic equivalent of greenstone-type strata could take on new importance.

In the area mapped, the Whiskers Creek Gneiss is present in two main patches, near Anvil and Ramsay in the northeast, and at the west edge in an area extending about 3 km (2 mi) southeast of Ironwood, including the area along Whiskers Creek, for which the rock is named.

The Whiskers Creek Gneiss consists of quartz, plagioclase, and hornblende or biotite, but in most of the area metamorphism has changed the mafic minerals to chlorite or epidote. The quartz content of most Whiskers Creek Gneiss is considerably lower than

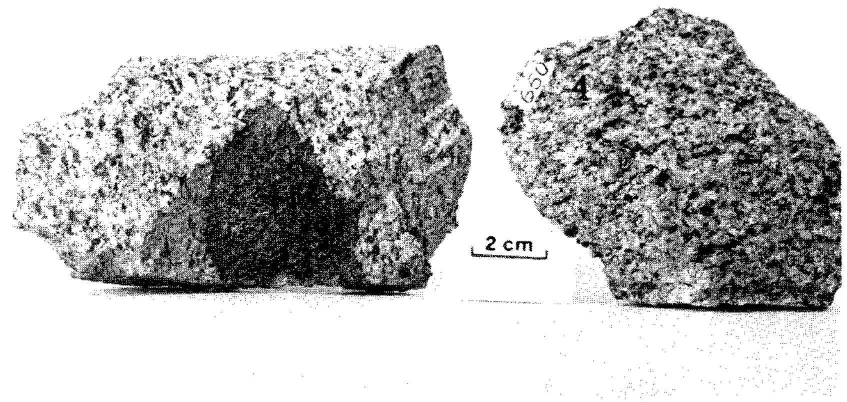


FIGURE 2.—Hornblendic Whiskers Creek Gneiss from the vicinity of Yale. Dark area on the left specimen is a hornblende-rich lens.

the other granitic rocks of the area, and the content of mafic minerals—hornblende, biotite, chlorite, and epidote—averages perhaps 15 percent, considerably higher than other granitic rocks. The plagioclase content exceeds that of the microcline 2½–6 times; in the intrusive quartz monzonites, plagioclase is much less predominant. Sphene and (or) leucoxene are common accessories, as are tiny prisms of apatite. A few minute crystals of a clear mineral were present in many specimens and were suspected to be garnet; they were identified as such with certainty in a few.

The quartz content of the Whiskers Creek Gneiss is between 12 and 18 percent in most specimens, although thin sections showed some samples contained as little as 8 percent and as much as 25 percent (table 2, fig. 3). Average quartz content of Whiskers Creek Gneiss xenoliths in Puritan Quartz Monzonite, however, is more than 21 percent.

The plagioclase of the Whiskers Creek Gneiss lacks zoning, except in some specimens collected underground in the Peterson mine (sec. 17, T. 47 N., R. 46 W.). The microcline is poikilitic, like that of other granitic rocks of the area. Locally the microcline grains are slightly larger than those of the quartz and plagioclase. Perthite is less common in the Whiskers Creek Gneiss than in the other granitic rocks.

The mafic minerals originally present varied systematically from north to south. In the northernmost outcrops, near Ironwood and Yale, hornblende predominated over biotite, and near Anvil

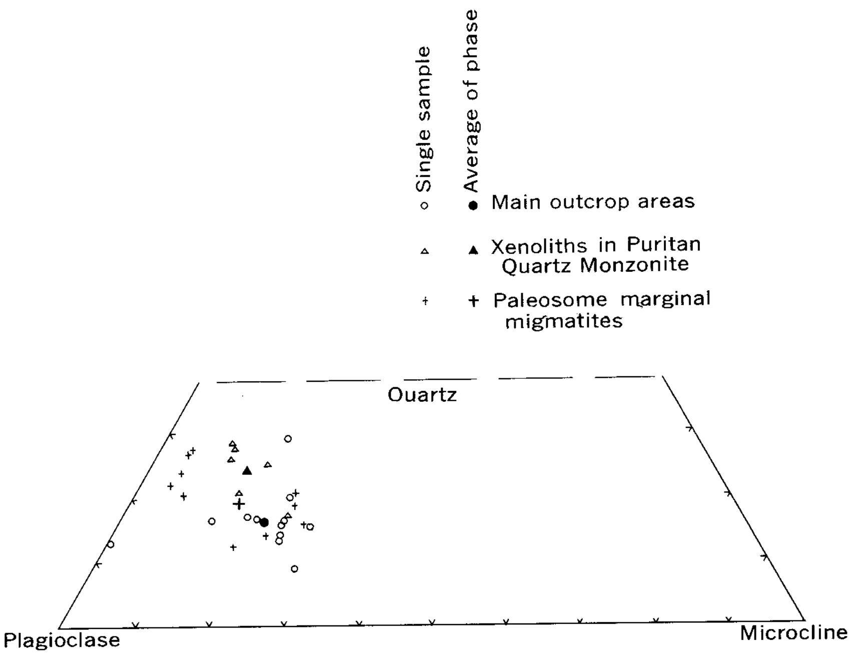


FIGURE 3.—Major mineral composition of 28 samples of Whiskers Creek Gneiss.

TABLE 2.—*Modal analyses of Whiskers Creek Gneiss (volume percent)*

	1	2	3
Quartz	14.0	21.6	16.2
Plagioclase	53.8	55.5	54.7
Microcline	15.2	11.4	11.2
Muscovite	.1	.2	.2
Hornblende	6.1	1.5	7.9
Biotite	1.0	4.5	4.3
Chlorite	5.6	2.9	3.1
Epidote	2.1	1.8	1.7
Calcite	.8	0	0
Other	1.2	.5	.6
Total	99.9	99.9	99.9

1. Main outcrop areas; average of 12 samples.
2. Zenoliths within Puritan Quartz Monzonite; average of 6 samples.
3. Paleosome, marginal migmatites east and west of main Puritan Quartz Monzonite pluton; average of 10 samples.

only hornblende and secondary minerals preserving the original hornblende shape are found. South of Anvil, in secs. 22, 27, 28 and 29, T. 47 N., R. 46 W., biotite content roughly equaled or exceeded hornblende. Chloritization of original mafic minerals has been erratic, and both fresh hornblende or biotite and completely chloritized hornblende or biotite may be present in the same outcrop.

Most outcrops of the Whiskeys Creek Gneiss contain a few to many scattered spots of hornblende or biotite (fig. 2), the origin of which is unknown. These spots are irregular wisps, perfect lenticles, or equidimensional blobs and measure 1–30 cm in large dimension. Generally, the more perfect lenses are associated with well-foliated phases, but this is not always so.

At several localities, the gneiss contains many rounded to angular fragments of dark hornblendic rock, and these fragmental rocks are interpreted to be the metamorphosed equivalents of coarse pyroclastic material, volcanic conglomerate, and conglomerate (fig. 4). The largest fragment noted was 15 by 25 cm (5.9 by 9.8 in). The hornblende content ranges considerably between different fragments at some localities, and the orientation of the schistosity is different in each fragment in some outcrops. Metamorphosed fragmental rocks in the Whiskers Creek Gneiss were noted at the following locations:

NE¼SW¼ sec. 15, T. 47 N., R. 46 W.
NW¼SE¼ sec. 23, T. 47 N., R. 47 W. (on the east slope of the hill)
SW¼SW¼ sec. 26, T. 47 N., R. 47 W. (on crest of hill, coarse angular fragments)
NE¼SW¼ sec. 35, T. 47 N., R. 47 W (east slope of rock hill, large rounded fragments)

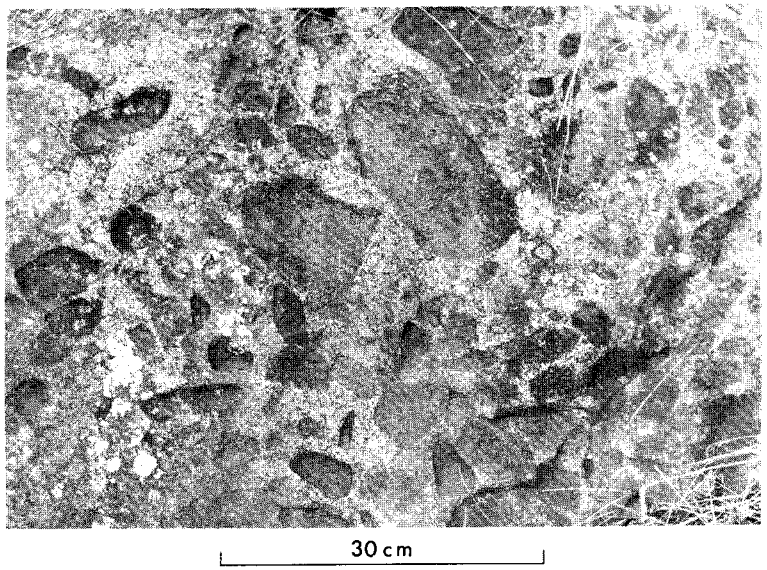


FIGURE 4.—Metaconglomerate in Whiskers Creek Gneiss, NE¼SW¼ sec. 15, T. 47 N., R. 46 W.

