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# Mafic-Ultramafic Layered Intrusion at Iron Mountain Fremont County Colorado

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# Mafic-Ultramafic Layered Intrusion at Iron Mountain Fremont County Colorado

By DANIEL R. SHAWE and RAYMOND L. PARKER

CONTRIBUTIONS TO GENERAL GEOLOGY

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G E O L O G I C A L   S U R V E Y   B U L L E T I N   1 2 5 1 - A

*Mafic and ultramafic rocks occur  
in a small layered funnel-shaped  
intrusive complex associated  
with younger alkalic rocks of  
the McClure Mountain Complex*



**UNITED STATES DEPARTMENT OF THE INTERIOR**

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**GEOLOGICAL SURVEY**

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## CONTRIBUTIONS TO GENERAL GEOLOGY

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By DANIEL R. SHAWE and RAYMOND L. PARKER

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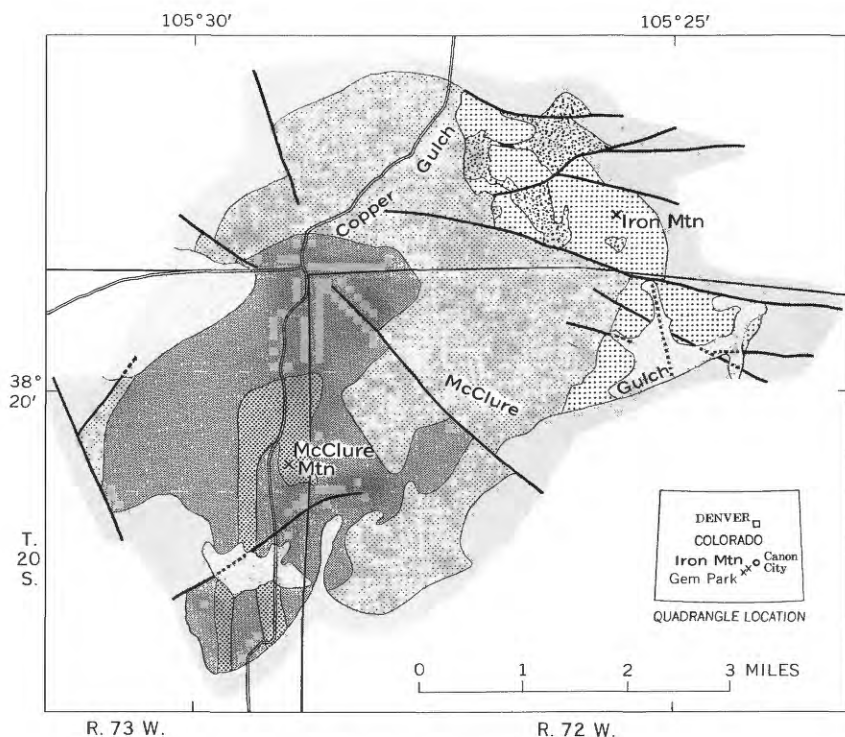
#### ABSTRACT

Mafic and ultramafic rocks form a small layered funnel-shaped intrusive complex, including several smaller associated discordant intrusions, within Precambrian metamorphic rocks in the vicinity of Iron Mountain, northern Wet Mountains, Colo. The mafic rocks consist of several gradational varieties of gabbro, pyroxenite, dunite, anorthosite, and magnetite iron ore and are made up principally of bytownite-labradorite, monoclinic pyroxene, magnesium-rich olivine, and titaniferous magnetite. Brown amphibole, probably kaersutite, is a late-stage primary mineral.

Part of the mafic complex is well layered, having originated through crystal settling in mafic magma. Conspicuous textures and structures that are characteristic of sedimentary rocks are graded bedding, crossbedding, and scour-and-fill. Discordant bodies of pyroxenite and anorthosite intrude the layered rocks and offer evidence that later differentiation had proceeded below or beyond the chamber in which the layered rocks accumulated. The mineralogic and chemical nature of the rocks and their close association with alkalic rocks of the McClure Mountain Complex indicate that these mafic and ultramafic rocks and the alkalic rocks are comagmatic.

#### INTRODUCTION

Mafic and ultramafic rocks in the form of a layered, funnel-shaped intrusive complex underlie an area of  $3\frac{1}{2}$  square miles in the vicinity of Iron Mountain in the northern Wet Mountains, Fremont County, Colo., about 11 miles southwest of Canon City. Parker and Hildebrand (1963) noted that these rocks form the northeastern part of a larger alkalic complex at McClure Mountain, which includes also various types of syenite, nepheline syenite, and mafic nepheline-bearing rocks (fig. 1). The complex at McClure Mountain was originally described in detail by Parker and Hildebrand (1963). Rocks of the complex exposed in the type area shown in figure 1, which encompasses about 20 square miles, are here formally designated the McClure Mountain



## EXPLANATION

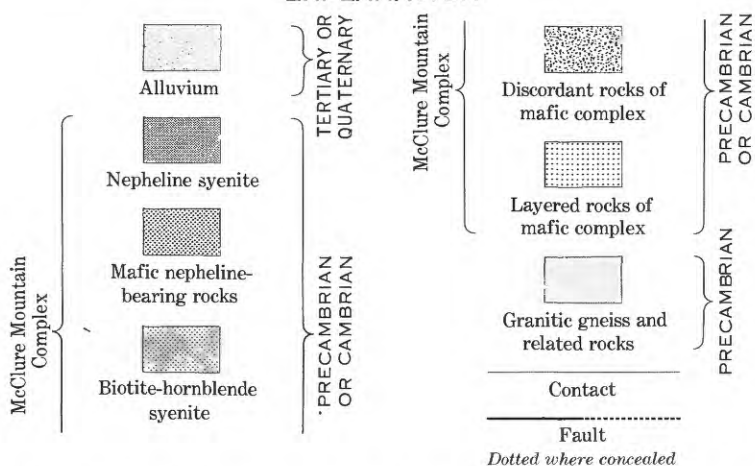


FIGURE 1.—Location and geologic setting of the mafic-ultramafic complex at Iron Mountain. Modified from Parker and Hildebrand (1963).



Complex. The complex, originally shown as Precambrian in age (Parker and Hildebrand, 1963), is now considered to be Cambrian or Precambrian. Significantly, mineralogy and chemistry of the mafic and ultramafic rocks of the layered intrusion, as determined in the present (1966) study, suggest that the layered intrusion and the alkalic rocks of the McClure Mountain Complex are comagmatic.

The mafic and ultramafic rocks at Iron Mountain discordantly intrude granite gneiss, amphibolite, and other metamorphic rocks of Precambrian age. The Iron Mountain rocks cut across foliation of the metamorphic rocks and are clearly younger than the regional metamorphism that has affected the gneisses and related rocks. At its west edge, the intrusive complex at Iron Mountain is intruded by biotite-hornblende syenite and locally by dikes and irregular bodies of nepheline syenite. These syenites are believed to be closely related in age and genesis to a syenite body which occurs about 6 miles to the southwest, and which has been dated by the Larsen zircon method as about 595 million years old (Christman and others, 1959). The Iron Mountain mafic and ultramafic rocks and other rocks of the McClure Mountain Complex are cut by conspicuous syenite porphyry dikes.

The only known commercial mineral deposit in the mafic and ultramafic rocks of the Iron Mountain area consists of titaniferous magnetite ore at the Iron Mountain mine, about a mile south of Iron Mountain on the south side of Sandy Creek. A few prospects are widely scattered in the mafic and ultramafic rocks; some of these expose iron ore, others contain minor iron and copper sulfides, and at least one exposes a small vein containing fluorite and galena. None of the prospects indicate minable deposits.

The Iron Mountain mine, which probably was operated on a very small scale as early as 1872, was described by Endlich (in Hayden, 1874), Putnam (1886), Chauvenet (1886, 1890), and Kemp (1899). The ore was described in detail and previous works were reviewed by Singewald (1913), and more recently the deposit was the subject of magnetic and gravity studies by the U.S. Bureau of Mines (Becker and others, 1961).

