# Magnetite Deposits of the Sterling Lake, N. Y.-Ringwood, N. J. Area

*By* PRESTON E. HOTZ

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1952

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# CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1952

## MAGNETITE DEPOSITS OF THE STERLING LAKE, N. Y.-RINGWOOD, N. J., AREA

By Preston E. Hotz


### ABSTRACT

The Sterling Lake and Ringwood area occupies about 45 sq miles in southeastern New York and northern New Jersey. Thirty-five magnetite mines and prospects are known and have been of considerable importance. Total production of iron ore from the two districts has been about 4,600,000 tons.

The area lies in rugged hills at the southern end of the New England physiographic province. The rocks of the area are chiefly pre-Cambrian gneisses with some interlayered marble. A few lamprophyric and diabasic dikes, which are considered to be of post-Ordovician age, possibly Triassic, intrude the older rocks. The pre-Cambrian rocks are similar to those described as Pochuck, Losee, and Byram gneiss in the New Jersey folios. For this report, however, they are subdivided and mapped in more detail than in the folios, and the formational names employed by earlier workers have been discarded in favor of a more descriptive terminology. The units mapped include: A group of metasedimentary rocks that correspond in part to the Pochuck gneiss of the New Jersey reports; quartz-oligoclase gneiss, equivalent, at least in part, to the Losee gneiss of the folios; hornblende granite and related facies which have been called Byram gneiss in New Jersey; granite pegmatite probably related to the hornblende granite. The metasedimentary rocks, which were originally largely calcareous but contained some quartzose sediments, have been subclassified as amphibolite and pyroxene amphibolite, skarn, garnetiferous quartz-biotite gneiss, and quartzite. Some thin discontinuous lenses of marble are present but could not be shown on the map.

Quartz-oligoclase gneiss is a granitoid rock of rather heterogeneous composition. It is characterized in many places by an abundance of dark inclusions and schlieren of pyroxene amphibolite and amphibolite. Granite ranges in composition from hornblende granite to alaskite. It is more uniform than the quartz-oligoclase gneiss, and inclusions are rare. Granite pegmatite related to the hornblende granite occurs as thin sheets, lenses, and irregular masses and is most plentiful in the vicinity of magnetite deposits. Thin pegmatite seams and veinlets from less than an inch to a foot or so wide also occur, especially in the metasedimentary gneisses.

Over most of the area the granitic rocks are conformable with the metasedimentary rocks; locally, however, they show crosscutting relationships. The relationship between hornblende granite and quartz-oligoclase gneiss is not clearly established, but the granite probably is younger and is intrusive into the quartz-oligoclase gneiss. The quartz-oligoclase gneiss is considered to have crystallized from material which was emplaced as a magma and which may have originated

at depth by partial melting of metasedimentary rocks. Modification by incorporation and reconstitution of amphibolite and pyroxene amphibolite was negligible, but locally there was some replacement of the country rock. The hornblende granite, alaskite, and related pegmatites are believed to have been formed by crystallization from a granitic magma.

Most of the rocks have visible planar and linear structures. The prevailing strike of the foliation is also the trend of the lithologic units. In general the foliation strikes northeast and dips at moderate to steep angles east and southeast, but in detail the foliation attitudes and distribution of the rock units reveal a pattern of folds. The trend of the lineation is constant, and, with rare exceptions, it plunges northeast at low to moderate angles. The gneissic structure in the metasedimentary rocks is largely secondary though some of the layering may reflect original compositional differences. Foliation and lineation in the granitic gneisses are considered to be mostly primary where there is no evidence of recrystallization, though locally they are certainly of secondary origin where the rock textures are crystalloblastic. The concordance of foliation and lineation in the granitic rocks with the gneissic structures of the metasedimentary rocks may be partly due to inheritance of earlier structures through replacement, and partly due to frictional drag in the magma. However, it seems more likely that tectonic forces were still operative at the time of magmatic emplacement and ceased shortly afterward, before complete crystallization.

Joints and faults affect the igneous and metasedimentary rocks alike. Most of the faults are transverse or oblique and have measurable apparent horizontal displacements of 800 to more than 1,100 ft. All the faulting followed the folding of the metasedimentary rocks and the consolidation of the granitic gneisses. In the mines the faulting is later than the deposition of magnetite.

Magnetite deposits were discovered in this area before the Revolutionary War. Deposits at Ringwood were known sometime before 1740; ore was discovered at the Sterling mine in 1750. The mines played an important role in the early history of the country and, with the other mines in New Jersey and New York, continued to be an important source of ore until late in the 19th century. The Cannon and Peters mines at Ringwood, N. J., were in operation until the 1930's. During World War II the Ringwood property was acquired by the U. S. Government and the Peters and Cannon mines were reconditioned and a modern concentrating plant was constructed, but no ore was produced during this period. The property was subsequently leased to private interests who produced a small amount of concentrates. In 1950 the Ringwood mines were still owned by the Government but were inoperative. The total production for the Ringwood district to 1931 was about 2,671,000 tons. In the Sterling Lake district of New York, the Sterling and Lake mines were the principal producers, and the Scott-Cook mine was the next largest, though considerably smaller in size and production. The Sterling and Lake ore bodies were more or less continuously mined from about 1750 to 1921. Operations at the Scott-Cook mine also ceased about 1921. None of the mines in the Sterling Lake district was in operation in 1950. Production data from this district are not complete, but total production has been about 1,900,000 tons.

Magnetite deposits in the area are of two general types; those in pyroxene amphibolite and less commonly in amphibolite, and those in skarn. The largest and most important deposits are in pyroxene amphibolite; those in skarn are less abundant and are likely to be small and discontinuous. The ore bodies occur in shoots in general zones of mineralization. Some of the shoots, exemplified by those at Ringwood, are elliptical or lenslike in cross section and have great continuity down the plunge. They may be described as pencillike. Horizontal dimensions range from a few tens of feet to more than 100 ft; mined distances down the plunge are as great as 2,000 ft. Several of these pencillike shoots commonly are grouped together in a general zone and are fairly discrete bodies separated from one another by barren or slightly mineralized rock. Many of the other ore shoots, particularly those in the Sterling Lake district, are more or less elongate tabular bodies which constitute a thicker part of a general zone of mineralization that may continue for several hundred feet along the strike. These shoots also plunge downward but are not so continuous as the pencillike shoots. They range from 10 to 20 ft in thickness, are as much as 100 or so ft in length, and may extend in depth for several hundred feet. The attitude of the shoots conforms to the structure in the adjacent gneisses. The shoot structure is interpreted as being inherited from earlier structures in the gneiss. There is little or no evidence that the magnetite bodies have been deformed. Pegmatite is generally closely associated with the ore, and antedates the introduction of magnetite. The deposits were formed by metasomatic replacement of preexisting rocks by iron-bearing solutions or vapors derived from a magmatic source, possibly represented by the hornblende granite.