Metaconglomerate was previous described in this type of rock in this area by Winchell (1888, p. 56–59).

Dark gray-green to black biotite-chlorite schist and gneiss and knotted feldspar-biotite rock of unknown origin are present within the Whiskers Creek Gneiss in high rock knobs in the NE¼NE¼ sec. 27, T. 47 N., R. 47 W.

The foliation in the Whiskers Creek Gneiss is probably a relict of bedding. The foliation is generally well developed, especially where the biotite or hornblende is in separate lamina, but at some places there is no foliation at all.

Southwest of Ramsay the bedding in the Ramsay Formation and the foliation in the Whiskers Creek Gneiss trend east and dip south, generally 50°–70°. Southwest and west of Anvil the foliation strikes northwest and north, suggesting a westward-plunging anticlinal fold. Southwest-plunging oriented hornblende grains in secs. 14 and 15, T. 47 N., R. 46 W., are compatible with this structural interpretation.

Southeast of Ironwood the vertical foliation trends N. 50° E. Two miles to the south the foliation, also mostly vertical, swings rather systematically from N. 30° E. to NS. in the more southeasterly outcrops. These systematic foliation changes in sec. 35, T. 47 N., R. 47 W. and NW¼ sec. 2, T. 46 N., R. 47 W., are the more surprising because most of the outcrops are complex migmatites that include combinations of Whiskers Creek Gneiss with both Puritan and Sunset Creek intrusive rocks, but the foliation of the gneiss seems to have survived this invasion by younger rock phases. If the change in foliation trend is inferred to represent folding, the axial line of this fold is about vertical.

TRANSITIONS OF RAMSAY FORMATION TO WHISKERS CREEK GNEISS

Although there is a complete gradation from bedded rocks of the Ramsay Formation to equigranular Whiskers Creek Gneiss, many features of the transition zone are complex.

The transition is best exposed along the western edge of the Ramsay Formation south of Anvil, where the zone is about 1 km (0.6 mi) wide. The contact shown on plate 1 approximately separates the areas in which each phase makes up over half of the rock exposed. Fingers of quartz-dioritic gneiss extend eastward across the zone, and, in the west part of the zone, lenses of bedded mica schists hundreds of metres long and tens of metres thick are present mostly enclosed in gneiss. The bedded lenses are interpreted to have been more siliceous strata than the enclosing beds and therefore more resistant to recrystallization.

Between 1.5 and 5 km (1 and 3 mi)) south of Ramsay, the Puritan Quartz Monzonite is relatively fine grained—presumably because of faster cooling—and the fringing aureole of contact metamorphosed gneisses is not fully developed. The most highly metamorphosed Ramsay Formation close to the Puritan contact is probably a biotite schist, relatively fine grained in secs. 25 and 26 and coarser southward in secs. 35 and 36, although there are few outcrops, especially east of the Black River fault, and many of these are Sunset Creek Intrusive Complex.

The transitional zone of the western patch of Whiskers Creek Gneiss is exposed west of the mapped area in sec. 34, T. 46 N., R. 2 E., Iron County, Wis. Successive outcrops from east to west are: extensively feldspathized fragmental rock containing 3–5 cm (1–2 in) feldspar grains; fragmental rock partly feldspathized, the matrix more so than the fragments; and relatively low-rank pyroclastic fragmental rock, unfeldspathized, but with the fragments drawn out into rods by flowage. Hornblendites, agmatitic breccias, and biotite schists are present within the Whiskers Creek Gneiss in southern Ironwood, in the NE¼ sec. 27, T. 47 N., R. 47 W., but their relationship to specific facies in the "greenstones" to the west is not known.

LOCAL FEATURES OF THE TRANSITION ZONE

Several lenses of bedded micaceous schist within Whiskers Creek Gneiss are present in the NE¼ sec. 22, the N½ sec. 23, and along the north edge of the S½ sec. 23, T. 47 N., R. 46 W. The quartz content of these metasediments ranges from trace amounts to about 50 percent, indicating a wide range in the composition of the original sediment. Hornblendite in the Whiskers Creek Gneiss about 60 m (200 ft) east and 120 m (400 ft) north of the SW cor. sec. 14, T. 47 N., R. 46 W. is a more mafic layer in the sequence, perhaps a metamorphosed basaltic flow.

Small cross-cutting dikes of unfoliated granodiorite smiliar in composition to the normal Whiskers Creek Gneiss, are present in the transitional zone in several places, as are more mafic bodies of albitic hornblendite. The latter consist of 40–60 percent hornblende, the balance being mostly albite of An 7–9 composition, fairly abundant accessory sphene, but no quartz. These hornblendites are not found in the main mass of the Whiskers Creek Gneiss and are generally on the Ramsay Formation side of the transition zone. North of the crest of the hill, in SE¼NE¼ sec. 14, T. 47 N., R. 46 W., many angular and rounded blocks of argillite and schist are embedded in a hornblende diorite matrix to

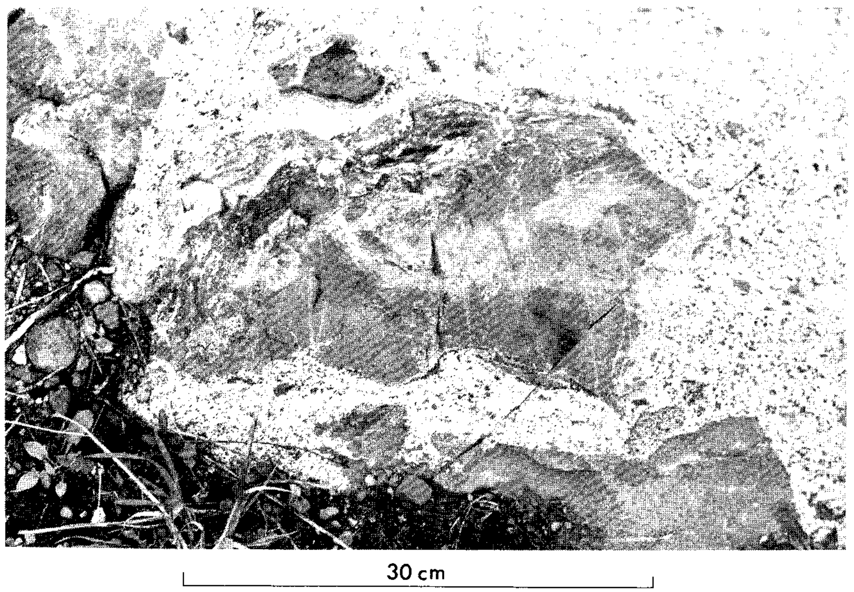


FIGURE 5.—Migmatitic blocks of Ramsay Formation in hornblende diorite of the Whiskers Creek Gneiss.

form an agmatite (fig. 5); this matrix must certainly have behaved as a liquid when the agmatite was formed. These small patches of mostly unfoliated dioritic rock showing features unmistakably related to intrusion as a liquid are tentatively interpreted to be locally mobilized material, but neither this nor any other explanation seems to fit them very well. It is not clear why all of these appear to be limited to the transitional zone and why none have been found really close to the Puritan Quartz Monzonite.

PURITAN-VAN BUSKIRK PLUTON

The geology of the Precambrian W rocks in the study area is dominated by the intrusive igneous body, here named the Puritan Quartz Monzonite, and its fringing gneisses. At its northern end, where field evidence indicates the igneous rock intruded sedimentary and pyroclastic rocks of the Ramsay Formation, the main body of the intrusive is porphyritic quartz monzonite, generally homogenous in both texture and composition. The east and west margins are either sharp contacts or relatively abrupt transitions to the Whiskers Creek Gneiss, a granodioritic fringe produced by granitization of the Ramsay Formation. Southward, the Puritan

Quartz Monzonite grades into the mixed rocks called the Van Buskirk Gneiss. The first gradational phase is crudely layered gneiss and migmatite, grading into distinctly layered and foliated migmatitic gneiss interspersed with areas of massive Puritan Quartz Monzonite as far as the Wisconsin boundary.

The name of the Puritan Quartz Monzonite is taken from the extensive exposures in SW¼ sec. 17 and NW¼ sec. 20, T. 47 N., R. 46 W., close to the site of the old Puritan mine, south of the community of Puritan. The Van Buskirk Gneiss is named for exposures in parts of secs. 12 and 13, T. 46 N., R. 47 W., in Michigan but close to the community of Van Buskirk in Wisconsin.

Whereas some of the porphyritic quart monzonite neosome in the Van Buskirk Gneiss is related to the Puritan intrusive period, the geographic extent of the Puritan pluton's influence is not known, and the origin of much of the Van Buskirk Gneiss in the project area is obscure. Layers 2 and 3 km (1.2 and 1.9 mi) wide of unstriped single-phase quartz monzonite, conformable to the enclosing striped gneiss, and a large mass of structureless quartz monzonite in the southern part of the area are mapped as part of the Puritan pluton because they are similar rocks, although they may be of quite different ages. The gneisses in the southeastern part of the area east of the Black River fault between McDonald Creek and Underwood Creek are somewhat more cataclastic and are less sharply divided into neosome and paleosome phases than the rest of the Van Buskirk Gneiss and may have been derived from a different country rock or from the same country rock at another time. The gneisses in this southeastern area may have existed in much their present form before the Ramsay Formation was deposited, making these gneisses the oldest rock unit in the area; or perhaps they were formed by metamorphism of part of the Ramsay Formation during an orogenic period preceeding the intrusion of the Puritan Quartz Monzonite. The distribution of the oldest type of mafic dikes and sills (group 1, p. 31) suggests that the Van Buskirk Gneiss southeast of the Whitney Creek-Palms Creek lineament (hereafter called the WC–PC lineament) may be older than that northwest of the lineament.