Rocks similar to those of Iron Mountain constitute a smaller mafic-ultramafic complex at Gem Park about 8 miles to the southwest. This complex, which is the subject of a separate study and is like that at Iron Mountain, is funnel-shaped and layered and contains local deposits of titaniferous iron ore. It differs, however, in the absence of much associated syenite, in the development of vermiculite in the mafic and ultramafic rocks, and in the development of abundant carbonatite dikes and associated niobium and rare-earth mineralization.

### STRUCTURAL FEATURES

The stratified complex at Iron Mountain consists of a sequence of igneous rock layers several thousand feet in total exposed thickness, which forms a spoon- or funnel-shaped body (now disrupted by faults) whose long axis trends northwestward (pl. 1). Gabbro, dunite, anorthosite, and pyroxenite are interlayered in all levels of the intrusive complex. The layers range in thickness from a fraction of an inch to several tens of feet; thicker layers appear to extend laterally thousands of feet and vary little in thickness. The rocks are generally medium grained (2–5 mm) and contain different proportions of the principal minerals—plagioclase, pyroxene, olivine, and magnetite. Small coarse-grained pegmatitic bodies composed principally of plagioclase and pyroxene occur locally in the layered series. The layered rocks appear to be nearly conformable to the contact because their strikes are everywhere nearly parallel to the surface trace of the contact with gneissic country rocks, except where both rock types are in fault contact. The layers commonly show a foliation, parallel to the layering, defined by the orientation of tabular mineral grains; no lineation is evident within layers.

Rock layers along the west margin of the layered intrusion commonly diverge strongly from the nearly conformable inward-dipping attitudes present throughout most of the remainder of the body. The local irregularities in attitude probably resulted from disruption during intrusion of the large biotite-hornblende syenite body against this contact. Local strong brecciation of layered rocks and intimate penetration by syenite along the west edge of the mafic and ultramafic complex also attest to the disruption effected by the syenite intrusion. Probably part of the original layered intrusion here has been displaced by syenite.

A large part of the layered rocks, in an area covering about one-half square mile in the southern part of the complex and adjacent to its west margin, is grossly out of orientation with the remainder of the complex. Here rock layers consistently strike nearly north and dip steeply to the west. The rock layers in this area are distinctive lithologically in that they contain abundant titaniferous magnetite; the Iron Mountain magnetite mine is located near the north end of this area.

Compositional layering, which is attributed to crystal settling and other phenomena closely analogous to processes forming sedimentary rocks (Wager and Deer, 1939), is an outstanding feature of the complex. Rhythmic layering (fig. 2) is common, as is graded bedding in some layers as much as 6 inches thick in which pyroxene and sparse



FIGURE 2.—Rhythmic layering in gabbro of the layered intrusion at Iron Mountain.

plagioclase at the base grade upward to sparse pyroxene and abundant plagioclase at the top (fig. 3). In places the rhythmic layers are graded, demonstrating cyclic deposition. Locally, thin-layered rocks have been scoured by currents in the magma, and the scours have been filled with igneous minerals that have settled from the magma and produced an igneous rock having low-angle crossbeds and being identical in structure with crossbedded sandstone (fig. 4).

The discordant intrusions within the layered complex are of two general types, pyroxenite and anorthosite. Pyroxenite, the most abundant, occurs principally in one large faulted intrusive body a little less than 1 square mile in area in the northern part of the layered complex (pl. 1). Most of this intrusion is coarse grained (about 1 cm) and nonfoliated and locally consists of peridotite and gabbro. Its intrusive character is demonstrated by its discordant nature and inclusion of fragments of layered rocks locally near the contact. In one



FIGURE 3.—Graded bedding in gabbro of the layered intrusion at Iron Mountain.

place about 1 mile southeast of the northwest tip of the complex, a small plug of coarse-grained pyroxenite appears to have forcefully perforated the layered rocks and dragged them upward peripherally (pl. 1). Locally the coarse-grained pyroxenite penetrates the layered rocks in fingers and includes leaves of the layered rock. At the north edge of the complex a body of nonfoliated fine-grained pyroxenite (2 mm and smaller) protruding into the country rocks (pl. 1) may be a separate intrusion or a chilled border facies of the coarse-grained pyroxenite intrusion.

Anorthosite occurs in three small discordant plutons (pl. 1) whose contacts seem to be nearly vertical. This rock is variable in grain size, ranging locally and abruptly from fine to coarse grained, and is non-foliated. At one place, three-fourths mile south of the northwest tip of the complex, the fact that intrusive anorthosite appears to cut across a septum of coarse-grained intrusive pyroxenite indicates that the anorthosite is younger than the pyroxenite.

Numerous faults have disrupted the rocks of the mafic and ultramafic igneous complex. The oldest faults recognized are in the northern part of the complex, where coarse-grained intrusive pyroxenite has been offset by eastward- and northeastward-trending faults that ap-

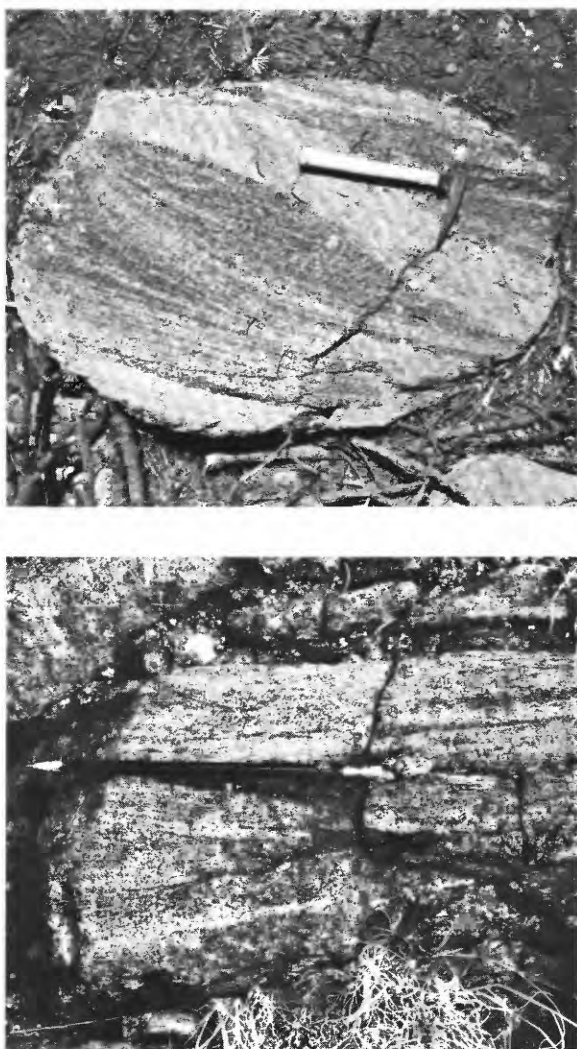


FIGURE 4.—Two views of scour-and-fill structure and crossbedding in gabbro of the layered intrusion at Iron Mountain.

pear to be intruded locally by anorthosite and are intruded by or cut by dikes of syenite. A postulated northward-trending fault in the southern part of the complex, concealed by alluvium, separates the disoriented magnetite-rich block from the nearly conformable layered rocks farther east. This fault may have formed during the intrusion of the adjacent biotite-hornblende syenite body, and if so, it is probably somewhat younger than the oldest faults farther north. Still younger



is a large eastward-trending fault that cuts the layered complex in half and offsets it more than 1 mile in a left-lateral sense. This large fault is not recognized on the west side of the alkalic McClure Mountain Complex (fig. 1), and apparently no comparable displacement of the rocks occurred there. The large fault probably formed chiefly as a result of an eastward displacement of country rock to make room for the intrusions of nepheline syenite in the southwestern part of the McClure Mountain Complex. Other faults cutting the mafic and ultramafic rock complex have offset the biotite-hornblende syenite contact along the west side of the southern part of the complex and are probably related in origin to the large east-west fault.

### PETROGRAPHY AND MINERALOGY

The mafic and ultramafic rocks forming the complex at Iron Mountain consist of a series of gradational types composed principally of plagioclase, pyroxene, olivine, and magnetite in different proportions. Specifically the rock types range from several varieties of gabbro to pyroxenite, dunite, anorthosite, and titaniferous magnetite iron ore. Some olivine-pyroxene rocks containing minor plagioclase are classed as peridotite, and olivine-plagioclase rocks, as troctolite. The different rock types contain variable small amounts of one or more accessory minerals, including brown amphibole, biotite, green spinel, pyrite, apatite, sphene, and rutile. Slightly altered rocks, some of them metasomatized as a result of syenite intrusion, here termed "syenitized," contain one or more of the following minerals: serpentine, aegirine, blue-green amphibole, chlorite, carbonate, sericite, potassium feldspar, zircon, and zeolite (?).