Most of the iron-bearing material is crystalline magnetite, though in some places small amounts of hematite are intimately associated with it. The grade ranges from about 35 percent to as much as 68 percent Fe. Most of the mines have furnished ore ranging between 40 and 60 percent Fe. The principal gangue minerals are unreplaced silicates from the rock in which the magnetite occurs. Most of the ore ranks as a nonbessemer type because of its phosphorus content, but because the phosphorus is contained in the mineral apatite, the ore is amenable to reduction by milling. The titanium content, which is probably mostly in the form of exsolved ilmenite in the magnetite, is generally low. The sulfur content, which is consistently low, is contributed by small amounts of pyrite, pyrrhotite, chalcopyrite, and molybdenite.

The concluding section of this report is devoted to a description of the individual deposits. Although many of the ore bodies are small or have been essentially worked out, the Sterling Lake and Ringwood area still contains some important reserves.

## INTRODUCTION

### LOCATION AND ACCESSIBILITY

The area described in this report is near Sterling Lake and Ringwood in Orange and Rockland Counties, southeastern New York, and Passaic County, northeastern New Jersey (fig. 32). The principal magnetite deposits lie at the southern end and east of Sterling Lake, N. Y., and at Ringwood, N. J., a village about 2 miles south of the New York-New Jersey State boundary. In general, those deposits in the Sterling Lake district belong to a structural unit, those in the Ringwood district have many features in common, and those having no especial relationship to one another or to either the Sterling Lake or Ringwood groups comprise a third group called other deposits.

The area is sparsely settled but is readily accessible by road. Ringwood can be reached by road the year round either from the south by way of Wanaque, N. J., on State Highway 210 which joins State Highway 23 near Bloomingdale, N. J., or by a paved road that joins

State Highway 17 at Sloatsburg, N. Y., about 4 miles northeast of Ringwood. The Sterling Lake district can be reached only by poor to improved dirt roads that connect with State Highway 17. One route, passable except in time of heavy snowfall, leaves Highway 17 about 2.2 miles north of Tuxedo, N. Y., and runs south and southwest about 4½ miles to the south end of Sterling Lake; the other, a poor dirt road generally impassable when there is much snow, joins the paved road to Ringwood from Sloatsburg at a point about 1.3 miles west of Sloatsburg and runs east and north to Sterling Lake, connecting with the road coming from the north. The nearest large city is Paterson, N. J., 13 miles to the southeast; New York city is 30 miles southeast. Two standard gage railroad spurs serve the area. One

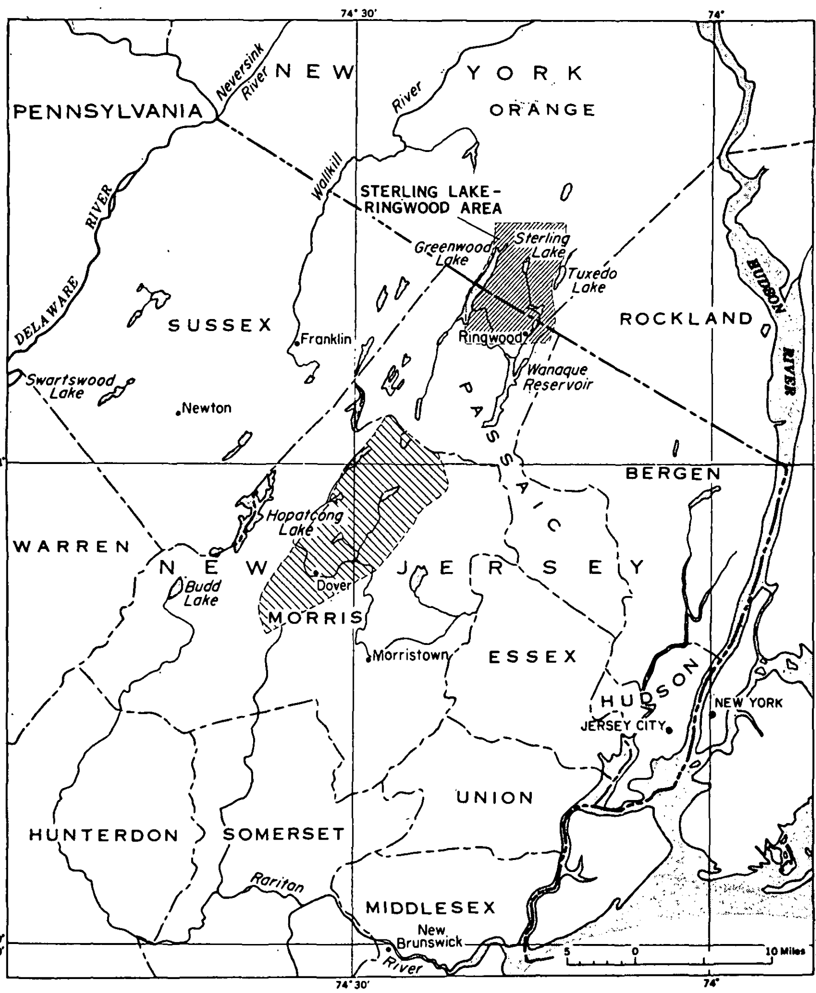


FIGURE 32.—Index map showing location of the Sterling Lake and Ringwood magnetite districts, New York and New Jersey.

spur running to the old Lake mine at Sterling Lake connects with the main line of the Erie Railroad at Sterlington, about half a mile south of Sloatsburg, N. Y. This track is unused and in need of repair. Another track, also a branch of the Erie Railroad, runs to the Ringwood mines from Wanaque, N. J.

## FIELD WORK

Several earlier workers have described the larger deposits and mines, but no detailed regional study of the pre-Cambrian rocks in which these deposits occur has been previously undertaken. During 1943 and 1944 the U. S. Bureau of Mines in cooperation with the U. S. Geological Survey explored the Redback magnetite deposits in the Sterling Lake district. B. F. Leonard of the Geological Survey logged and studied the drill core and made some reconnaissance field studies. In 1944 the U. S. Geological Survey undertook a detailed geologic study of the Sterling Lake and Ringwood area and the magnetite deposits as part of its wartime investigation of mineral reserves. The surface geology of an area of about 45 sq mi was mapped on a scale of 2 in. equals 1 mile and included parts of the Greenwood Lake, Ramapo, and Ramsey quadrangles. In a few places where greater detail was desired, aerial photographs having a scale of about 2,000 ft to the inch were used. Accessible parts of the underground workings of the Cannon and Peters mines at Ringwood and the Scott mine at Sterling Lake were studied and mapped. No detailed magnetic work was done by the Geological Survey though a dip needle was used to determine the position of ore zones and to test for possible occurrences of ore. A dip-needle map of the Scott-Cook ore zone was prepared by the Bureau of Mines. Some dip-needle maps were made available by the Sterling Iron and Railway Company. These maps show all the important deposits in the Sterling Lake district.