PURITAN QUARTZ MONZONITE

The Puritan Quartz Monzonite is a medium- to coarse-grained rock containing conspicuous rectangular to somewhat rounded poikilitic 1 to 3-cm (0.5- to 1.5-in) long microcline phenocrysts that make up 1/10–½ of exposed surfaces (fig. 6). The size and abundance of phenocrysts are most uniform in the northcentral single-phase part of the pluton and least uniform in the southern

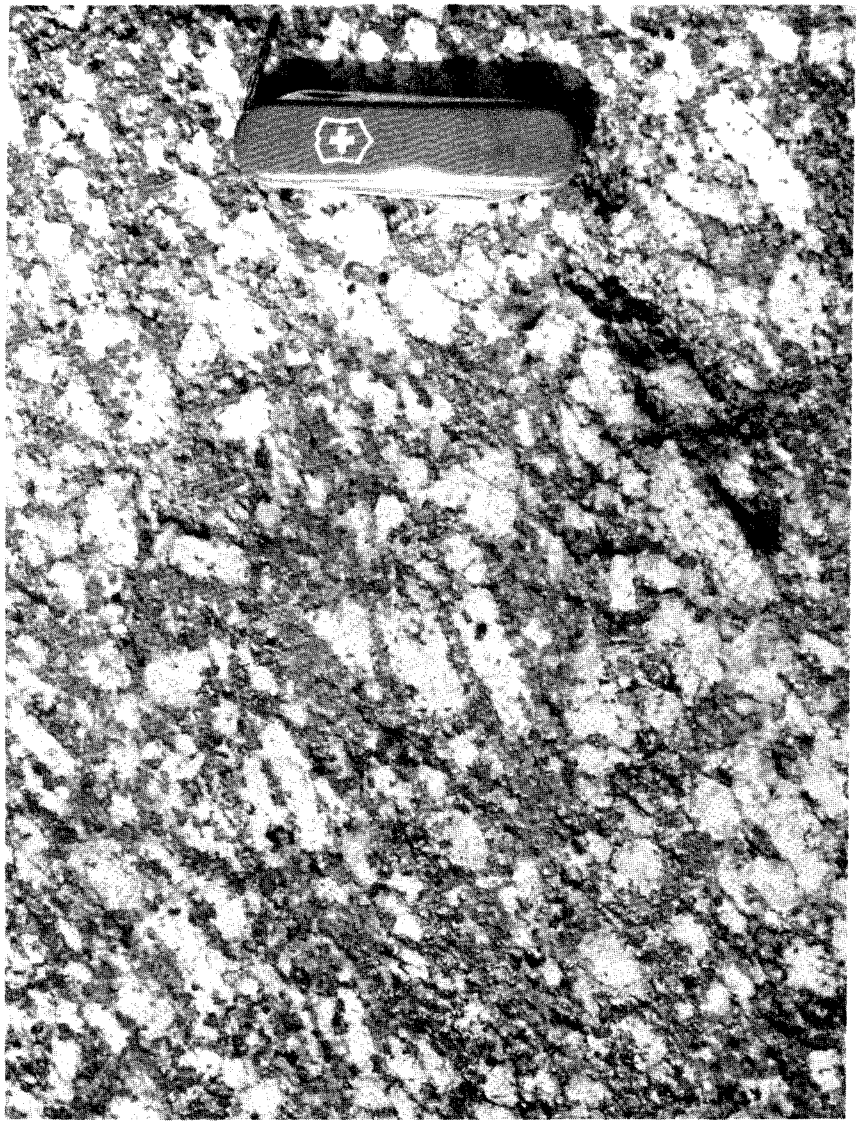
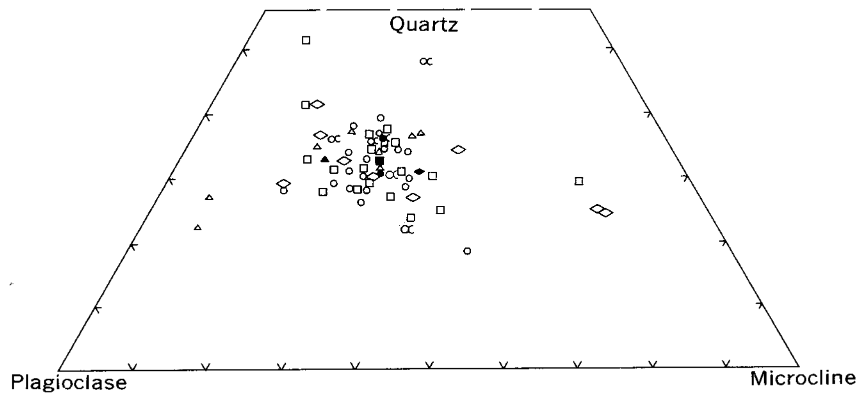


FIGURE 6.—Puritan Quartz Monzonite neosome within the Van Buskirk Gneiss. The largest phenocrysts are 3 cm (1½ in) long, the knife is 7 cm. (3 in). Roadside outcrop in SE¼SW¼ sec. 12, T. 46 N., R. 47 W.

and southeastern outlying areas of Puritan Quartz Monzonite. In the northern part, the general grain sizes and phenocryst sizes are smaller at the margins of the intrusive and close to larger xenolithic blocks. Within a few metres (tens of feet) of the contact on the west side and within 600 m (2,000 ft) of the contact on

the east side, the phenocrysts are smaller or entirely absent. In the southern parts of the pluton, phenocrysts locally are as large as 5 cm (about 2 in) and the relative proportion of phenocrysts is more uneven.

The Puritan Quartz Monzonite is a rock of relatively simple mineral composition, and the results of modal analyses of separate slices were surprisingly similar considering the possibility for strong bias caused by the coarse phenocrysts (fig. 7). The average



Single slice counted 500 or more points	Average of all slices in group	
○	●	Puritan Quartz Monzonite, northern single phase area
◇	◆	Puritan Quartz Monzonite, single phase area in secs. 8, 16, 17, 19, and 20, T. 46 N., R. 46 W.
∝	∝ (filled)	Puritan Quartz Monzonite single phase area in secs. 3, 4, and 5, T. 46 N., R. 46 W.
△	▲	Puritan Quartz Monzonite, marginal phase adjacent to northern single phase area
□	■	Puritan Quartz Monzonite, migmatite zone adjacent to Van Buskirk Gneiss

FIGURE 7.—Major mineral composition of 59 samples of Puritan Quartz Monzonite.

TABLE 3.—*Modal analyses of Puritan Quartz Monzonite (volume percent)*

	1	2	3	4	5
Quartz	29.4	29.4	31.8	30.3	30.6
Plagioclase	39.0	33.9	35.0	43.9	37.3
Microcline	25.7	29.8	24.6	18.1	25.3
Muscovite	1.0	1.8	1.3	.9	1.0
Biotite	1.6	2.5	5.4	2.3	2.5
Chlorite	2.2	1.0	.6	3.2	1.8
Epidote	.2	.8	.8	.5	.8
All others	.9	.9	.6	.8	.8
Total	100.0	100.1	100.1	100.0	100.1

1. Puritan Quartz Monzonite, northern single phase area; average of 18 samples.
2. Puritan Quartz Monzonite, single phase area in sec. 8, 16, 17, 19, and 20, T. 46 N., R. 46 W.; average of 9 samples.
3. Puritan Quartz Monzonite, single phase area in secs. 3–5, T. 46 N., R. 46 W.; average of 5 samples.
4. Puritan Quartz Monzonite, marginal phases adjacent to northern single phase area; average of 8 samples.
5. Puritan Quartz Monzonite, migmatitic zone adjacent to Van Buskirk Gneiss; average of 19 samples.

mineral composition of 18 specimens from the main northern part is shown in table 3.

The Puritan Quartz Monzonite is mostly pale pinkish gray. The pink is that of feldspars, and the biotite or chlorite and quartz are gray. In some places the phenocrysts seem more pink than the matrix feldspars, and in a few locations all the feldspar is white, resulting in a light gray rock. The color of the feldspar is not related to its composition but to the degree of metamorphism, as indicated by the alteration of the biotite to chlorite; very roughly, when half or more of the biotite is altered to chlorite, the feldspars are pink. (Boone, 1969, found color change to be related to biotite alteration but was able to relate the color to composition and degree of alteration of the feldspar as well).