The most striking microtextural aspect of all the layered rocks is that the most abundant mineral in any particular rock type tends to be euhedral and that it forms a mesh, and minerals of lesser abundance are molded around the major crystals and are interstitial to them. This relation is illustrated for pyroxenite in figure 5, for olivine-rich gabbro in figure 6, and for titaniferous magnetite iron ore in figure 7. The relation is evident not only on a large scale in layers several feet thick in the layered intrusion but also in detail in layers a fraction of an inch thick (fig. 8). Furthermore, on a scale of a fraction of an inch to a few inches, the densest minerals generally predominate in the lower part of a graded layer, and the lightest minerals, in the upper part (fig. 8). Crystal-settling origin of the layered rocks is further illustrated by the tendency of tabular crystals, particularly plagioclase, that ordinarily lie parallel to the layering to be locally "propped up" at divergent angles on more equant mineral grains. In the layered series as a

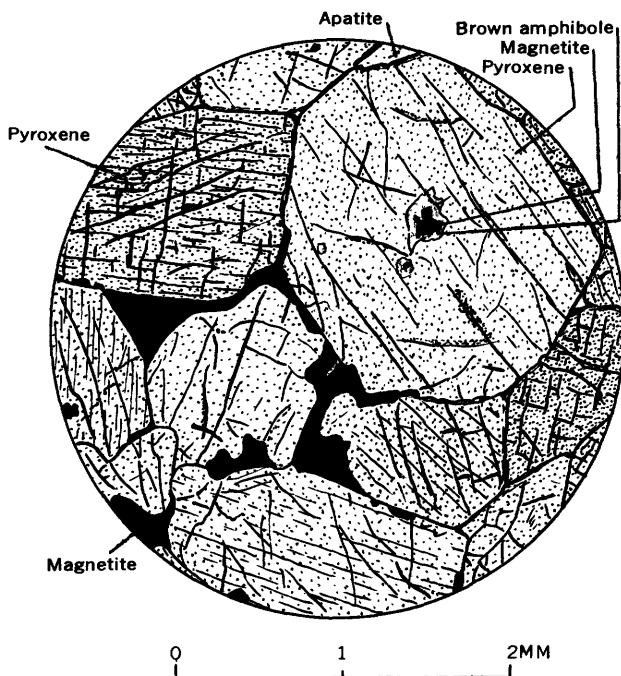


FIGURE 5.—Pyroxenite of the layered series, sample IM-3-64, southeastern part of the north half of the complex. Euhedral monoclinic pyroxene and interstitial magnetite and apatite.

whole the mesh crystals are of the same composition as the corresponding interstitial crystals. Many of these euhedral mesh crystals are fitted closely as a result of additional growth after accumulation. Thus it is apparent that both adcumulus growth—additional growth of mesh crystals—and interstitial growth of minor minerals took place in equilibrium with the overlying magma.

No systematic variation in composition of pyroxene and plagioclase in different layers of the layered series has been detected, which suggests that cryptic layering is not present.

The mineral species in the different rock types, as well as the specific relations of one mineral to another, provide further evidence for the origin of the complex. The four major minerals—plagioclase, pyroxene, olivine, and magnetite (plus alteration products)—together generally compose 90 percent or more of the rocks and commonly, 98–100 percent (table 1). The modes shown in table 1 are probably representative, but examples of more extreme composition than these undoubtedly can be found within the complex at Iron Mountain.

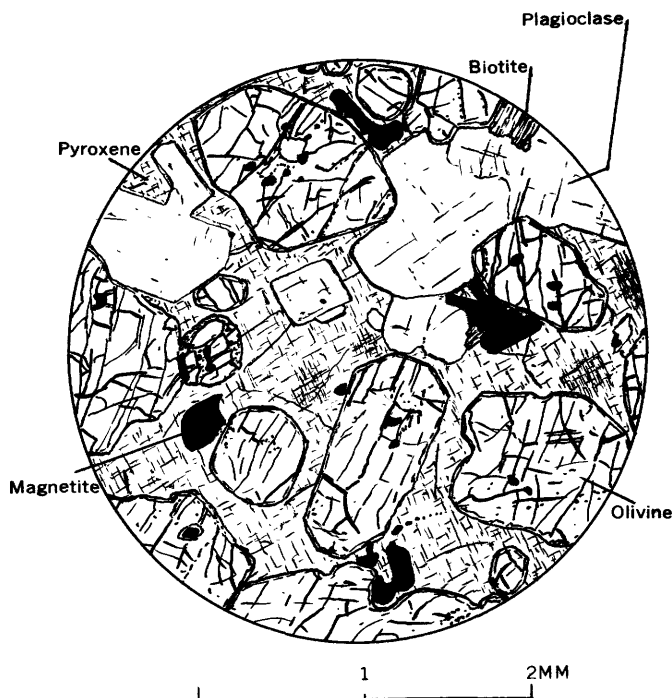


FIGURE 6.—Olivine-rich gabbro of the layered series, sample IM-10-64, north-central part of the complex. Ophitic monoclinic pyroxene encloses olivine, plagioclase (calcic labradorite), biotite, and magnetite.

Plagioclase, which makes up 5 to 90 percent of the unaltered rocks, occurs as tabular crystals mostly 0.2–3 mm long (range 0.1–10 mm) which tend to be euhedral where abundant (fig. 8) and anhedral and interstitial where sparse (fig. 12). Clusters of closely packed crystals show smooth mutual boundaries, which probably resulted from accumulus growth (fig. 9). Plagioclase has common and abundant albite twins and common but less abundant pericline and carlsbad twins. Locally twin lamellae are bent slightly, suggesting some post-crystallization deformation. Composition of the plagioclase in discordant anorthosite intrusions ranges from labradorite to calcic labradorite; plagioclase as calcic as bytownite occurs in the large discordant pyroxenite intrusion. Composition of plagioclase in the pyroxenites of the layered series commonly ranges from calcic labradorite to calcic bytownite, and that in the anorthosites of the layered series ranges from bytownite to calcic bytownite. Plagioclase in gabbro of the layered series (for example, fig. 8) is sodic to calcic labradorite in fine-



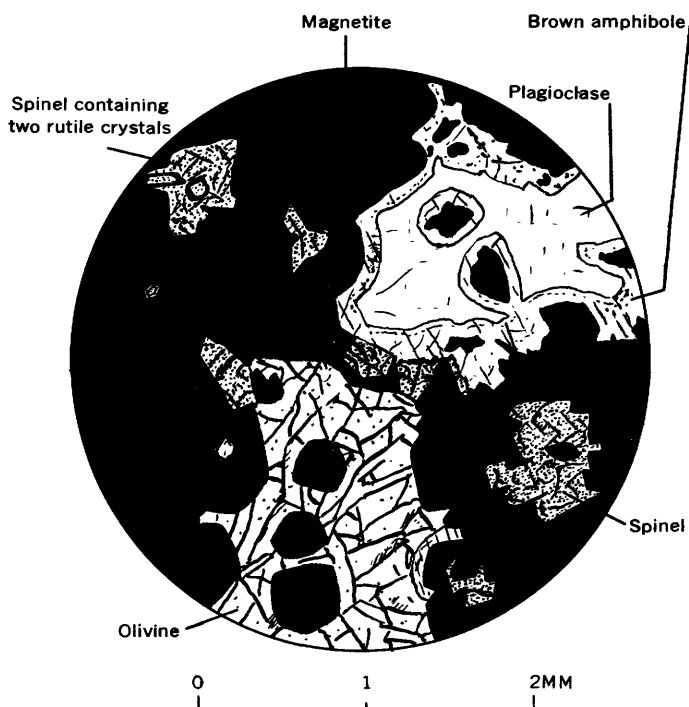


FIGURE 7.—Titaniferous magnetite iron ore of the layered series, sample IM-18-64, Iron Mountain mine area. Euhedral to subhedral magnetite and spinel and interstitial olivine and plagioclase (labradorite). Magnetite and labradorite show typical reaction rim of brown amphibole.

grained, crossbedded varieties and is as calcic as sodic bytownite in coarser grained varieties. Plagioclase in the layered series is virtually unzoned, but that in the discordant intrusions tends to have slight progressive zoning.