The work was conducted under the supervision of A. F. Buddington. H. E. Hawkes assisted in all of the underground work and some of the surface mapping. R. E. Comer of the Jones and Laughlin Ore Company and H. R. Beckwith of Alan Wood Steel Company extended many courtesies. Prof. S. J. Shand of Columbia University lent thin sections and polished specimens of ore collected by R. J. Colony in southeastern New York.

## PREVIOUS WORK

Much of the historical data included in this part of the report is taken from R. J. Colony's (Colony, 1923, pp. 7–30) excellent historical review of geologic studies in southeastern New York and northern New Jersey.

The gneisses of the Highlands—the area in northern New Jersey and southeastern New York is commonly spoken of as the Highlands—have been studied for many years because of their scientific interest as well as the economic importance of the magnetite deposits. One of the earliest accounts was given by W. W. Mather (1839) in which the character and distribution of the "primitive" rocks in Orange County and a list of the various iron mines were given. The first detailed description of Highland geology in New Jersey appeared in a report by H. D. Rogers (1840, pp. 12–14) who described the gneisses as folded and metamorphosed sediments, and speculating on the origin of the magnetites, he conceived them to be of igneous origin. Seventeen years later, however, William Kitchell (1857) concluded that the magnetite ores were metamorphosed sediments, contemporaneous in origin with the rocks in which they occur. This view of the origin of the rocks and their magnetite deposits was retained for many years. Detailed work by Wolff (1893, pp. 368–369) and Nason (1895) in New Jersey seemed to add supporting evidence to the theory of the sedimentary origin of the iron ore. In 1904, however, a very careful study of the gneisses in New Jersey convinced A. C. Spencer (1905 pp. 247–253) of their igneous origin.

Spencer was supported by W. S. Bayley who, in his description of the pre-Cambrian geology of the Passaic quadrangle (Bayley, Darton, and others, 1908), postulated an igneous origin for Spencer's Losee and Byram gneisses but remained doubtful of the manner of origin of the magnetite ores. Then, in a report issued in 1910, Bayley (1910) described in detail all the known iron ore bodies in New Jersey, as well as the general geology of the rocks in which they occur. In the section on the origin of the magnetite deposits he states that "* * * in all cases the ores are regarded as being of magmatic origin * * * related to deep seated magmas portions of which intruded the overlying rocks and * * * solidified as the various gneisses now constituting the principal rocks of the Highlands * * *."

Meanwhile C. P. Berkey had been making intensive studies of the pre-Cambrian rocks in southeastern New York and was able to discriminate and recognize several units to which he attributed an igneous origin (Berkey, 1907; 1911; 1921). One of the most important steps in untangling the complexities of Highlands geology was the recognition of a sedimentary series that had been intensely folded and metamorphosed before the invasion of the igneous bodies. C. N. Fenner (1914) attached much importance to the control exerted by the structures in the pre-Cambrian sedimentary rocks on the mode of intrusion of the igneous magma. W. S. Bayley (*in* Bayley, Salisbury and Kümmel, 1914, p. 5) in the Raritan folio suggested for the first time that though some of the gneisses are undoubtedly of igneous origin "* * * large amounts of preexisting rock material may have been * * * dissolved and assimilated by the invading magmas."

The latest investigation of the magnetite deposits and their enclosing gneisses was that by R. J. Colony (1923), who made valuable contributions to the knowledge of the structure of the ore deposits as well as suggestions about their origin.

## GEOGRAPHY

The Sterling Lake and Ringwood area lies at the southeastern end of the New England physiographic province, a subdivision of the Appalachian Highlands division. The region is characterized by a pronounced northeast-southwest trend of ridges and valleys. Altitudes range from about 300 ft in the south near Ringwood to a little more than 1,300 ft north of Sterling Lake. In general the topographic relief is moderate.

Those parts of the terrain occupied by well-foliated gneisses consist of relatively narrow parallel ridges, but where the bedrock is more massive or less well-foliated, rounded or broad-topped uplands predominate. The layers of granitoid gneiss and pegmatite stand as sharp ridges separated by a narrow trough underlain by less-resistant gneisses. In places the topography reflects folded structures in the rocks. In general, physiographic expressions of folds are much more apparent on aerial photographs than on the topographic maps. A subordinate trend, readily apparent on the aerial photographs and to some extent on the topographic map, is the fairly well defined trenchlike features striking nearly east-west across the predominant northeast-southwest ridges and valleys. In places the trenchlike features interrupt minor drainage lines, and small valleys and ridges are offset along them. These trenches are physiographic expressions of major cross faults.

The region is about 25 miles north of the Wisconsin terminal moraine of the continental ice sheet (Salisbury, 1902, pp. 231–260); hence, the topography has been modified by glaciation. Over most of the region, the ice movement apparently has accentuated the ridge and valley topography. The ridges have been scraped clean so that they have abundant bedrock outcrops, whereas in the valleys outcrops are scarce except for occasional roche moutonnées. Much of the southern part of the district is covered with glacial debris, and south of Ringwood kames are conspicuous topographic features. Several of the natural lakes and ponds, which add to the beauty of the region, are impounded by moraines.

Drainage lines closely follow the principal physiographic trends, most of them being alined in a northeast-southwest direction. A few streams run more or less across the regional structure, their location being controlled possibly by zones of weakness along faults or closely spaced joints. Swamps have been formed where the smaller streams were dammed by beavers.

The whole area is heavily wooded, deciduous trees and shrubs predominating over scattered evergreens.

## GEOLOGY

### GENERAL STATEMENT

The rocks underlying the Sterling Lake and Ringwood area are chiefly pre-Cambrian gneisses with some interlayered marble (pl. 19). A few lamprophyric and diabasic dikes, which are considered of post-Ordovician age or possibly Triassic, intrude the older rocks. Quaternary glacial and stream deposits represent the latest episode in the geologic history of the area.

The pre-Cambrian gneisses are similar to those described as the Pochuck, Losee, and Byram gneiss in the Franklin Furnace (Spencer, 1908, pp. 4–6), Raritan (Bayley, Salisbury, and Kümmel, 1914, pp. 7–9), and Passaic (Bayley, Darton, and others, 1908, pp. 3–6) folios, New Jersey. Four general groups of rocks were recognized and mapped in the Ringwood and Sterling Lake area. They are: a group of metasedimentary rocks, which in part correspond to the Pochuck gneiss of the New Jersey reports; quartz-oligoclase gneiss, in part at least equivalent to the Losee gneiss of the folios; hornblende granite and related facies which have been called Byram gneiss in New Jersey; and granite pegmatite probably related to the hornblende granite.

The first group has been divided by the writer into pyroxene amphibolite and amphibolite, skarn, garnetiferous quartz-biotite gneiss, and quartzite.

The quartz-oligoclase gneiss as mapped is a unit of wide variation and includes granitoid rocks with a few schlieren of amphibolite or pyroxene amphibolite, and intermediate varieties between these rocks and migmatitic facies in which but 50 percent of the rock is granitic quartz-oligoclase gneiss. Hence there is a problem of identification, and some of the rocks might well be classified and mapped with the metasedimentary rocks.