VAN BUSKIRK GNEISS

The Van Buskirk Gneiss is a generally layered and migmatitic rock gradational into the Puritan Quartz Monzonite pluton. As typically developed in the vicinity of Van Buskirk, it is a crudely to sharply layered gneiss consisting of alternation of strongly foliated biotitic quartz diorite and equigranular to porphyritic quartz monzonite (itself locally layered by coarse and fine alternations of grain size and crude orientation of the tabular phenocrysts (fig. 8)). The foliated quartz diorite is at many places crosscut by the porphyritic rock; thus the foliated rock is interpreted to be older, a paleosome of preexisting layered rock. The same type of paleosome is locally abundant as angular blocks suspended in a matrix of porphyritic quartz monzonite or granodiorite: this agmatite makes up a significant part of the Van Buskirk Gneiss (fig. 9).

FIGURE 8.—Foliated Van Buskirk Gneiss, SE¼SW¼ sec. 13, T. 46 N., R. 47 W. Dark layers are biotite-rich. Knife is 7 cm (3 in) long.

Local patches or outcrop areas made up entirely of structureless porphyritic quartz monzonite occur within the gneiss and migmatite.

The distinctness of the banding in the Van Buskirk Gneiss increases southward, as does the abundance of foliated biotitic quartz dioritic gneiss. Near the Puritan-Van Buskirk boundary,

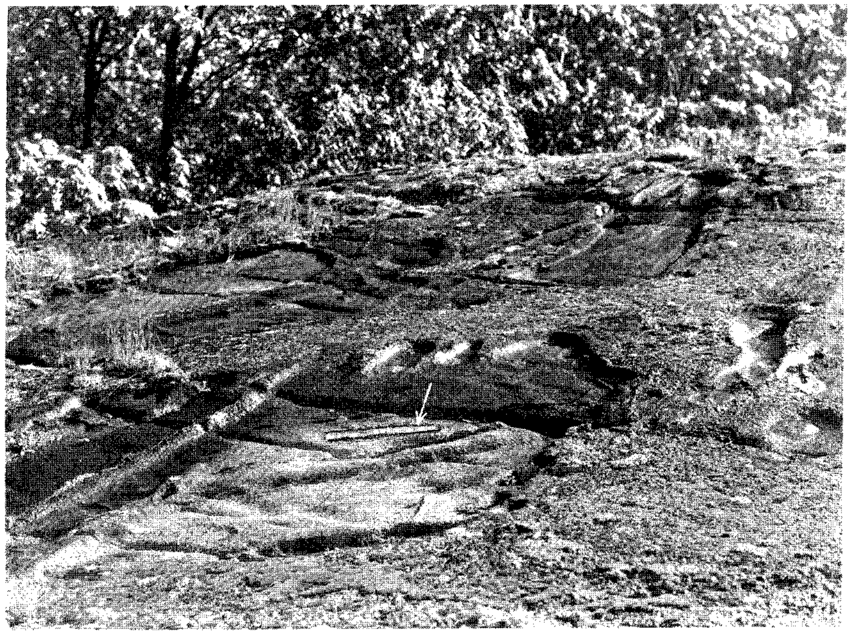


FIGURE 9.—Agmatitic blocks of foliated biotite gneiss in porphyritic quartz monzonite neosome, Van Buskirk Gneiss, SW¼SE¼ sec. 18, T. 46 N., R. 46 W. The blocks of foliated gneiss have weathered below the surface of the neosome. Arrow points to 30-cm scale.

the Van Buskirk Gneiss contains only crude grain-size layering and local included masses of paleosome—xenoliths or perhaps "roof pendants".

Foliation and layers in the Van Buskirk Gneiss vary considerably in trend but are generally east-west and dip steeply. In detail, as in a single large outcrop, the layers are mostly straight and even and the foliation is contorted at only a few outcrops. Coarse to fine striping in the porphyritic rock is anastamosing at some places.

Although the neosome is generally a coarse porphyritic rock, in many places indistinguishable from the Puritan Quartz Monzonite, it grades locally into a coarser grained rock containing abundant potash feldspars 2–5 cm (1–2 in.) long. This in turn grades into a very uneven textured feldspar pegmatite. Aplitic layers, probably similar in composition, were also observed. Intricately meandering ptygmatic quartz-feldspar veinlets are common in the paleosome.

Plagioclase in the Van Buskirk Gneiss south of the WC–PC lineament has much less zonation, and quartz grains are more

strained and contain more fine hairlike inclusions south of the lineament.

The mineral compositions of single specimens of neosome from the Van Buskirk Gneiss vary much more than those of specimens of the Puritan Quartz Monzonite, but the average modal analyses of both are very similar (table 4, fig. 10), lending support to the idea of a common origin. In contrast, the parts of the Van Buskirk Gneiss regarded as paleosome contain less, or even no microcline, and generally contain much more biotite than the neosome. This applies to the dark layers in the banded gneisses and to the old agmatitic blocks ("xenoliths") as well.

TABLE 4.—*Modal analyses of the Van Buskirk Gneiss (volume percent)*

	1	2	3	4
Quartz	29.0	29.4	28.6	27.8
Plagioclase	52.1	48.4	42.5	32.5
Microcline	.9	3.1	20.7	28.8
Muscovite	2.4	1.6	1.7	2.2
Biotite	13.2	15.2	3.9	6.4
Chlorite	.6	.4	.8	.4
Epidote	1.1	.9	1.3	1.4
All others	.7	.9	.6	.5
Total	100.0	99.9	100.1	100.0

1. Van Buskirk Gneiss paleosome, south of WC–PC lineament; average of 11 samples. Includes 3 samples from area east of Black River fault.
2. Van Buskirk Gneiss paleosome, north of WC–PC lineament, west of Black River fault; average of 6 samples.
3. Van Buskirk Gneiss neosome, south of WC–PC lineament; average of 22 samples. Includes 16 samples from area east of Black River fault.
4. Van Buskirk Gneiss neosome, north of WC–PC lineament, west of Black River fault; average of 5 samples.

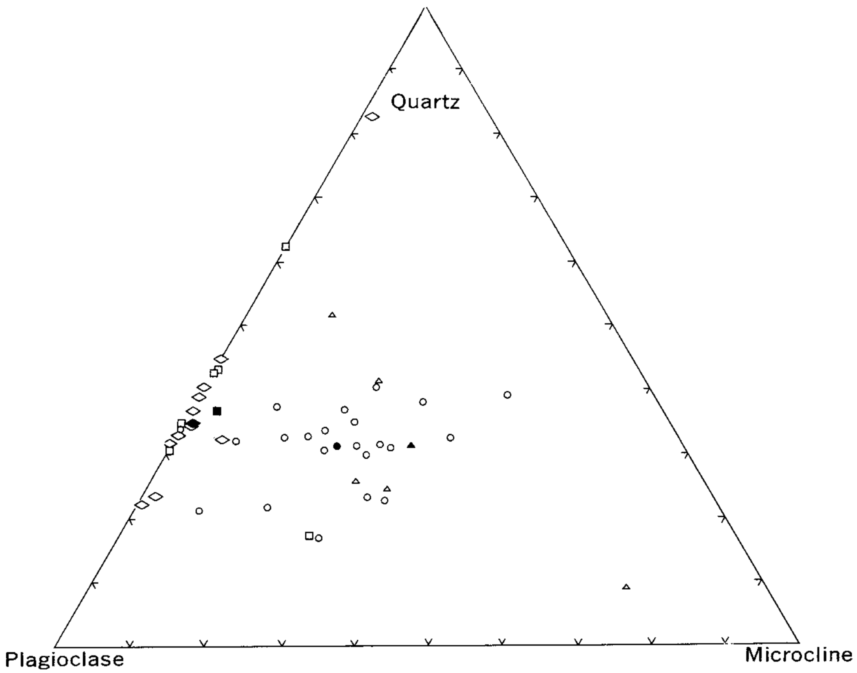
MINEROLOGY OF THE PURITAN-VAN BUSKIRK PLUTON

Modal analyses of 140 specimens of various phases of this complex pluton are shown in tables 3 and 4.

Quartz—Quartz fills interstices between feldspars where the feldspar has a euhedral or subhedral form and appears sutured where replacement processes have tailored the grain shapes. It generally has an undulatory extinction that tends to be more pronounced in the southern part of the area. Most grains contain abundant minute fluid inclusions, especially on healed fractures. Fine hairlike "rutilation" is present in some quartz in many slices and common in one third of them.

Small rounded blebs of unstrained quartz containing very few inclusions are enclosed within certain grains of plagioclase and microcline and are a common form of poikilitic inclusion in the phenocrysts. Quartz is also a constituent of myrmekite patches.

Plagioclase—Sodic plagioclase makes up 34–44 percent of the Puritan Quartz Monzonite and 30–52 percent of the Van Buskirk



Single slice counted 500 or more points	Average of all slices in group		
◇	◆		Van Buskirk Gneiss, paleosomes; from localities southeast of WCPC Lineament
□	■		Van Buskirk Gneiss, paleosomes; from localities northwest of WCPC Lineament
○	●		Van Buskirk Gneiss, neosomes; localities southeast of WCPC Lineament
△	▲		Van Buskirk Gneiss, neosomes; localities northwest of WCPC Lineament

FIGURE 10.—Major mineral composition of 44 samples of Van Buskirk Gneiss.