Pyroxene, ranging in content from 0 to 85 percent, is present principally as nearly equant grains, 0.2–5 mm in diameter (mostly about 2 mm), and also tends to be euhedral where abundant (figs. 5, 8, 12) and interstitial where sparse. In some rocks pyroxene oikocrysts as much as 10 mm long enclose euhedra of olivine and plagioclase (fig. 6). Pyroxene where abundant also occurs as closely packed crystals with mutual boundaries. The pyroxene is light brownish gray and only slightly pleochroic. It is commonly twinned, mostly by simple twins that bisect the conspicuous prismatic cleavages and are parallel to (100) in rocks of both the layered series and discordant intrusions. Multiple twins also parallel to (100) are numerous in fine-grained

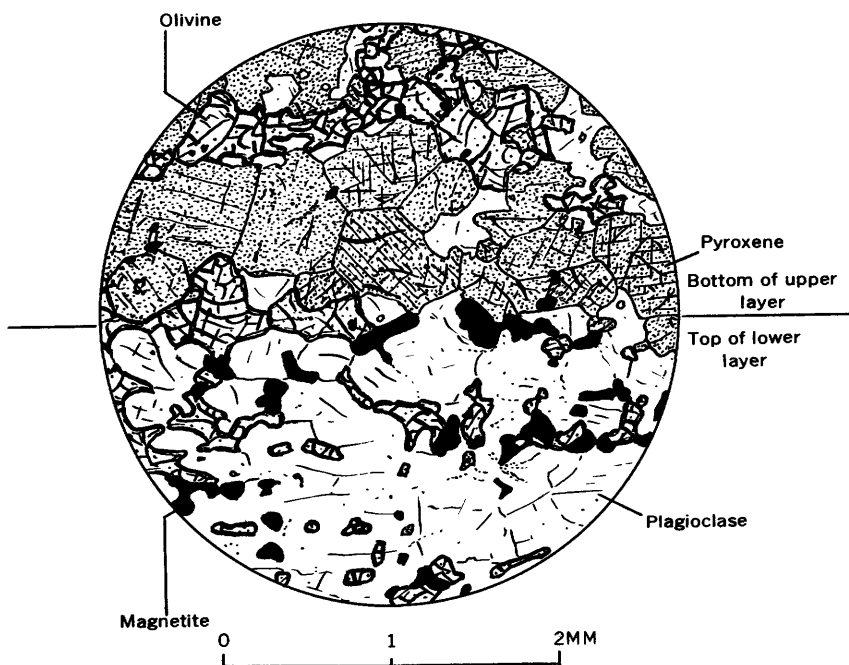


FIGURE 8.—Fine-grained crossbedded gabbro of the layered series, sample IM-8-64, northeastern part of the complex. Closely packed subhedral to euhedral monoclinic pyroxene crystals and interstitial magnetite, olivine, and plagioclase (calcic labradorite) make up the base of a graded layer about 10 mm thick (upper half of field), which changes upward to slightly smaller grains of subhedral labradorite and lesser amounts of even smaller subhedral pyroxene and interstitial magnetite and olivine. Top of the graded layer (top of next lower layer shows in lower half of field) is similar but contains more labradorite and olivine and less pyroxene which tends to be anhedral and interstitial.

pyroxene of the large discordant pyroxenite intrusion. Nearly all of the pyroxene is monoclinic. Maximum extinction angles approach  $45^\circ$ ;  $2V_z$  is moderate, ranging from  $49^\circ$  to  $58^\circ$  with moderate dispersion  $r > v$ ; intermediate indices of refraction range from 1.694 to 1.712. These properties suggest that the clinopyroxenes fall in the region of composition occupied by salite-augite-ferroaugite. Optical data on pyroxenes from the complex are given in table 2. Only in the large discordant pyroxenite intrusion does the pyroxene tend to be slightly to strongly zoned progressively, and none of the clinopyroxenes contain detectable exsolution lamellae.

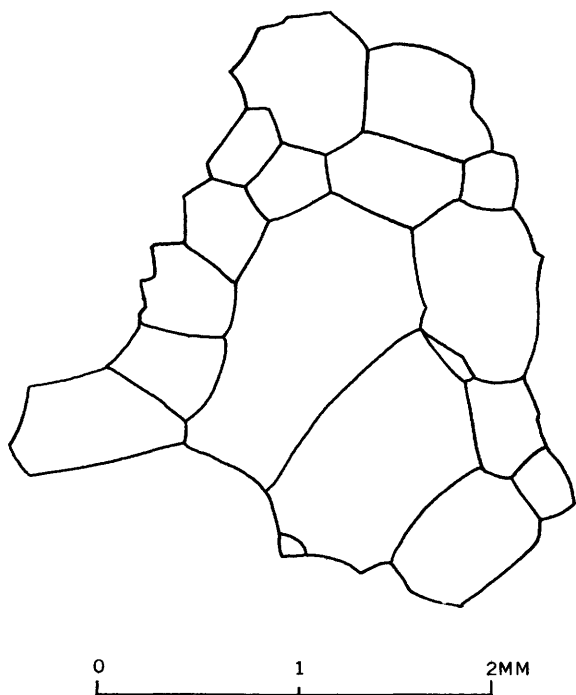


FIGURE 9.—Mutual boundary relations of closely packed plagioclase crystals (sodic bytownite) in gabbro of the layered series, sample IM-6-64, southeastern part of north half of the complex.

Schiller structure is common in monoclinic pyroxene of all the rocks of the layered series and in the discordant intrusions, but it is abundant in only a few rocks, such as anorthosite in the discordant intrusion in the northwestern part of the complex and pyroxenite of the layered series at the northwest tip of the complex. In this latter rock, hourglass structure defined by intense schiller formation is conspicuous (fig. 10). The schiller structure in pyroxene of these rocks is not the result of exsolution lamellae of either monoclinic or orthorhombic pyroxene, but rather it consists of extremely small rods of black opaque mineral, probably magnetite, oriented along crystallographic directions. Schiller structure is conspicuous locally where fine-grained pyroxenite, not clearly related to the large mass outlined on plate 1, intrudes coarse-grained pyroxenite of the large discordant pyroxenite intrusion (two specimens of sample 16, table 1). Here pyroxene having schiller structure forms a prominent selvage in coarse-grained pyroxenite at the contact with the fine-grained pyroxenite and in thin zones bounding large crystals of pyroxene included within the fine-grained

TABLE 1.—*Estimated modes of Iron Mountain*

[Tr, trace; ---,

	Layered complex							
Sample..... Field No. (IM-).....	1 18-64	2 1-64	3 34-64	4 7-64	5 6-64	6 8-64	7 21-64	8 17-64
Major minerals								
Plagioclase.....	15	25	30	50	45	40	Tr	60
Pyroxene.....		2	12	20	30	30	30	30
Olivine.....	7	<sup>2</sup> 30	50	25	20	15	10	-----
Magnetite.....	67	<sup>2</sup> 6	5	3	3	15	5	9
Accessory minerals								
Brown amphibole...	5	2		2	2		15	
Biotite.....	.5		3				7	
Green spinel <sup>1</sup> .....	5	Tr	.0004	.002	.003		.03	
Pyrite <sup>1</sup> .....	Tr	.0006		.003	.002		.03	
Apatite.....					Tr	Tr	3	1
Sphene.....								
Rutile.....	.5							
Secondary minerals								
Serpentine.....		<sup>2</sup> 35	( <sup>3</sup> )	( <sup>3</sup> )	( <sup>3</sup> )		( <sup>3</sup> )	
Aegirine.....								
Blue-green amphibole.....				Tr				
Chlorite.....								
Carbonate.....								
Sericite.....								
Potassium feldspar.....							( <sup>4</sup> ) 30	
Zircon <sup>1</sup> .....								
Zeolite(?).....	Tr							

<sup>1</sup> Insoluble residue, in weight percent, after hydrofluoric acid digestion of rock, as determined by G. J. Neuerburg, according to method of Neuerburg (1961); pyrite may include some chalcopyrite.