All the gneisses are involved in a complex pattern of folds. At most places the relations between the quartz-oligoclase gneiss and the horneblende granite are obscure, but the hornblende granite probably is the younger, and certainly both are younger than the metasedimentary rocks.

Most of the gneisses have visible planar and linear structures. The planar structure, or foliation, is expressed by the parallel orientation of platy minerals and layers of different color and mineral composition, whereas lineation is shown by the parallelism of prismatic or rodlike minerals.

The magnetite deposits are interpreted as replacements of bodies of pyroxene amphibolite and skarn, apparently formed after, though possibly essentially contemporaneous with, the emplacement of the granite and related pegmatite.

## METASEDIMENTARY ROCKS

Metasedimentary rocks are the oldest in the district. The writer believes that they were originally sedimentary rocks which were so metamorphosed that most of them now bear no resemblance to the parent material. This view is substantiated by their mode of occurrence, composition, and resemblance to similar rocks whose original sedimentary character has been demonstrated in other regions.

### METAMORPHOSED CALCAREOUS ROCKS

#### OCCURRENCE AND DISTRIBUTION

Lenticular beds of marble are interlayered with the pyroxene amphibolite and are commonly associated with skarn. In only very few places is marble exposed, but the presence of a layer of marble may be indicated by a series of alined small depressions or sink holes. Unexposed beds of marble are indicated in some places by characteristic silication products that may be present as resistant selvages along the unexposed, leached marble contacts. Diligent search where sink holes and ledges of calcareous pyroxene amphibolite are found may lead to the discovery of small exposures of marble. Diamond drilling at the Scott mine and along the Redback mineralized zone indicates that the average thickness of the marble remnants is probably between 10 and 20 ft.

Skarn is an old Swedish mining term for aggregates of dark silicate minerals rich in iron, magnesia, and lime (Holmes, 1928, p. 211). In the Sterling Lake and Ringwood area the term has been applied to the dark, medium- to coarse-grained granular rocks whose principal mineral constituent is pyroxene and which may contain hornblende or garnet. Skarn occurs as lenticular bodies few of which are more than about 100 ft wide, and which are several hundred feet to more than 1,000 ft long. Thin but continuous bodies of skarn interlayered with amphibolite crop out northeast of Sterling Lake and in the Spruce Swamp area northeast of old Sterling Furnace. At the north end of Sterling Lake and on the New York-New Jersey border a mile east-northeast of the Peters mine at Ringwood, layers of skarn are enclosed in granitic gneiss. A narrow but continuous belt of skarn is interlayered with marble and dark gneiss for more than a mile northward from Spruce Swamp along the Redback mineralized zone. Some light-green pyroxene skarn was cut in a few of the drill holes east of the Scott mine.

Pyroxene amphibolite and amphibolite are widely distributed throughout the area. The former is by far the more abundant. These two rock types were mapped together and are shown as a single unit on the geologic map. Several layers such as those west and east of Sterling Lake can be traced for considerable distances. Elsewhere, as for example in the southern part of the area, they are less continuous and appear as large inclusions in the quartz-oligoclase gneiss and hornblende granite. On a smaller scale, schlieren and layers of pyroxene amphibolite and amphibolite from a few inches to a score of feet thick occur in the quartz-oligoclase gneiss, and less commonly in the hornblende granite.

### MARBLE

The marble is light gray to white, fine- to medium-grained, and commonly distinctly granular. Thin sections show a more or less definite orientation of calcite granules in some specimens. Most specimens are speckled with disseminated silicate minerals. Diopsidic pyroxene, andraditic garnet, sphene, and magnetite occur in small to moderate amounts. Rounded bodies of clear quartz, some plagioclase, and, in places, scapolite and small amounts of apatite were observed in some specimens. Figure 33 is a photomicrograph of a thin section of marble containing garnet and pyroxene.

A thin marble layer within magnetite-bearing skarn in the Redback magnetite zone contains many small greenish metacrysts of serpentine. A very few remnants of an original mineral that looks like olivine were identified as chondrodite by the weak pleochroism that some of the grains show under the microscope (fig. 34).

### SKARN

Two principal kinds of pyroxene skarn have been recognized in the region. One is dark green to almost black in hand specimens; the other type is pale green to greenish gray. A rarer type contains significant amounts of hornblende in addition to dark pyroxene, and a still more rare variety of dark, garnetiferous pyroxene skarn has been recognized. Most of the narrow skarn layers north and northeast of Sterling Lake are dark skarn; the large body east of Sterling Lake is the light variety.

Typical dark pyroxene skarn is medium- to coarse-grained, granular, and massive. The stubby crystals of pyroxene are recognized easily and minor amounts of hornblende or biotite are common. In thin section a typical specimen consists of about 90 percent light-green to greenish-gray or colorless, faintly pleochroic pyroxene crystals

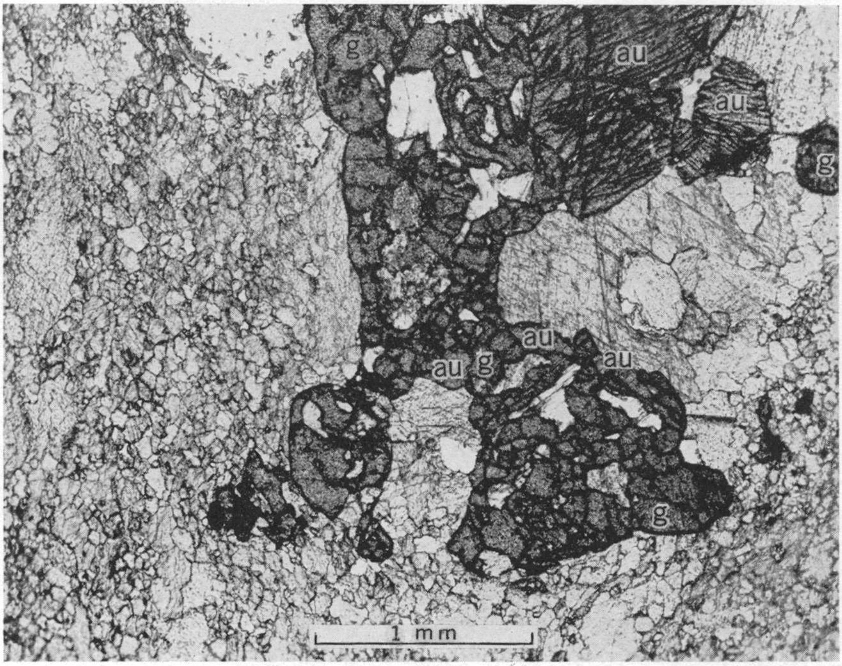


FIGURE 33.—Photomicrograph of thin section of silicated marble containing garnet and augite. Garnet (g), augite (au), calcite (light gray). Ordinary light.