Gneiss. Subhedral to anhedral grains are dominant but a few are euhedral. Generally, the grains are partly or entirely albitized and clouded by minute grains of muscovite and locally by epidote, clinozoisite, or chlorite; in relatively few specimens the plagioclase is quite fresh.

Zoning or relict zoning of the plagioclase is present in more than one-half of the thin sections and common in one-third of them. Most of the true zoning has been destroyed by metamorphism, but relict zoning is preserved by variations in abundance of alteration minerals.

Twinning is generally present in the plagioclase, but no systematic relationship between twin laws and rock type is apparent. In some specimens, polysynthetic twinning is absent in as much as half the plagioclase, and, in many grains, it has been destroyed by metamorphism.

A few plagioclase grains in some specimens contain antiperthitic patches of microcline. Myrmekite is common in small grains and as rims on large grains at the contacts between plagioclase and microcline. Narrow unclouded rims are also common at plagioclase-microcline interfaces.

Microcline.—Microcline in phenocrysts and in groundmass grains forms 18–30 percent of the Puritan-Van Buskirk pluton except in paleosome phases, where it is very sparse. The microcline is perthitic and contains abundant tiny poikilitic grains of plagioclase and a few of quartz. Grid twinning is found in most grains. The perthite occurs in many forms, the most common of which is stringers, especially groups of fine evenly dispersed and similarly oriented stringers. Locally, these stringers are arranged en echelon. Irregular patches are common, and flamelike perthite areas occur along the edges of the microcline adjacent to plagioclase grains.

Muscovite.—All rocks in the pluton contain small amounts of muscovite as discrete mineral grains; the muscovite ranges from 0.9 to 2.4 percent of the rock volume. It is also common in fine grains in altered plagioclase.

Mafic constitutents.—The major original mafic mineral in the Puritan-Van Buskirk pluton was biotite. As a result of metamorphism of the original biotite, chlorite or epidote are now common. The biotite and the pseudomorphs after it occur in irregular books and long shreds filling intergranular areas. They comprise 1.6–5.4 percent of the various neosome phases and about 15 percent of the Van Buskirk paleosome phase. Most specimens contain a few minute apatite prisms, mostly enclosed in the biotite, but some within other minerals. Sphene and associated leucoxene grains are fairly common. Traces of allanite are found in part of the Puritan Quartz Monzonite from the northern area and in most of the single-phase quartz monzonite from the southern part of the area.

APOPHYSES AND MARGINAL PHASES

At many places in the migmatitic rocks in the pluton, there are dikes and irregular masses of a fine gray, dark gray, or dull brown "salt-and-pepper" biotite granodiorite. These are interpreted to be chilled Puritan intrusive because they are very similar to apophyses extending from the northern part of the pluton outward into Whiskers Creek Gneiss. Some of these intrusives are a few centimetres to a few metres thick; but others occupy entire outcrops, and their full size is not known. These biotite-rich rocks (5–14 percent biotite) are especially common in the eastcentral migmatitic part of the area, where I think the Puritan was intruded at a relatively shallow depth (modification of the country rock is least here), and in the adjacent metamorphosed Ramsay Formation in secs. 25–29 and 33–36, T. 47 N., R. 46 W., and secs. 4 and 5, T. 46 N., R. 46 W.; they are common in sec. 36, T. 47 N., R. 47 W. More than one generation of medium- to fine-grained Puritan apophyses can be recognized at a few outcrops.

At many localities, the "salt-and-pepper" granodiorite is characterized by sparse 0.5- to 1.0-cm (0.2- to 0.4-in) poikilitic phenocrysts. The phenocrysts may be as scarce as 1 per 1,000 cm^2 (155 in^2) and are therefore difficult to obtain in hand specimens. Lamellar twinning was noted in a few, so at least part of them are plagioclase, unlike "typical" Puritan Quartz Monzonite which has only microcline phenocrysts.

Magnetite in 2 to 5 mm (0.1- to 0.25-in) grains generally surrounded by 5 mm (0.25 in) depletion shells in which no dark mineral occurs are present at several localities in larger masses of the "salt-and-pepper" granodiorite. Perhaps only a few grains may be present in an outcrop, or they may be as common as a grain per 4 cm^2 (about 0.62 in^2). Magnetite-bearing "salt-and-pepper" granodiorite was found on the east bank of the Black River at Granite Rapids, in the SW¼SW¼ sec. 26, T. 47 N., R. 46 W., the NW¼ sec. 4, T. 46 N., R. 46 W., and NW¼ sec. 33, T. 47 N., R. 46 W.

PEGMATITES AND APLITES RELATED TO THE PURITAN QUARTZ MONZONITE

Quartz-feldspar pegmatite dikes, some containing a few percent muscovite, are locally common in the Puritan-Van Buskirk pluton.

The pegmatite is commonly associated with equigranular alaskite and aplite. Only those pegmatite-aplite masses having gradational contacts with enclosing rocks are here regarded as Puritan age. Several outcrops contain pegmatites of two ages; the older is assumed to be Puritan and the younger Sunset Creek age. Contemporary pegmatites are rare or lacking in the main Puritan Quartz Monzonite but are abundant in the neosome portions of the Van Buskirk Gneiss.

The mineralogy of the Puritan pegmatites is very simple. They consist mostly of perthitic microcline with lesser amounts of quartz; a few percent of muscovite is present locally, and biotite is even less common. No unusual accessories were observed.

Giant crystals, 30 cm (1 ft) or more across, of graphically intergrown perthite and quartz, are not uncommon. Layering of coarse- and fine-grained pegmatite is locally abundant; some layers are fine and aplitic. In the Van Buskirk Gneiss, a common variety of contemporary pegmatite consists of close-packed nearly euhedral microcline crystals 3–5 cm (1–2 in) long.

Irregular patches of an unusual pegmatitic phase are made up of widely scattered large single crystals of microcline and quartz in a quartz monzonite matrix. In an outcrop 122 m (400 ft) south and 122 m (400 ft) west of the center of sec. 2, T. 46 N., R. 47 W., single crystals as long as 15 cm (6 in) are widely dispersed in a matrix of uniform, slightly porphyritic medium-grained quartz monzonite. At other places, such as an outcrop 214 m (700 ft) north and 365 m (1,200 ft) east of the SW cor. sec. 12, T. 46 N., R. 47 W., and another outcrop 320 m (1050 ft) north and 490 m (1,600 ft) west of the center, sec. 7, T. 46 N., R. 46 W., abundant single crystals of feldspar in a granitic matrix seem to be related and locally gradational to a "normal" pegmatite. At the second location cited, agmatitic blocks of paleosome are included in the pegmatitic matrix; at the other two places, agmatitic blocks occur nearby. Although it seems improbable that any direct genetic relationship exists between the pegmatite and the included paleosome, pegmatites of this type seem to favor locations within the main neosome but occur only close to margins or included masses of older rock.

COMPARISON OF THE VARIOUS PHASES OF THE PURITAN-VAN BUSKIRK PLUTON

The mineral composition of various parts of the Puritan-Van Buskirk pluton is compared by plotting modal quartz, plagioclase, and microcline on triangular diagrams (figs. 7 and 10). The average modal compositions for all Puritan and neosome phases are very close to the "3,000 kg/cm² trough" of Tuttle and Bowen (1958, p. 56). Only the average mode for layers of paleosome in the Van Buskirk Gneiss has a plagioclase-to-microcline ratio markedly different from the rest: this seems compatible with the interpretation that the paleosome represents unresorbed layers of a preexisting foliated rock. The neosome of the northernmost Van Buskirk Gneiss contains more biotite, but is otherwise generally similar to the Puritan Quartz Monzonite, as it should be if their common origin proposed here is to be acceptable. Composition of the Puritan Quartz Monzonite is more varied south of the WC–PC lineament than north of it, but the average modes for the two areas are also very similar. The quartz in rocks from the southern area is more strained, and more replacement of feldspar by quartz has occurred.

Distribution of radioactive minerals.—The total gamma radiation from the Puritan Quartz Monzonite is very uniform and is derived from potassium plus traces of uranium and thorium (table 1). The radiation from the neosome part of the Van Buskirk Gneiss is also generally uniform and about equal to that of the Puritan, but the radiation from the paleosome is mostly lower than both. Some pegmatitic streaks contain local sources of radiation that are several times greater than that of the other rocks. Potassium and uranium are the main radiation sources in the gneisses; thorium content is about half that in the Puritain Quartz Monzonite, although some of the anomalously radioactive spots in the gneisses are caused by thorium.

SUNSET CREEK INTRUSIVE COMPLEX

The leucocratic multitextured pegmatites, including granitic and aplitic phases and a smaller number of even-textured quartz-monzonite dikes form a distinctive group of small intrusive bodies, called the Sunset Creek Intrusive Complex, in all the other Precambrian W rocks throughout the area, except in a narrow strip near Ramsay and Ironwood. The dikes terminate northward along an east-west line that closely parallels the later pre-Animikie erosion surface (pl. 1). These dikes occur in the Puritan Quartz Monzonite, the fringing Whiskers Creek Gneiss, and for several miles both east and west of the mapped area in the Ramsay Formation. At a few localities, pegmatitic material that is probably part of the Sunset Creek Intrusive Complex cuts "Group 1" mafic dikes that in turn cut Puritan Quartz Monzonite, but the best evidence for regarding the Sunset Creek intrusives as an entirely separate intrusive event is the lack of any relationship between

the distribution of these dikes and the metamorphic zoning in their host rocks.