<sup>2</sup> Olivine and alteration products—serpentine (35 percent) and magnetite (5 percent)—constitute 70 percent of rock.

Sample	Locality in relation to Iron Mountain	
	Distance in miles	Direction
1. Foliated magnetite rock.....	0.9	S. 25° E.
2. Dunitic rock.....	.6	S. 20° E.
3. Olivine-rich gabbro.....	1.0	N. 75° W.
4. Olivine gabbro, coarse-grained.....	.2	S. 35° W.
5. Olivine gabbro.....	.4	S. 15° W.
6. Olivine gabbro, fine-grained.....	.2	N. 30° W.
7. Olivine gabbro, syenitized.....	.8	N. 40° W.
8. Gabbro, fine-grained.....	1.3	S. 20° E.
9. Troctolite.....	1.5	S. 40° E.
10. Pyroxenite.....	.5	S. 15° E.

mafic and ultramafic rocks, in volume percent  
not detected]

Layered complex—Continued					Border zone	Discordant intrusion				
9 11A-64	10 3-64	11 2-64	12 32-64	13 14-64	14 25-64	15 19-64	16 22-64	17 22-64	18 5-64	19 33-64

Major minerals—Continued

50	7	10	20	70	35	20	10	10	72	70
1	85	85	70	13	55	60	70	48	20	20
20			Tr	6		18	7	7		
8	5	3	5	4		1	2	10	5	1

Accessory minerals—Continued

1	2	1	5	3		1	5	20	Tr	
Tr			Tr	Tr		Tr	2	Tr		1
.001	.002	Tr	Tr	.015		.004	Tr	2	.05	
.00002	.0001	.004	.05	.007		.0008	.08		.07	.0001
Tr	1			1	Tr		Tr	Tr	Tr	Tr
					10					

Secondary minerals—Continued

20			Tr	2		(3)	3	3		3
		Tr		1						
	Tr	1							1	
		Tr	Tr						1	Tr
										5
										.01

<sup>2</sup> Included with olivine.  
<sup>4</sup> Included with potassium feldspar.

Sample	Locality in relation to Iron Mountain	
	Distance in miles	Direction
11. Pyroxenite.....	0.5	S. 15° E.
12. Pyroxenite.....	1.8	N. 65° W.
13. Anorthosite.....	1.4	S. 50° W.
14. Gabbro.....	.8	N. 20° W.
15. Olivine gabbro.....	.9	N. 55° W.
16. Pyroxenite, coarse-grained.....	1.1	N. 45° W.
17. Pyroxenite, fine-grained.....	1.1	N. 45° W.
18. Anorthosite.....	.4	S.
19. Anorthosite, syenitized.....	1.5	N. 65° W.

TABLE 2.—*Optical data for clinopyroxenes from Iron Mountain rocks*

Field No.	$2V_z$	$n_x$	$n_y$	$n_z$	Pyroxene	Rock type
<b>Discordant intrusions</b>						
IM-28-64 <sup>1</sup> ---	49	1. 706	1. 711	1. 726	Ferroaugite-----	Pyroxenite.
28-64 <sup>1</sup> ---	50	1. 705	1. 710	1. 730	-----do-----	Do.
22-64 <sup>1</sup> ---	51	1. 691	1. 695	1. 718	Augite-----	Do.
22-64 <sup>1</sup> ---	55	1. 693	1. 696	1. 718	Salite-----	Do.
31-64-----	54	1. 688	1. 694	1. 715	Salite-augite-----	Anorthosite.
<b>Layered complex</b>						
WM-64-828---	47	1. 698	1. 708	-----	Augite-ferroaugite.	Gabbro.
64-891---	49	1. 698	1. 705	1. 720	Augite-----	Do.
IM-10-64 <sup>1</sup> ---	50	1. 696	1. 703	1. 721	-----do-----	Olivine-rich gabbro.
10-64 <sup>1</sup> ---	50	1. 696	1. 702	1. 722	-----do-----	Do.
WM-64-829---	52	1. 699	1. 709	1. 722	Ferroaugite-----	Gabbro.
64-827---	54	-----	1. 712	-----	-----do-----	Do.
64-827---	58	1. 696	1. 700	1. 717	Salite-----	Do.

<sup>1</sup> Optical data determined by I. J. Witkind, U.S. Geological Survey.

pyroxenite that must have been plucked from the walls of coarse-grained pyroxenite. It appears that a disequilibrium between previously crystallized coarse-grained pyroxene and the melt of the fine-grained intrusion resulted in exsolution of magnetite and formation of schiller.

Clinopyroxenes from the complex at Iron Mountain are plotted on the pyroxene composition diagram, figure 11, on the basis of optic angles and indices of refraction. These clinopyroxenes lie in a zone that extends across the fields of augite and salite and projects into the field of ferroaugite. The zone lies close to the trend line of alkaline olivine basalt clinopyroxenes as determined by Wilkinson (1956, p. 727) from a plot of these minerals. The plot of the Iron Mountain clinopyroxenes, however, shows no apparent relation to either the general trend of tholeiitic clinopyroxenes (Poldevaart and Hess, 1951, p. 479) or the trend of Skaergaard clinopyroxenes (Muir, 1951, p. 701).

Orthorhombic pyroxene has been recognized in only one rock. A fine-grained gabbro of the layered series (sample 8, table 1) contains about 25 percent hypersthene and only 5 percent monoclinic pyroxene. The hypersthene is pleochroic from very pale yellow pink to very pale green, and it has parallel extinction and a large optic angle (—). Locally the hypersthene has very thin exsolution lamellae of monoclinic pyroxene parallel to (100). Some schiller structure is also evident in this hypersthene, but the exsolved dark rods are not as opaque as those observed in monoclinic pyroxene of the Iron Mountain rocks.

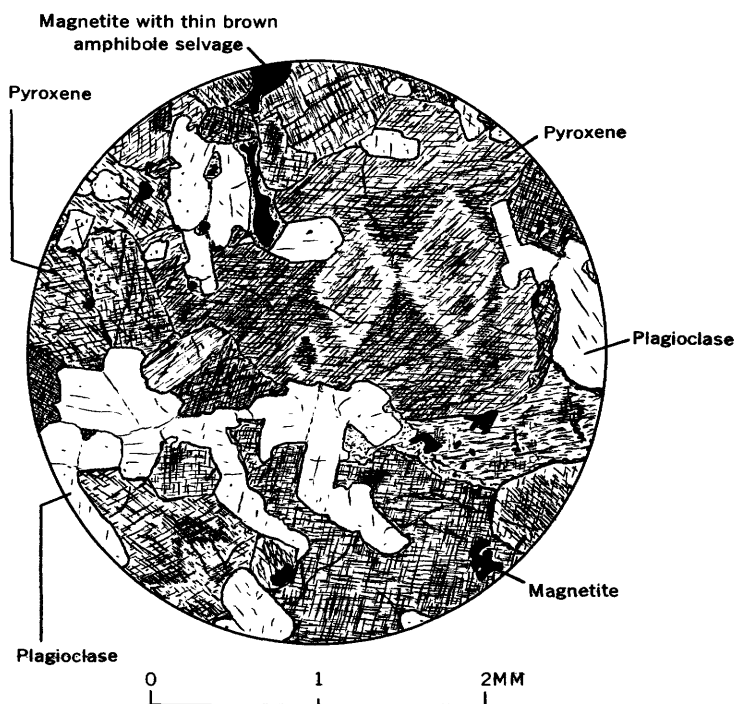


FIGURE 10.—Hourglass structure resulting from schiller in monoclinic pyroxene of pyroxenite of the layered series, sample IM-32-64, northwest tip of the complex. Pyroxene optically encloses euhedral plagioclase (calcic bytownite). Brown amphibole locally rims magnetite blebs.