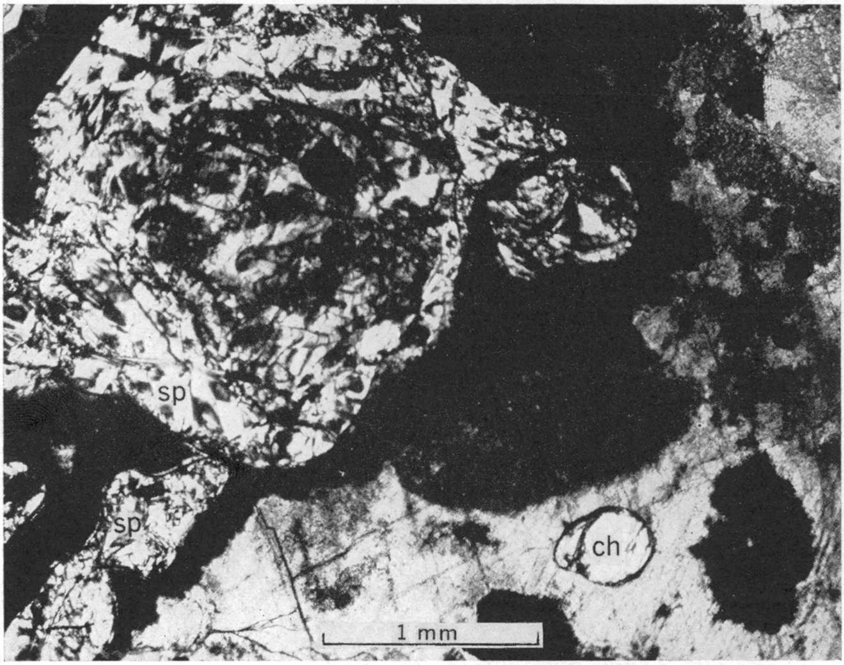


FIGURE 34.—Photomicrograph of thin section of silicated marble containing serpentine and chondrodite. Chondrodite (ch), serpentine (sp). Crossed Nicols.

(fig. 35). Small, irregular spots of greenish-brown hornblende and biotite partly replace the pyroxene. In addition some small rounded apatite crystals and granules of sphene are embedded in the pyroxene and are accompanied by a few specks of magnetite.


FIGURE 35.—Photomicrograph of thin section of typical dark skarn. Ordinary light.

The optical properties of pyroxene from two typical specimens of dark skarn are:

| Specimen | $\alpha$ | $\beta$ | $\gamma$ | $\gamma-\alpha$ | z to c | (+) 2V | Pleochroism |
|---|---|---|---|---|---|---|---|
| 109 | 1.707 | 1.713 | 1.729 | 0.022 | 44° | 62° | x Greenish-yellow. y Green. z Brownish-green. |
| R-1-46 | 1.691 | 1.696 | 1.718 | 0.027 | 43° | 57° | Colorless, nonpleochroic. |

According to the data given by Hess (1949, p. 64) for the skarn pyroxenes, no. 109 is a salite whose composition is about $Fe_{24}$ (of total Fe+Mg+Ca; Ca constant near 50 percent); R-1-46 is also a salite ($Fe_{17}$).

Light-colored skarn is massive and medium- to coarse-grained. The large subhedral pyroxene crystals are intergrown to form a rough granular mass. The color of the hand specimen ranges from light-green to gray-green or white with a faint greenish cast. Small irregular cavities formed by the leaching of calcite are abundant in places.

This light skarn is seen in thin section to be an intergrowth of subhedral crystals of colorless pyroxene. A few granules of sphene and a little magnetite are common accessories. Plagioclase is present in only very subordinate amounts. A thin section of light skarn from a drill hole near the Redback mine contains pyroxene and interstitial calcite (fig. 36). In this specimen the pyroxene replaces calcite.

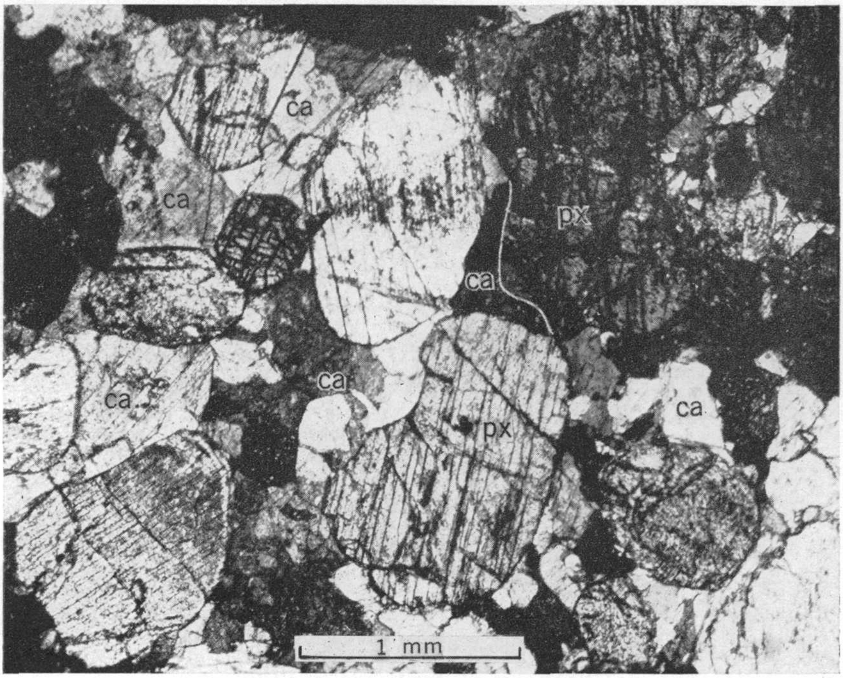


FIGURE 36.—Photomicrograph of light skarn with interstitial calcite. Pyroxene (px), calcite (ca). Crossed Nicols.