The name Sunset Creek Intrusive Complex is given in this report to the multitextured leucocratic rocks exposed in the large bedrock hill in the NW¼NW¼ sec. 25, T. 47 N., R. 46 W., northeast of Sunset Creek. Here, as elsewhere in the area, these rocks range in texture from fine aplite through granite to coarse pegmatitic rock containing single crystals many centimetres across. At the specific locality mentioned above, single crystals are less than 30 cm (1 ft) across, but at other localities they are 60 cm (2 ft) across. The Sunset Creek intrusives are particularly abundant near Sunset Creek and in secs. 24 and 23 to the north and northwest.

The pegmatites are very leucocratic and devoid of accessory minerals; feldspar and quartz always comprise more than 95 percent, usually 98–99 percent, of their volume. Modal compositions are given in table 5 and figure 11. Coarse quartz and feldspar

TABLE 5.—*Modal analysis of 16 samples of the Sunset Creek Intrusive Complex*

Total points counted	7,362
Mineral	**Volume percent**
Quartz	30.2
Plagioclase	40.9
Microcline	25.3
Muscovite	1.4
Biotite	.4
Chlorite	.8
Epidote	.3
Other minerals	.7
Total	100.0

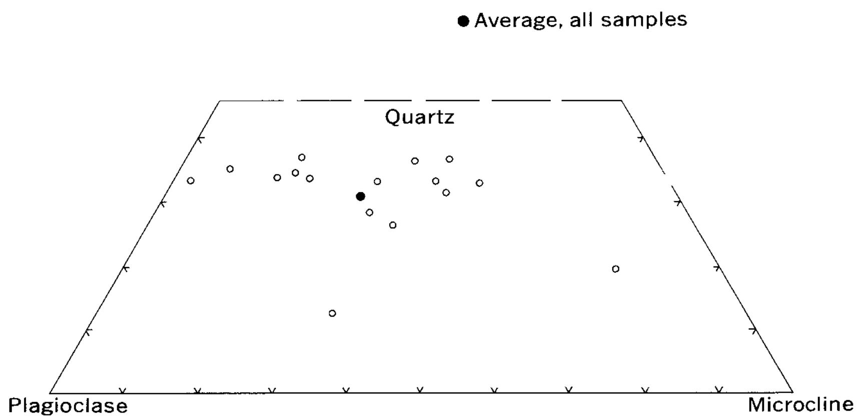


FIGURE 11.—Major mineral composition of 16 samples of the Sunset Creek Intrusive Complex.

locally form clean separate crystals, but graphic intergrowths are probably more common. Interstices between the large crystals are commonly filled with rock of granitic or aplitic texture. Zoning is rare; in some well-defined tabular pegmatites, quartz and feldspar form zones along the walls whereas quartz is more abundant in the centers. In large pegmatite masses, as in the SE¼NE¼ sec. 23, T. 47 N., R. 46 W., about on the section line, layered bodies 30 cm–1 m (1–3 ft) thick and as much as 6 m (20 ft) long are made up of alternating layers of coarse and fine pegmatite.

Muscovite is a minor constitutent of some pegmatites but is absent in most. Biotite was only rarely seen, and no unusual accessory minerals were found.

About 90 m (300 ft) west of the center of the NW¼ sec. 23, T. 47 N., R. 46 W., almost monomineralic pegmatite forms two outcrops, each many metres across. One is of white quartz, about 15 m (50 ft) to the southeast is a large mass of salmon-colored microcline that grades on one side to pegmatitic granite.

The Sunset Creek intrusives tend to be unevenly radioactive; many are somewhat more radioactive than the Puritan Quartz Monzonite, reflecting the somewhat higher potash content and perhaps a little more uranium. The thorium content of these rocks might be less than that of the Puritan Quartz Monzonite (table 1). The gamma radiation of some pegmatites is relatively low, and that of quartzose cores is generally very low.

GRANOPHYRIC FELDSPAR-QUARTZ PORPHYRY

Dark gray porphyritic rock, containing unevenly distributed pink feldspar and white quartz phenocrysts in a very granophyritic matrix, is present at two places within the Van Buskirk Gneiss in the southern part of the area; a third locality in Ironwood, described by Irving and Van Hise (1892, p. 112–113), may be similar rock, but I did not see it in the field. Neither hydrothermal alteration nor sulfides were noted in the porphyritic rocks during the field examinations. Although these porphyritic granophyric rocks would seem hypabyssal in origin, intrusion of such rocks at shallow depth into the Van Buskirk Gneiss is incompatible with the proposed geologic history.

Two small porphyry outcrop areas are at the northernmost locality in the SE½NE¼ sec. 9, T. 46 N., R. 46 W. Here the matrix of the rock is largely a granophyric intergrowth of quartz and plagioclase, but irregular patches of potassic feldspar also occur. Most of the matrix is clouded, some of it densely so, by

fine alteration products, probably the result of metamorphic changes.

Quartz phenocrysts are generally less than 5 mm (about 0.2 in) across and are strongly strained and much embayed. A rim in the matrix surrounding the quartz, about 0.1 mm (about 0.004 in) thick, contains abundant flakes of biotite and common leucoxinated lath- or needle-shaped grains.

The generally dark fine-grained rock contains scattered 5- to 20-cm (about 2- to 7.9-in) blobs of pegmatite-like quartz-feldspar rock, and some granitic patches having rather vague outlines. No contacts with the adjacent gneissic country rocks were seen, and the total area occupied by this porphyry is not known. I think that the quartz feldspar porphyry has been cut by a northeast-trending metadiabase dike that passes very close to the center of the NE¼ sec. 9.

The southern porphyry locality is in the NE¼NE¼ sec. 20, T. 46 N., R. 46 W., on the north slope of a large rocky hill. Red plagioclase grains 3–6 mm (0.1–0.3 in) long are enclosed in a fine plagioclase-quartz granophyric matrix. Ragged groups of biotite and chloritized biotite flakes are common. Some adjacent outcrops of dark-gray micaceous schist and some enclosed lenses of schist are pyrite bearing, but no analyses were made of these rocks.

A porphyritic rock containing phenocrysts of orthoclase, microcline, plagioclase, and quartz in a fine, probably granophyric, feldspar-quartz matrix, was described by Irving and Van Hise (1892, p. 112–113). This porphyry, in the NE¼ sec. 27, T. 47 N., R. 47 W., is described as containing patches of coarse granitic rock in the finer matrix (probably like the rock in the sec. 9 locality). The location given by Irving and Van Hise is in a residential part of Ironwood, within the Whiskers Creek Gneiss; I did not find this outcrop in the field.

MAFIC INTRUSIVE ROCKS

Dark mafic dikes and sills are common in Precambrian W rocks of the region. The mafic intrusives are of widely different ages; the oldest host rocks are believed to contain mafic intrusive rocks of all age groups, and successively younger hosts contain fewer mafic intrusives that have simpler metamorphic histories. Descriptions of dikes of Precambrian X and Y ages are included here because mafic rocks are sensitive indices of metamorphic change and provide the best key to the succession of metamorphic events in the area. Four groups of mafic intrusives have been differentiated in the Ironwood-Ramsay area on the basis of composition,

TABLE 6.—*General groups of mafic intrusive rocks, from oldest to youngest*

Group	Major minerals present	Relative abundance	Texture	Directional trends	Preceding metamorphic grade	Most recent metamorphic grade	Relationship to country rocks
1	Plagioclase (mostly much altered) hornblende, chlorite, epidote/clinozoisite, leucoxene, as much as 5 percent quartz.	Abundant	Nonporphyritic	Mostly NE	Amphibolite	Greenschist-amphibolite (If later grade equals or exceeds earlier, distinction from group 2 and some group 3 dikes is lost).	Mostly in Van Buskirk Gneiss SE of WC-PC lineament, rare NW of lineament; Probably cut by Sunset Creek intrusives.
2*	Plagioclase, hornblende, biotite, chorite, epidote/clinozoisite, leucoxene.	Minor	Porphyritic	NE. and NW	Amphibolite (older metamorphic cycle not always recognized).	Greenschist—high greenschist.	All Precambrian W (relationship to Sunset Creek intrusives is not known).
3	Plagioclase, augite, hornblende, chlorite, epidote/clinozoisite, leucoxene, iddingsite.	Common	Nonporphyritic	Mostly NE. and NW.	Low green schist (north) to amphibolite (south) (Penokean event).	Greenschist in north part of area only (Keweenawan event); no second metmorphism in southeast part of area.	Precambrian W and X host rocks.
4	Andesine, augite, olivine, iddingsite, chlorite, epidote/clinozoisite, titano-magnetite or leucoxene.	Minor	Nonporphyritic	Not determined.	None	Greenschist in NW part of area only; Unmetamorphosed elsewhere.	These are presumbaly all pre-Mellen intrusive rocks, but some much younger dikes could be included.