Olivine, ranging in content from 0 to 70 percent including alteration products, serpentine and magnetite, occurs mostly as subhedral to euhedral crystals where it is abundant (fig. 6) and as anhedral grains and interstitial material where sparse (figs. 7, 8). Crystals commonly are 0.5–3 mm in length and range from 0.1 to 5 mm. In some rocks, crystals about 1 mm long occur in clusters as much as 10 mm in diameter. The olivine is nearly colorless and has a large optic angle (–). It commonly is as much as 50 percent altered to serpentine minerals and magnetite that fill sagenitic webs traversing the host mineral. Plagioclase surrounding altered olivine crystals in rocks of the layered series is commonly strongly cracked and the radiating cracks tend outward to become nearly parallel to layering in the rock. Oriented rectangular exsolution platelets in olivine in coarse-grained olivine gabbro of the large discordant pyroxenite intrusion (sample 15, table 1) give the impression of a coarse schiller structure. The platelets are as much as 0.1 mm long and about 1–5

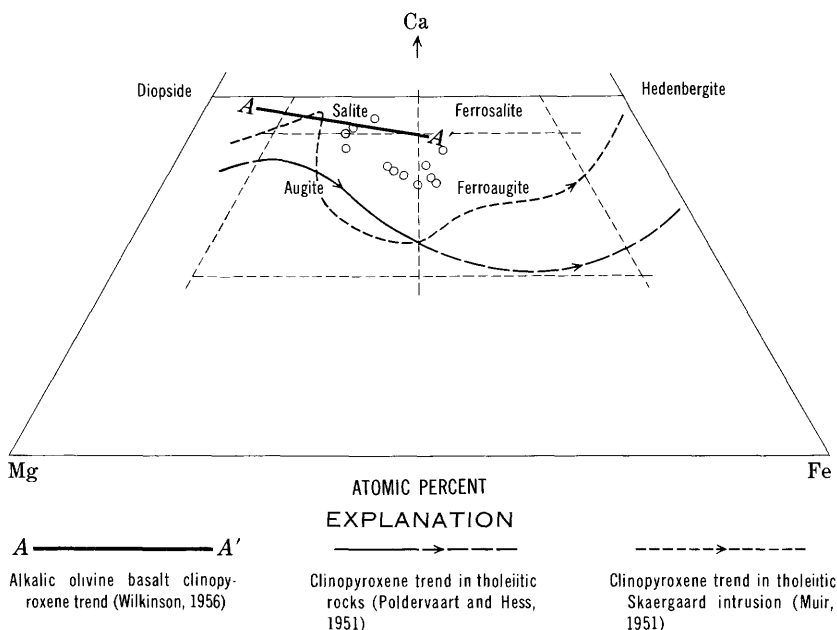


FIGURE 11.—Composition diagram showing field of clinopyroxenes from Iron Mountain and crystallization trends of alkalic and tholeiitic clinopyroxenes. Pyroxenes are plotted on the basis of optical properties on Muir's (1951) revision of Hess' (1949) optical properties curves.

microns thick; they consist of black opaque mineral, magnetite(?) in numerous rodlike dendrites lying in the plane of the platelet. The olivine is chrysolite (magnesium rich), as its index of refraction is near 1.68 and its optic angle  $2V_x$  is about  $84^\circ$ . The composition determined by X-ray diffraction is  $fo_{75}$ , according to the curve of Yoder and Sahama (1957).

Magnetite, ranging in content from 0 to 67 percent and commonly 5–10 percent in the rocks studied here, occurs mostly as equidimensional grains that are anhedral or interstitial where sparse (figs. 5, 6, 8, 10) and as euhedral crystals where abundant (fig. 7). Grain size is chiefly 0.1–0.3 mm but ranges from 0.05 to 2 mm. Where associated with serpentine as an alteration product of olivine, magnetite occurs in tiny blebs and stringers less than 0.05 mm wide. According to Singewald (1913, p. 133), the magnetite contains microscopic intergrowths of ilmenite in the form of a delicate network of dots (or blebs) and closely spaced short lamellae. Some magnetite contains larger intergrowths of lathlike ilmenite about 1–2 mm long. The average composition of the ore (Singewald, 1913) is 47.86 percent Fe, 12.95 percent  $TiO_2$ , and 0.03 percent P.



Accessory minerals constitute 1–5 percent of most rocks, but they are virtually absent in some rocks and are as abundant as 25 percent in others (table 1). Brown amphibole is present in almost all the rocks; its content ranges from a trace to 20 percent and commonly is 1–5 percent. It is widely associated with all the major minerals and locally appears to be a reaction product between pairs of these or between the major minerals and magma; it probably is a late-stage primary mineral. It occurs commonly as a selvage on magnetite (figs. 5, 7, 10), but also rims plagioclase crystals against magnetite (fig. 7), olivine, and pyroxene, and in many rocks fills interstices between these minerals. That it is a reaction product is suggested by the fact that in a sample of iron ore (fig. 7) it occurs universally between magnetite and plagioclase but only rarely elsewhere. It occurs also in patches in monoclinic pyroxene, apparently as a replacement of that mineral, and as euhedra in the cores of some pyroxene crystals, an occurrence which suggests a possible early origin (fig. 12). The brown amphibole is pleochroic—X=light brown, Y=reddish brown, and Z=dark reddish brown (absorption scheme  $Z \geq Y > X$ ); has maximum ex-

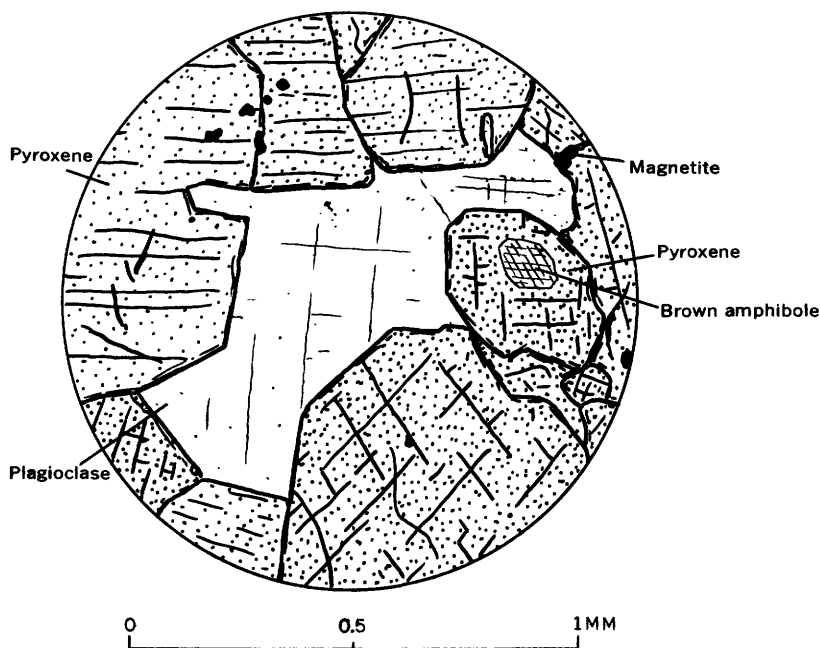


FIGURE 12.—Euhedral brown amphibole core in euhedral monoclinic pyroxene in fine-grained pyroxenite of the discordant pyroxenite intrusion, sample IM-28-64, north end of the complex. Plagioclase (labradorite) is interstitial to euhedral pyroxene.

inction angle about  $15^\circ$ ; and has large optic angle ( $2V_x=78^\circ-80^\circ$  and moderate dispersion  $r>v$ ). Indices of refraction are  $n_x=1.668$ ,  $n_y=1.688$ , and  $n_z=1.700$ . The mineral is classed as kaersutite, a soda-rich brown amphibole.

Biotite, ranging in content from 0 to 7 percent, occurs in magnetite iron ore as an interstitial mineral and in layered gabbro as subhedral to euhedral crystals 0.1–1 mm across. In places it appears to be the last primary mineral to be crystallized and elsewhere seems to be the result of a late-stage reaction with brown amphibole or replacement of it. It is pleochroic from yellowish brown to reddish brown, except that it is brownish green where the rocks have been syenitized along obvious late cracks.