The pyroxene of this light skarn is diopside containing about 5 percent (Hess, 1949, p. 640) of the hedenbergite molecule. The following table shows the optical properties of pyroxene from three typical specimens of light skarn.

| Specimen | $\alpha$ | $\beta$ | $\gamma$ | $\gamma-\alpha$ | z to c | (+) 2V |
|---|---|---|---|---|---|---|
| R1-9.18 | 1.671 | 1.678 | 1.700 | 0.029 | 42° | 58° (?) |
| 24 | 1.673 | 1.681 | 1.701 | 0.028 | 42° | Moderate. |
| 25 | 1.672 | 1.680 | 1.702 | 0.027 | 42° | 62°. |

A dark gneiss identified megascopically as hornblende skarn is interbedded with true dark pyroxene skarn and pyroxene amphibolite near the Redback ore zone. Under the microscope (fig. 37) it appears

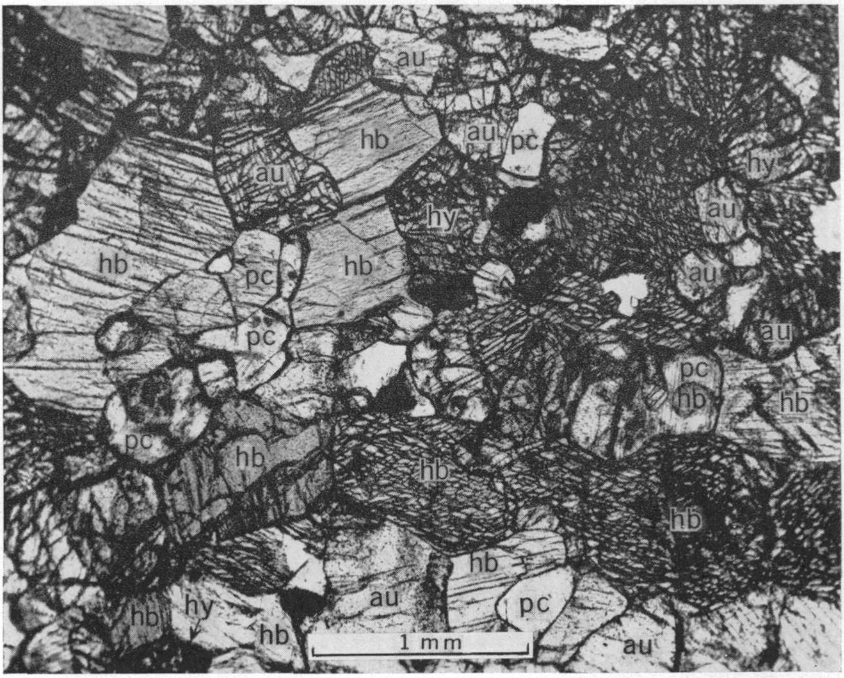


FIGURE 37.—Photomicrograph of rock intermediate between skarn and pyroxene amphibolite. Hornblende (hb), augite (au), hypersthene (hy), plagioclase (pc). Ordinary light.

to be a rock intermediate between skarn and pyroxene amphibolite. It consists of a crystalloblastic intergrowth of green hornblende, diopside, and hypersthene, with small interstitial grains of calcic plagioclase (bytownite, $An_{80}$). Hornblende replaces the pyroxene.

Garnet-pyroxene skarn is rare in the Sterling Lake and Ringwood area and forms no bodies of any importance. Only one or two occurrences were noted. Dark-brown garnet and deep bluish-green pyroxene are the principal minerals; rounded grains of quartz are present in subordinate amounts.

East of the Scott mine 10 ft of coarsely crystalline garnet-pyroxene rock overlying pale-green diopside skarn were cut in a diamond drill hole. The garnet is brown, presumably andradite,[1] the calcium-iron garnet. The garnet was probably formed in the skarn by hydrothermal action contemporaneous with the intrusion of pegmatite which occurs above and below the garnetiferous zone. Brown garnet-pyroxene skarn also is found near the Redback mine.

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[1] The densities and refractive indices of two skarn garnets were determined approximately.

SR–137–45: sp gr, 3.754; r. i. 1.822
SR–34–44: sp gr, 3.749; r. i. 1.843

The composition indicated by reference to Kennedy's (1947) charts is andradite with a substantial amount of the grossularite molecule.

## PYROXENE AMPHIBOLITE AND AMPHIBOLITE

Pyroxene amphibolite and amphibolite typically are dark-gray, greenish-gray, or black, with a medium-grained, equigranular texture. Foliation is best revealed in varieties containing biotite, especially when the biotite is concentrated in thin laminae. When platy minerals are lacking, the foliated structure may not be readily seen, though parallel layers differing slightly in mineral composition reveal the gneissic character of the rock in some outcrops. Linear structures due to the parallelism of inequidimensional minerals are usually distinguishable.

Amphibolite is not always readily distinguishable from pyroxene amphibolite in hand specimens. As a general rule, however, amphibolite is recognizable by its darker color and abundance of hornblende.

In places, the rocks are migmatitic and are composed of alternating layers of light granitic material and darker mafic-rich layers. Most of the granitic leaves are quartz-oligoclase gneiss. The light and dark layers may be distinct and the boundaries between them sharp, or there may be an intimate mixing and interchange of material. The extreme product is a rock in which irregular patches and zones of light material abound with dark shreds and streaks of mafic material.

Pyroxene amphibolite is composed primarily of pyroxene and plagioclase in crystalloblastic intergrowth (figs. 38 and 39). Plagioclase, amounting to about 65 to 70 percent of the rock, is somewhat more abundant than in the amphibolite. Its composition ranges

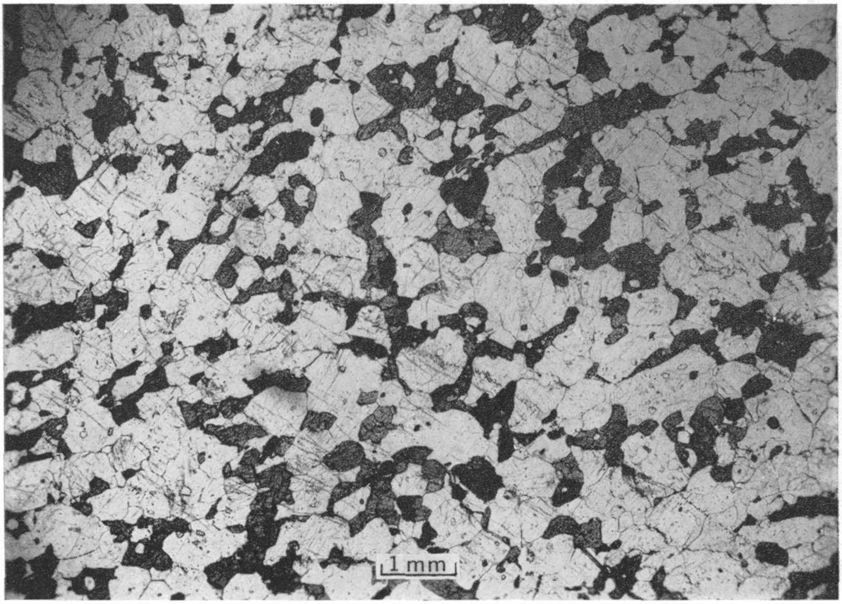


FIGURE 38.—Photomicrograph of pyroxene amphibolite. Ordinary light.