* Group 2 is less well defined than other groups and may have been locally confusd with group 1.

distribution, and relative age (table 6). Most of the mafic intrusives can be roughly classified in the field by their color, texture, and magnetic properties, but examination of thin sections is needed for final assignment to a group.

Internally, the mafic intrusives seem uniform in composition and grain size, but a few of the large ones are notably inhomogeneous. Fine-grained margins were found in many places, and contacts were probably generally chilled on the mafic bodies of all ages. Most of the mafic rocks, especially the abundant group 1 intrusive rocks in the southern part of the area, contain traces of pyrite.

An important inference to be drawn from the mafic rock distribution is that the Van Buskirk Gneiss south of the WC–PC lineament may be significantly older than any rocks to the north of the lineament.

MAGNETIC VARIATION RELATED TO MAFIC INTRUSIVES

Strong positive magnetic anomalies are generally associated with the augitic diabase dikes, including those group 3 intrusives which are metamorphosed no higher than the middle of the greenschist facies. Most, and perhaps all, major anomalies are positive, in contrast with the negative polarity of Keweenawan-age (Precambrian Y) dikes further east in northern Michigan (Balsley and others, 1949). The "strong" magnetic anomalies range from 2,000 to as much as 16,000 gammas. Most of the higher grade once-metamorphosed dikes and all of the twice-metamorphosed dikes have no magnetic anomaly (that is, the magnetic variation is 200 gammas or less) related to them, but a few are somewhat anomalous, about 300 gammas magnetic variation, and certain few dikes as magnetic as 1,000 gammas. Most of these anomalies are also positive, but at least one with negative sign was noted.

GROUP 1 MAFIC INTRUSIVES

Old twice-metamorphosed nonporphyritic intrusives are the most abundant, making up over half of the dike swarm in the southern part of the area. These dikes are generally the largest also, one dike being at least 185 m (600 ft) wide and probably many kilometres long.

The minerals in group 1 intrusives are mainly hornblende and plagioclase, plus chlorite, epidote, clinozoisite, and calcite to the extent that the rocks have been modified by the second cycle of metamorphism. Sphene, leucoxene, apatite, and pyrite are common accessories, and a few specimens contain magnetite, biotite, stilpnomelane, quartz, tremolite, or ilmenite. Strongly zoned new plagioclase of intermediate composition is characterized by a pale red-brown tint in part of the grains that I have not seen in any unmetamorphosed mafic dikes.

The best evidence for two successive periods of metamorphism is the complete destruction of the original diabasic texture during the first amphibolite facies cycle, resulting in a rock in which prisms of amphibole dominated the grain. The second metamorphic cycle destroyed the amphibole partly or entirely but generally left relicts of the amphibolitic texture. The intensity of the second cycle increased southeastward so that old dikes in secs. 25, 26, 35, and 36, T. 47 N., R 46 W. have been remetamorphosed to mid-greenschist facies, and those 6 km (3.7 mi) southeastward, near McDonald Lake, have been remetamorphosed to the amphibolite facies. Where the grade of the second metamorphic cycle was as high or higher than the first, the evidence for the first cycle is lost, as it is near McDonald Lake and in the area southward to the Wisconsin border.

Although a few group 1 mafic intrusives definitely cut rocks of the main mass of the Puritan Quartz Monzonite, they are most abundant southeast of the WC–PC lineament, and many or most of them may be older than the Puritan pluton.

One pre-Puritan mafic dike was identified in a patch of Whiskers Creek Gneiss included within the Puritan Quartz Monzonite, near the midpoint of the west side, NW¼ sec. 36, T. 47 N., R. 47 W. A vertical tabular mass of very dark hornblendite, 3 m (10 ft) thick, trends N. 50° W. in a complex outcrop. This mafic rock contains about 56 percent hornblende, 28 percent strongly zoned plagioclase, 11 percent biotite, 2 percent epidote derived from alteration of plagioclase, 1 percent each of sphene and muscovite, and only 0.5 percent quartz. It is relatively unaffected by post-Puritan metamorphism because of its location.

Rhythmic layering and local segregation of coarse mineral grains, especially hornblende, were found southwest of McDonald Lake in the study area's largest mafic bodies, those of group 1. Rhythmic layers about 2 cm (0.8 in) thick were observed at two localities: near the W¼ cor. sec. 14, T. 46 N., R. 46 W., and also about 380 m (1,250 ft) north of the SW cor. sec. 15, of the same township. The layers are conspicuous on weathered surfaces but the mineralogic contrasts causing them are subtle, and it is not clear if they represent modified cumulate textures or a metamorphic feature. The layers probably roughly parallel the sides of the intrusive bodies at both localities.

Sharply defined younger dikes are rather common within older dikes, and in many places near McDonald Lake group 3 (and 4?) dikes seem more abundant in the group 1 dikes than in the granitic rocks nearby.

Puzzling irregular pod-shaped masses of feldspar-rich magnetic metadiabase are present within nonmagnetic metamorphosed hornblendic dikes in several places southeast of the WC–PC lineament. The metamorphic grade of the magnetic rock seems to be about the same as the enclosing rock, but I think that microscopic textures indicate the pods are younger and have undergone at least one less period of metamorphism than the host dike.

GROUP 2 MAFIC INTRUSIVES

These relatively sparse intrusives are very similar to the group 1 rocks, but they contain 3- to 30-mm spots which mark the former sites of feldspar phenocrysts; they are generally dikes less than 30 m (100 ft) thick, and they occur in equal abundance north and south of the WC–PC lineament. Because the group 2 dikes cut the northcentral part of the Puritan pluton as much as they cut gneisses south of the WC–PC lineament, they are thought to be younger and to deserve a separate group classification.

GROUP 3 MAFIC INTRUSIVES

The once-metamorphosed augitic diabase intrusives are present in the strata of Precambrian X age and in all the older rocks in the area, but they do not occur in rocks of Keweenawan age. The intensity of the metamorphism that affected these intrusives increased toward the south, from very low greenschist facies in the Precambrian X age rocks near Anvil to amphibolite facies west of McDonald Lake. In the northern part of the area, it is hard to distinguish these rocks from younger unmetamorphosed diabase, and in the southernmost outcrops, group 3 metadiabases look the same as group 1 dikes. Magnetic variation over these dikes is generally great but is presumed to decrease southward.

The least metamorphosed group 3 intrusives contain 45–58 percent calcic plagioclase (An 58–70 percent), 6–9 percent magnetite-ilmenite, as much as 8 percent relict material after olivine, 1 percent biotite, and 1 percent apatite; the remainder is mostly augite. Compositions of these dikes tend to be bimodal; in dikes containing 45–48 percent plagioclase, as much as 3 percent quartz is present; all the rest contain 54–58 percent plagioclase, and only traces of quartz.

GROUP 4 MAFIC INTRUSIVES

Unmetamorphosed and slightly metamorphosed diabasic intrusives are present in small numbers in all rocks in the region except post-Powder Mill-age strata north of the mapped area. In the northwest part of the study area (near Ironwood), these dikes were affected by the Keweenawan thermal event that produced a westward-increasing metamorphic gradient in the Ironwood Iron-formation and that was probably related to emplacement of the Mellen gabbro-anorthosite. A line marking the threshold of metamorphism trends northeastward through Bessemer. Because so few dikes of this group were studied, it is not certain that all are pre-Mellen in age.

Most of the intrusives of this type are dikes less than 3 m (10 ft) thick; 10 m (30 ft) was the greatest thickness. Textures are generally diabasic, and margins are distinctly chilled. Plagioclase (48–63 percent An) makes up 45–55 percent of the rock, and augitic pyroxene, 27–36 percent. As much as 3 percent of one large dike is an iddingsitelike material relict after olivine. Opaque minerals, partly magnetite, make up 5–13 percent of the volume, and many of the grains appear in thin-section as lacy fretworks. Dikes in this group are all magnetic and are associated with strong magnetic anomalies.

METAMORPHISM

The metamorphic history of the Ironwood-Ramsay area is complex, but four separate metamorphic events have been recognized. The evidence of early events has been blurred by later ones, and it is only because mafic dikes have been intruded in many different places between each event that it is now possible to make the distinctions.

The oldest recognizable metamorphic event was the formation of the broad contact aureole related to intrusion of the Puritan Quartz Monzonite. The shape of the area affected is generally defined by the shape of the outer boundary of the Whiskers Creek Gneiss; effects of the event are probably not recognizable in the country rock more than 2–3 km (1–2 mi) outside the outer Whiskers Creek Gneiss boundary. Before subsequent metamorphism, the highest grade amphibolite facies rock near the Puritan pluton consisted mostly of plagioclase, hornblende, quartz, and microcline.

The second period of metamorphism, probably regional in scope, took place during Precambrian W time but caused alteration of group 1 and group 2 mafic intrusives that cut the Puritan Quartz Monzonite. Although the mineral suites formed by this event were everywhere overprinted by later metamorphic changes, palimpsets after earlier amphibole grains indicate that the dikes were metamorphosed to a lower stage of the amphibolite facies. No regional gradient has been identified for this event.