Green spinel, ranging in content from 0 to 5 percent, is present in most of the Iron Mountain rocks, and it is invariably associated with magnetite. It is abundant only in titaniferous magnetite iron ore and fine-grained discordant pyroxenite (samples 1 and 17, table 1). Spinel occurs as anhedral in magnetite, yet in magnetite iron ore where it is abundant it tends to occur as subhedral to euhedral grains (fig. 7). In this rock the fact that magnetite is molded around spinel crystals and spinel is molded against magnetite crystals suggests that the two minerals crystallized almost simultaneously.

Pyrite is present in trace amounts in virtually all the rocks. It was not recognized in thin section, but it was identified by G. J. Neuerburg of the U.S. Geological Survey in the insoluble residues remaining from hydrofluoric acid digestion of the rocks. Some chalcopyrite accompanies the pyrite.

Apatite was recognized in about half the mafic and ultramafic rocks summarized in table 1; it ranges in content from a trace to 3 percent. Apatite occurs as minute prismatic crystals, 0.005–0.1 mm long, chiefly in plagioclase, but locally it forms larger grains and is interstitial between pyroxene and plagioclase. It probably crystallized both early and late. Apatite content exceeds 1 percent only in a syenitized gabbro of the layered series (sample 7, table 1) which contains about 30 percent potassium feldspar and very little remnant plagioclase. In this rock apatite occurs as stubby to needlelike crystals about 0.01 mm wide and as much as 0.5 mm long. The apatite is mostly in feldspar, but locally needles extending from feldspar entirely through mafic minerals suggest a late replacement origin of the apatite.

Sphene was recognized in only a few of the rocks. It occurs as sparse euhedral crystals in some of the discordant pyroxenite and in some of the discordant anorthosite. A sphene content of about 10 percent occurs in one unusual gabbro body within the large discordant pyroxenite intrusion near the contact of the intrusion with gneissic

and amphibolitic country rocks (sample 14, table 1) at the north end of the complex. This sphene occurs as slightly rounded equant grains, about 0.1 mm in diameter and smaller, concentrated in layers in the gabbro. The layers may be flowage layers, or they may be relict layers of included wall rocks that have been assimilated by the gabbro magma. These layers contain no magnetite.

Rutile was recognized only in titaniferous magnetite iron ore (sample 1, table 1). About 0.5 percent rutile as prisms 0.2–0.5 mm long occurs mostly enclosed in spinel grains (fig. 7). Here it is probably an early crystallized mineral.

Secondary minerals constitute 0–35 percent of the mafic and ultramafic rocks at Iron Mountain. With the exception of serpentine altered from olivine, probably most of the secondary minerals have resulted from slight alkali metasomatism or syenitization, related to intrusion of the syenitic rocks on the west side of the mafic-ultramafic complex and of dikes within the complex.

Serpentine is present in amounts ranging from a trace to 35 percent in most of the olivine-bearing rocks. It has replaced as much as 50 percent of the olivine, in which it occurs in sagenitic webs that vein the olivine.

Bright-green aegirine (3 percent) rims monoclinic pyroxene in syenitized anorthosite of the large intrusion in the northwestern part of the complex (sample 19, table 1). Blue-green amphibole (trace to 1 percent) forms small sparse bladed clusters in or bordering pyroxene and olivine in a few rocks of the layered series (samples 4, 11, 13, table 1). Chlorite, as an alteration of mafic minerals, is in only a few of the rocks of the complex; it ranges in content from a trace to 2 percent. Carbonate, ranging in content from a trace to 1 percent, occurs in only a few rocks, and in these mostly in plagioclase. Locally it rims magnetite and in turn is rimmed by sericite in one syenitized intrusion of anorthosite (sample 19, table 1). Sericite occurs as a trace in a few rocks, where it principally replaces plagioclase, and is abundant (5 percent) only in the syenitized intrusive anorthosite and in syenitized gabbro of the layered series (sample 7, table 1). Potassium feldspar was recognized only in the syenitized gabbro of the layered series where it constitutes 30 percent of the rock and where it, along with some sericite, apparently has replaced virtually all the original plagioclase. The feldspar is mottled in appearance, almost perthitic; its index of refraction is about 1.52; and it occurs as mostly untwinned mosaic grains 0.1–2 mm across.

Zircon was identified by G. J. Neuerburg in only one rock, the syenitized intrusive anorthosite (sample 19, table 1), in the insoluble

residue remaining from hydrofluoric acid digestion of the rock. Because of the other evidence for alkali metasomatism of this rock and lack of zircon in any of the other mafic and ultramafic rocks, the mineral is considered to be of epigenetic origin.

A bladed mineral that is probably a zeolite (it has low birefringence and low relief) occurs in trace amounts in plagioclase in the magnetite iron ore of the layered series (sample 1, table 1).

### CHEMISTRY

Chemical analyses of nine samples of mafic and ultramafic rocks from the complex at Iron Mountain are shown in table 3. Rocks of the layered complex contain 40–47 percent  $\text{SiO}_2$ , 3.2–16 percent  $\text{FeO}$ , 1.0–2.6 percent  $\text{Na}_2\text{O}$  plus  $\text{K}_2\text{O}$ , 6.5–25 percent  $\text{MgO}$ , 0.03–0.4 percent  $\text{P}_2\text{O}_5$ , and 0.07–0.3 percent  $\text{MnO}$ . Those of the discordant intrusions contain 44–51 percent  $\text{SiO}_2$ , 1–5 percent  $\text{FeO}$ , 0.6–4.4 percent  $\text{Na}_2\text{O}$  plus  $\text{K}_2\text{O}$ , 1.3–14 percent  $\text{MgO}$ , 0.02–0.06 percent  $\text{P}_2\text{O}_5$ , and 0.03–0.13 percent  $\text{MnO}$ . Both groups of rocks have similar average amounts of  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{TiO}_2$ ,  $\text{Cl}$ , and  $\text{F}$ .

Spectrographic analyses detect a relatively small number of minor elements in the mafic and ultramafic rocks (table 3). Most of these elements are in nearly normal amounts for such rocks, although Ni and Cr are lower than normal and Sr, and in some rocks Ba, are higher than normal.

Norms of the chemically analyzed rocks (table 3) show no quartz in any of the rocks, 1–4 percent nepheline in six rocks and 0.05–2.5 percent hypersthene in the remaining three.

TABLE 3.—*Chemical analyses, norms, modes, and spectrographic analyses of Iron Mountain mafic and ultramafic rocks*  
[Chemical analyses by Ellen Daniels; spectrographic analyses by A. L. Sutton, Jr.; 0, looked for but not found; Tr, trace]

Sample	Layered complex					Discordant intrusions			
	1	2	3	4	5	6	7	8	9
Field No..... Laboratory No.....	IM-10-64 D-101005	WM-64-827 D-100996	IM-20-64 D-101006	WM-62-73 D-100986	WM-64-828 D-100997	WM-64-829 D-100998	WM-64-824 D-100995	IM-28-64 D-101007	IM-31-64 D-101008

Chemical analyses in weight percent									
SiO <sub>2</sub> .....	40.31	42.81	43.28	46.74	46.88	46.99	44.00	46.07	51.05
Al <sub>2</sub> O <sub>3</sub> .....	7.31	17.08	24.82	21.10	11.18	11.47	9.67	8.73	26.94
FeO.....	2.81	5.53	1.54	1.51	3.47	3.09	4.36	4.07	8.80
MgO.....	15.61	7.49	3.22	4.93	5.12	4.73	4.95	3.83	1.08
CaO.....	25.22	6.53	9.41	7.48	10.61	10.68	13.66	11.95	1.29
Na <sub>2</sub> O.....	5.34	13.59	12.44	13.62	19.47	20.02	20.01	21.42	12.47
K <sub>2</sub> O.....	.88	2.18	1.55	2.41	1.07	.94	.47	.94	3.78
H <sub>2</sub> O.....	14	.22	.19	.21	.09	.07	.12	.18	.62
H <sub>2</sub> O+.....	1.22	.62	2.64	.67	.35	.26	.53	.40	.92
TiO <sub>2</sub> .....	.02	.07	.25	.07	.01	.03	.16	.08	.08
P <sub>2</sub> O <sub>5</sub> .....	.54	2.57	.11	.72	.83	1.71	1.57	1.81	.28
MnO.....	.05	.37	.03	.13	.08	.03	.04	.06	.02
CO <sub>2</sub> .....	.29	.15	.07	.13	.13	.13	.13	.11	.03
Cl.....	.38	.78	.39	.33	.02	.03	.56	.37	.48
F.....	.01	.02	.02	.03	.00	.00	.01	.02	.01
	.01	.04	.01	.02	.02	.02	.02	.04	.02
Subtotal.....	100.14	100.05	99.97	100.07	100.33	100.20	100.26	100.08	99.87
Less 0.....	.00	.02	.00	.02	.01	.01	.01	.02	.01
Total.....	100.14	100.03	99.97	100.05	100.32	100.19	100.25	100.06	99.86