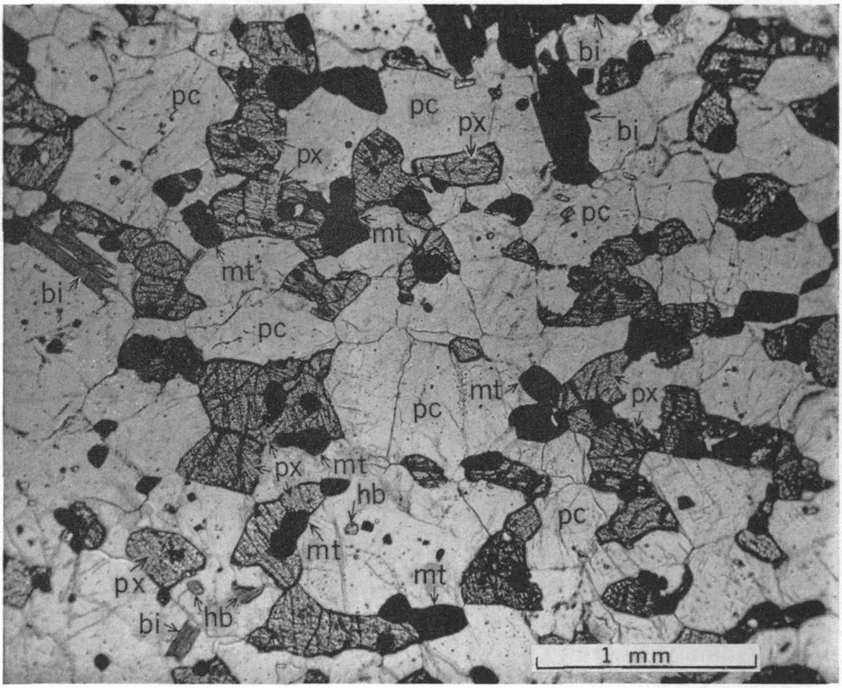


FIGURE 39.—Photomicrograph of pyroxene amphibolite. Plagioclase (pc), pyroxene (augite) (au), biotite (bi), magnetite (mt), hornblende (hb). Ordinary light.

from andesine ($An_{40}$) to oligoclase ($An_{20}$) and is oligoclase-andesine ($An_{30}$) in most of the specimens studied. Modal compositions of pyroxene amphibolite are given in table 1 (p. 170).

Two kinds of pyroxene—augite and hypersthene—occur together in most of the pyroxene amphibolite. They are intergrown with each other or exist as separate grains. Augite may occur without hypersthene, the latter usually being the less abundant. The augite is nonpleochroic and colorless or very pale green in thin section. Hypersthene is distinctly pleochroic: from green or colorless to reddish yellow. It commonly is more or less altered to weakly birefringent fibrous or scaly uralite. Augite is altered to hornblende in a few specimens.

The optical properties of augite from three typical specimens of pyroxene amphibolite are:

| Specimen | $\alpha$ | $\beta$ | $\gamma$ | $\gamma-\alpha$ | z to c | 2V |
|---|---|---|---|---|---|---|
| 108 | 1.686 | 1.693 | 1.709 | 0.023 | 52 | (+) 60° (measured). |
| 44 | 1.687 | 1.694 | 1.715 | 0.028 | 50 | (+) 62° (estimated). |
| 110 | 1.689 | 1.695 | 1.715 | 0.026 | 45 | (+) 62° (measured). |

The optical constants of hypersthene from two specimens of pyroxene amphibolite also were measured and are:

| Specimen | $\beta$ | $\gamma$ | 2V | Composition |
|---|---|---|---|---|
| 44 | 1.713 | 1.716 | (−) 52° | $En_{53}$. |
| 114 | 1.711 | 1.714 | (−) 56° | $En_{55}$. |

It was found that $\alpha$ could not be measured with sufficient accuracy, so only $\beta$ and $\gamma$ were determined and the optic angle was measured on the universal stage. The composition was obtained from the graphs by N. F. M. Henry (1935, pp. 221–226) using 2V and $\gamma$.

Pale reddish-brown flakes of biotite may be present in small amounts ranging from a trace to as much as 5 percent. Some of it may have formed at the time of recrystallization, but commonly, especially in and near the ore zones, it is obviously a later constituent. In most specimens it replaces pyroxene or hornblende, and in some specimens porphyroblastic plates of biotite enclose grains of quartz.

All specimens contain some magnetite which seldom exceeds 10 percent of the volume of the rock. Small anhedral to subhedral granules scattered through the rock partly replace pyroxene or hornblende.

Apatite, as small oblong grains, ranges from a trace to as much as 1 percent. Very small crystals of zircon were seen in a few slides.

Amphibolite is composed of plagioclase ranging from andesine ($An_{40}$) to oligoclase-andesine ($An_{30}$), and common green to brownish-green hornblende, accompanied by smaller amounts of pyroxene and biotite. Hornblende constitutes about 40 percent of the rock in most specimens. The optical characteristics of hornblende from typical amphibolites are:

| Specimen | $\alpha$ | $\gamma$ | $\gamma-\alpha$ | z to c | (−)2V | Pleochroism |
|---|---|---|---|---|---|---|
| 5 | 1.673 | 1.693 | 0.020 | 14° | [1] 60° | x Yellow.<br>y Yellow-green.<br>x Brownish-green. |
| 11 | 1.643 | 1.661 | 0.018 | 24½° | n. d. | x Pale straw.<br>y Pale yellowish-green.<br>z Pale bluish-green. |
| 83 | 1.667 | 1.691 | 0.024 | 23° | [2] 69° | x Yellow.<br>y Greenish-yellow.<br>z Yellowish-green. |

[1] Estimated.
[2] Universal stage.

The pyroxene is hypersthene and augite and may constitute from 10 to 20 percent of the amphibolite. Both varieties may occur together, or augite may be present to the exclusion of hypersthene.

Figure 40 is a photomicrograph of a typical specimen of amphibolite. Approximate modes of specimens of typical amphibolite, determined by Rosiwal analyses of thin sections, are listed in table 1 (p. 170).

TABLE 1.—*Approximate modes (volume percent) of amphibolite and pyroxene amphibolite*

| | Specimen | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Amphibolite | | | Pyroxene amphibolite | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Plagioclase | 37.9 | 47.4 | 73.0 | 73.0 | 63.1 | 70.4 | 66.2 | 76.5 |
| Quartz | ------- | ------- | ------- | 1.1 | 9.5 | 5.8 | ------- | 0.6 |
| Hornblende | 45.1 | 43.1 | 20.4 | 2.2 | 3.5 | 3.0 | Tr. | 1.5 |
| Clinopyroxene | 9.4 | ------- | Tr. | 1.3 | 7.2 | 7.7 | 18.9 | 10.9 |
| Orthopyroxene | 3.0 | ------- | ------- | 20.0 | 3.0 | 10.1 | 5.5 | 9.6 |
| Biotite | 2.2 | 1.3 | 5.3 | Tr. | 5.6 | 0.4 | Tr. | Tr. |
| Magnetite | Tr. | Tr. | 2.0 | Tr. | 0.2 | 0.1 | 0.3 | 0.2 |
| Zircon | ------- | ------- | Tr. | ------- | ------- | ------- | ------- | ------- |
| Scapolite | 2.0 | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | 96.8 | 91.8 | 100.7 | 97.6 | 92.1 | 97.5 | 90.9 | 99.3 |
| Average grain size (mm) | 0.58 | 0.24 | 0.27 | 0.28 | 0.22 | 0.27 | 0.23 | 0.39 |