Regional metamorphism of the third period affected the widely distributed group 3 dikes, some of which are in the east-trending block faults that are here associated with the Penokean orogeny. The dikes cut the Palms-Ironwood-Tyler sequence and are probably all late Precambrian X age; the metamorphism is probably also late Precambrian X (also Penokean, but later than the block faulting and dike intrusion). The intensity of the third period of metamorphism increased southward, the greenschist-amphibolite facies isograd passing close to McDonald Lake and trending about N. 60°E.

Penokean-age metamorphic effects on the Ironwood Iron-formation are probably very slight between Ironwood and Ramsay because the iron-formation in the bed of the Black River at Ramsay is unmetamorphosed or only slightly so. At Ironwood and westward in Wisconsin, any Penokean-age mineral changes are probably obliterated by effects of the later Keweenawan metamorphic event. Eastward from Ramsay, the iron-formation and mafic dikes and sills in the iron-formation were increasingly modified by Penokean metamorphism.

The southward-increasing metamorphism probably associated with the Penokean orogeny has progressively reduced the magnetic susceptibility of the Precambrian W country rock to produce the marked magnetic gradient 5–7 km (3–4½ mi) southward from the Ironwood-Ramsay area (Philbin and Vargo, 1966). This broad gradient is too wide to be related to magnetite in the Ironwood Iron-formation. The magnetic contours trend about N. 70° E. and closely parallel Penokean isograd lines rather than the base of the iron-formation. The downward end of the gradient coincides with the the "middle greenschist/upper greenschist facies boundary" (pl. 1). From there southeast to the edge of the mapped area, the magnetic pattern has little relief and no gradient.

The last thermal event to affect the Precambrian rocks of the Gogebic district produced the relatively broad contact metamorphic aureole around the mafic Mellen intrusive of Precambrian Y age. Ironwood Iron-formation and flows of the Powder Mill Group at Ironwood were weakly affected by this event (lower range of greenschist facies and equivalent), but there is no certain evidence of Precambrian Y metamorphism between Bessemer and Ramsay. Greenschist facies metamorphic mineral changes in specimens from the Powder Mill Group 5–8 km (3–5 mi) east of Ramsay suggest that an eastward-increasing metamorphic gradient is present in the area as well as the westward-increasing one.

STRUCTURAL GEOLOGIC HISTORY

An early period of folding, three periods of uplift and erosion, and the northward tilting of a large block are the major events in the structural history of the Ironwood-Ramsay area.

The earliest well-defined structural event was the folding of the Ramsay Formation (now partly Whiskers Creek Gneiss); this took place before intrusion of the Puritan Quartz Monzonite. Strike directions show that folds trend generally eastward and local variations in strike suggest fold axes plunge southwestward (as near Anvil, in sec. 14, T. 47 N., R. 46 W.). The few lineation data obtained also indicate southwest axial plunges.

Deep erosion of the crystalline rocks to a surface of low relief produced the unconformity marking the Precambrian W–X boundary. Upon this platform surface were deposited a cratonic suite, the Sunday Quartzite and Bad River Dolomite (only preserved west of the area in Wisconsin and in Michigan, east of Wakefield). It is assumed but not proven that these sedimentary units were originally continuous across this central part of the Gogebic district.

Differential unwarp and erosion of parts of the Sunday Quartzite and Bad River Dolomite were followed by deposition of the Palms Formation, Ironwood Iron-formation, and Tyler Formation. The map trace of the erosional unconformity and the very uniform lithology of the thin shallow-water Palms Formation indicate an erosional surface of very low relief.

In all of the Gogebic district west of Ramsay, Mich., deformation during the Penokean orogeny, at the end of Precambrian X time, was limited to an east-trending system of nearly vertical block faults, most of which were upthrown on the north side. Near Wakefield, Mich., and eastward from there, Penokean deformation may have been considerably more complex. Many group 3 mafic dikes are east trending, parallel to the step faults, and some were injected on the faults. The faults offset Precambrian X strata and the Precambrian W–X unconformity, but the extent of the faults in Precambrian W rocks cannot be judged because no suitable horizon markers are present.

Differential uplift, perhaps accomplished entirely by the Penokean block faulting, caused partial erosion of the Precambrian X Tyler Formation near Ironwood, and complete removal of the Tyler plus part of the Ironwood Iron-formation at Wakefield. The Penokean faulting probably also caused a 5–15° (20–25° according to Hotchkiss, 1923, p. 676) southward tilt of the Precambrian X strata before the Precambrian Y beds were deposited unconformably on them.

The north-dipping monoclinal structure along the entire length of the Gogebic district in Wisconsin and Michigan [over 100 km (62 mi)] developed gradually during Precambrian Y time but mostly at the time of the unconformity between lower and middle Keweenawan strata (as defined by Hubbard, 1968). The long rigid block of Precambrian W crystalline rock plus the stratified veneer of Precambrian X and lower Precambrian Y layers appear to have tilted northward as a unit without internal differential movement; however, the nature of the southern edge of the block has not been identified.

The southward extent of the postulated block, and the position of a bounding "hinge line" (alternatively, if the rocks are folded instead of tilted as a block, the relative amount of flexure and the axial position) may be recorded in the paleomagnetism of group 3 and older mafic intrusives. A comparison of pairs of samples that are interpreted to come from different locations on the same northwest-trending dike would probably provide the most significant data. W. J. Hinze of the Department of Geosciences, Purdue University, has taken many oriented samples of the mafic intrusives and has made preliminary measurements on some of them, but the results thus far are not sufficient to draw any conclusions about the applicability of the method.

After lower Keweenawan time, perhaps at the same time as northward tilting, the Precambrian X and Y strata were cut by a series of faults that are now nearly vertical and that strike from N. to N 60°E. (most are about N. 25°E.). Most of these faults do not offset the Precambrian W–X contact and have not deformed the Precambrian W rocks, but the Black River fault, that seems to belong to this group, can be traced in the Precambrian Y and X strata and in the Precambrian W rocks as far as sec. 3, T. 46 N.,

R. 46 W. Beyond sec. 3 it is inferred to extend several kilometres south of the Wisconsin border along a valley thought to be controlled by linear structures in the bedrock.

ECONOMIC MINERAL POTENTIAL

Detailed mapping of the Ironwood-Ramsay area provided little evidence to warrant further prospecting for economic mineral deposits in Precambrian W rocks. Special features examined include zones of sericitic alteration, some sulfide in quartz monzonite, and disseminated sulfide in extensive thick mafic dikes. Evidence of sulfide concentrations in the greenstone sequence was looked for but not found.

Extensive zones of sericitic alteration in quartz monzonite are exposed in an old railroad cut at the abandoned Newport mine (NE¼ sec. 24, T. 47 N., R. 47 W.) and east of the Black River in the SW¼ sec. 26, T. 47 N., R. 46 W. On a small rock knob in the NE¼ of this same sec. 26 is a small patch of alteration containing some associated sulfide. These sericitized rocks now consist of quartz, muscovite, and microline, most of the plagioclase having been altered to muscovite, which perhaps has been subsequently coarsened and recrystallized by metamorphism. No K_2O analyses were made, but the minerals present suggest considerably more potash than that in the original rock. One sample from the Newport mine locality and one from the Black River locality were analysed and the base metal content was found to be negligible.

All the mafic dikes in the area contain traces of pyrite, and the greatest amount of sulfide is in the group 1 dikes especially common in the southern part of the area. Most of the sulfide-bearing dikes are less than 30 m (100 ft) thick and have a simple tabular form, but in sec. 15, T. 46 N. R. 46 W., one large northeast trending group 1 dike seems to be as much as 180 m (600 ft) thick. At two places this dike contains alternate light and dark mineral layers that suggest a cumulate texture.

However, even those rocks with the greatest sulfide content contain less than 0.5 percent sulfide visible under low magnification. Samples were collected for analysis by taking 8–30 random chips from each outcrop. Of 30 samples analysed, 21 samples contained 25–200 ppm Cu, 6 contained 300 ppm Cu, 2 contained 500 ppm Cu, and 1 contained 700 ppm Cu. The locations of the samples having 500 and 700 ppm are shown in table 7. The higher copper values seem to occur in dikes of various ages. In the 30 samples, the cobalt content ranged from 20 to 100 ppm, and the range for nickel was 30–150 ppm.

TABLE 7.—*Base-metal analyses of three mafic dikes*

Location	Copper (ppm)	Nickel (ppm)	Cobalt (ppm)	Dike group containing sample (see table 6)
190 m (620 ft) south, 550 m (1,800 ft) east, NW cor. sec. 8, T. 46 N. R. 46 W	500	100	70	2
335 m (1,100 ft) south, 370 m (1,220 ft) west, NE cor. sec. 24, T. 46 N., R. 47 W	700	70	50	4
690 m (2,250 ft) north, 120 m (400 ft) east, SW cor. sec. 9, T. 46 N., R. 46 W	500	150	50	1

The metavolcanic rock strata of the Ramsay Formation fit the model of a favorable environment for volcanogenic sulfides in "greenstone belts," especially those horizons in the Ramsay Formation which separate generally mafic from generally felsic beds. The total area of the Ramsay Formation and Whiskers Creek Gneiss examined in this study is so small that the failure to find any particular sulfide enrichment cannot have much significance in evaluating the "greenstone belts" to the east and west.

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