Norms in weight percent									
Orthoclase, or.....	0.836	1.308	1.161	1.249	0.532	0.414	0	0	3.706
Albite, ab.....	7.454	18.416	11.539	18.216	4.170	2.674	0	0	32.276
Anorthite, an.....	15.795	36.481	62.306	46.565	25.444	24.064	19.225	19.225	55.375
Leucite, lc.....	0	0	0	0	0	0	.558	.837	0
Nephelite, ne.....	0	0	1.056	1.133	2.648	2.864	2.124	4.246	0
Halite, hl.....	.017	.033	.017	.050	0	0	.017	0	.017
Wollastonite, wo.....	3.413	9.939	.496	7.683	29.397	30.059	26.889	33.899	1.609

TABLE 3.—*Chemical analyses, norms, modes, and spectrographic analyses of Iron Mountain mafic and ultramafic rocks—Continued*

Sample	Layered complex					Disordant intrusions			
	1	2	3	4	5	6	7	8	9
Field No.	IM-10-64	WM-64-827	IM-20-64	WM-62-73	WM-64-828	WM-64-829	WM-64-824	IM-28-64	IM-31-64
Laboratory No.	D-101005	D-100996	D-101006	D-100986	D-100997	D-100998	D-100995	D-101007	D-101008
Norms in weight percent—Continued									
Enstatite, en	3.852	6.945	0.373	5.196	22.928	23.553	21.715	28.479	3.057
Ferroferrite, fs	1.594	2.229	.073	1.897	3.258	3.148	2.002	.848	.871
Ferrosilite, fo	41.805	6.603	16.724	0.501	2.456	2.130	8.726	.982	.135
Fayalite, fa	19.065	2.336	3.609	3.824	0.385	0.313	.887	.032	.042
Calcium orthosilicate, cs	0	0	0	0	0	0	2.255	1.158	0
Magnetite, mt	4.120	8.070	2.309	2.204	5.033	4.484	6.349	5.925	1.173
Ilmenite, il	1.037	4.912	.216	1.377	3.477	3.251	2.995	3.451	.538
Apatite, ap	1.120	.882	.073	.310	.190	.071	.085	.143	.048
Fluorite, fr	.016	.049	0	.029	.034	.038	.038	.077	.040
Calcite, cc	.874	1.755	.047	.756	.045	.068	1.279	.845	1.104
Total	99.999	99.990	100.000	99.989	99.995	99.994	99.992	99.982	99.990
Salic.	24.103	56.239	76.080	67.212	32.794	32.847	26.763	24.341	91.373
Femic.	75.896	43.751	23.921	32.777	67.202	67.147	73.229	75.640	8.617
Dioptside, di	6.585	19.059	.942	14.776	55.553	56.791	50.608	63.027	3.078
di-wo	3.413	9.939	.496	7.683	29.397	30.059	26.889	33.699	1.609
di-en	2.243	6.904	.373	5.196	22.928	23.553	21.715	28.479	1.143
di-fs	.928	2.216	.073	1.897	3.258	3.148	2.002	.848	.326
Hypersthene, hy	2.275	.054	0	0	0	0	0	0	2.459
hy-en	1.609	.041	0	0	0	0	0	0	1.914
hy-fs	.666	.013	0	0	0	0	0	0	.545
Olivine, ol	60.870	8.939	20.333	13.325	2.841	2.443	9.613	1.015	.178
ol-fo	41.805	6.603	16.724	9.501	2.456	2.130	8.726	.982	.135
ol-fa	19.065	2.336	3.609	3.824	.385	.313	.887	.032	.042
Modes in volume percent									
Plagioclase	25	52	69	66	25	17	4	4	88
Pyroxene	15	30	5	17	71	80	84	88	12
Olivine	56	4	20	14	0	0	6	0	0
Magnetite	2	7	2	2	2	2	2	1	<1
Brown amphibole	1	6	<1	1	2	<1	Tr	5	Tr
Biotite	1	<1	<1	1	2	Tr	2	1	Tr
Green spinel	.0002								
Pyrite	.0001		<.0001			Tr	2	.0003	



## CONCLUSIONS

The layered nature, general structure, and composition of the complex at Iron Mountain indicate that it was formed principally through processes of fractional crystallization and crystal settling in mafic magma. Repeated layers, a few to several tens of feet thick, of gabbro, dunite, pyroxenite, and anorthosite attest to the cyclic recurrence of crystal settling. Details of rhythmic layering and of such features as graded bedding, scour-and-fill structure, and crossbedding, shown by the minerals of different densities that make up the layers, clearly document the crystal settling and accumulation processes and suggest perhaps the action of convection currents in the magma.

The discordant intrusive bodies of pyroxenite and anorthosite show that after the layered series magma was intruded, differentiated in place, and consolidated, additional surges of magma rose from below and intruded the consolidated layered series. These magmas were differentiating in a deeper level at the time the layered series was fractionating, and the large pyroxenite intrusion came in probably when the layered rocks were still hot and plastic. The common interfingering of the pyroxenite and layers of the stratified complex, and the local upbowing of stratified layers around small bosses of pyroxenite, indicate this. On the other hand, the layered rocks were probably quite frozen by the time anorthositic magma was intruded, as the anorthosite bodies appear to have punched their way upward with little disturbance of the surrounding layered rocks. Zoning of plagioclase and monoclinic pyroxene in rocks of the discordant intrusions shows that crystallization of these magmas had commenced prior to intrusion up to the level of the stratified mafic and ultramafic rocks.

The complex at Iron Mountain is similar in many of its features to several previously described mafic layered complexes such as the Skaergaard Complex, Greenland (Wager and Deer, 1939), the Stillwater Complex, Montana (Hess, 1960; Jackson, 1961), and the Duluth Gabbro Complex (Taylor, 1964), but in some respects it differs markedly from them. With respect to details of layering and crystal-settling textures and structures, the complex at Iron Mountain is similar to these previously well-studied complexes. Also the intrusion of younger but probably related gabbro into the rocks of the layered series of the Duluth Gabbro Complex is similar to the occurrence at Iron Mountain.

The complex at Iron Mountain differs from the Skaergaard, Stillwater, and Duluth Gabbro Complexes principally in its chemical and mineralogic composition. The latter complexes are tholeiitic, trending toward silica-saturated and oversaturated differentiates, whereas the complex at Iron Mountain is alkalic, consisting of undersaturated



rocks. The alkalic and undersaturated nature of the Iron Mountain rocks is supported by the chemical analyses and norms. Six of the nine chemically analyzed rocks show normative nepheline, and the other three rocks are barely saturated as shown by the lack of nepheline and the minor amount of normative hypersthene. The alkalic nature of these rocks is shown by the virtual absence of orthopyroxene and by the abundance of clinopyroxene of salite-augite-ferroaugite composition and magnesium-rich olivine. The clinopyroxenes do not contain exsolution lamellae so common in the pyroxenes of the tholeiitic rocks. These mineral assemblages and features of the Iron Mountain rocks are similar to those described by Wilkinson (1956) as typical of undersaturated mafic alkalic rocks. The presence of kaersutite, a soda-rich amphibole, as a late-stage primary mineral in nearly all rocks of the complex at Iron Mountain also indicates the alkalic affinity of the magma.

In view of the fact that the complex at Iron Mountain is structurally integral with the larger McClure Mountain Complex of syenites, nepheline syenites, and other alkalic rocks and in addition consists of undersaturated mafic and ultramafic rocks of alkalic affinities, it is reasonable to conclude that the Iron Mountain and McClure Mountain rocks are part of a comagmatic series.

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