1. From Ringwood-Wanaque road 0.5 mile north of junction with Greenwood Lake road. Dark, medium-grained, granoblastic. Fresh, twinned oligoclase-andesine ($An_{30}$) partly replaced by scapolite. Green hornblende ($\alpha$=1.673, $\gamma$=1.693, 2V=60°, z to c=14°), pale green augite, and partly altered hypersthene. Reddish-brown biotite partly replaces hypersthene and hornblende (fig. 40).
2. From southeast end Tip-Top mine (Sterling Lake district). Dark, medium-grained, crystalloblastic with well-developed preferred orientation of hornblende, more or less equant development of plagioclase. Plagioclase is andesine ($An_{41}$) slightly clouded by alteration. Pale green hornblende ($\alpha$=1.643, $\gamma$=1.661, z to c=24.5°), brown biotite, magnetite replacing hornblende.
3. From 0.7 mile northwest of Little Cedar Pond in tongue of pyroxene amphibolite. Medium-grained crystalloblastic intergrowth of plagioclase, hornblende, and minor biotite. Plagioclase is oligoclase-andesine ($An_{32}$); green hornblende ($\alpha$=1.667, $\gamma$=1.691, z to c=23°, 2V=69° [universal stage]). Few tiny zircon grains surrounded by dark haloes in biotite.
4. From dark, massive, medium-grained rock on ridge 1 mile west of Sterling Lake. Texture medium-grained, equigranular, granoblastic, showing slight grain alinement. Clear, twinned andesine ($An_{38}$), some quartz, abundant hypersthene and augite. Some granular, brownish-green hornblende and disseminated granules of magnetite.
5. From hanging wall of Long Mine (Sterling Lake district). Fine- to medium-grained crystalloblastic intergrowth of equigranular augite, partly altered hypersthene, a small amount of green hornblende, and clear oligoclase-andesine ($An_{30}$). Porphyroblastic plates of reddish-brown biotite poikilitically enclose clear quartz, replace earlier mafic minerals, including scattered granules of magnetite. Some quartz as rounded granules enclosed in plagioclase.
6. From outcrop east of Long Mine. Medium-grained, granoblastic texture with anhedral to subhedral mafic minerals exhibiting slight orientation. Plagioclase ranges from $An_{36}$ to $An_{48}$, well-twinned and unaltered. Some albite rims on plagioclase. Two kinds of quartz: small granules enclosed in plagioclase, and clear, slightly strained, locally rimming pyroxene, interstitial to plagioclase which it partly replaces. Pyroxenes are augite ($\alpha$=1.687, $\beta$=1.694, $\gamma$=1.714, z to c=50°), and strongly pleochroic hypersthene ($En_{53}$) $\beta$=1.713, $\gamma$=1.716, 2V=52°) (fig. 38).
7. From west of Scott shaft. Plagioclase is medium oligoclase containing some antiperthitic inclusions of potash feldspar. Only slightly altered, faintly pleochroic hypersthene; clinopyroxene is colorless, nonpleochroic, with extinction corresponding to augite. Brown biotite restricted to few flakes, one of which encloses a little quartz. Magnetite replaces pyroxene and in turn a few granules are replaced by biotite (fig. 39).
8. From witnin quartz-oligoclase gneiss, east side Jennings Brook 1 mile WSW. of Little Cedar Pond. Medium-grained, granoblastic texture, composed of plagioclase (andesine, $An_{38-41}$), augite and hypersthene. Dark-green hornblende and magnetite both partly replace pyroxene.

## ORIGIN

Pyroxene amphibolite, amphibolite, skarn, and marble were formed by the metamorphism of calcareous sedimentary rocks. Marble was formed by the recrystallization of limestone. Serpentine, chondrodite, and diopside in some of the marble suggests that it was originally dolomitic.

Both light and dark skarn are found in conjunction with marble and adjacent to or very near granite or pegmatite. In some drill cores, light-colored skarn grades into marble, and microscopic study has shown that the pyroxene replaces calcite in the marble. Pyroxene skarn associated with limestone (or marble) in the vicinity of granitic intrusions has been noted elsewhere in similar metamorphic terrains

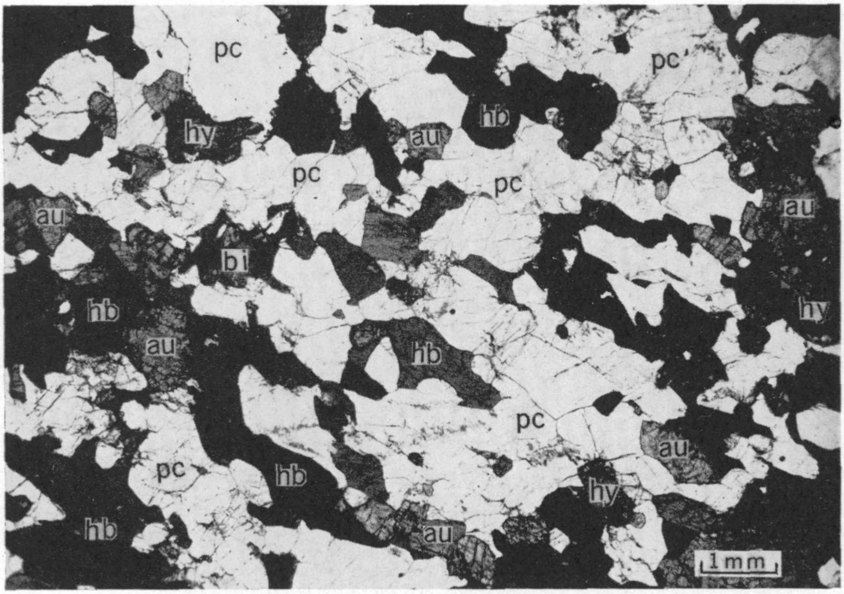


FIGURE 40.—Photomicrograph of amphibolite. Plagioclase (pc), hornblende (hb), pyroxene (augite) (au), hypersthene (hy), biotite (bi). Ordinary light.

(Buddington, 1939, p. 168; Eskola, 1914, pp. 225–234). The evidence is completely in favor of the development of the skarn from marble. The transformation is attributed to replacement of the marble by magmatic solutions or vapors bearing magnesia, iron, and silica (Turner, 1948, p. 125). The variation from light, diopsidic skarn to dark skarn in which the pyroxene is richer in the hedenbergite molecule is due to a difference in iron content. It is doubtful that the marble itself was capable of yielding much iron. Probably the difference is due to the amount of iron supplied by the replacing solutions or vapors.

Pyroxene amphibolite and amphibolite may have originated in any one of several ways. Metamorphism of mafic igneous rocks such as gabbro or diorite, volcanic flows or tuffs, the metasomatic alteration of limestone by granitic solutions, or the metamorphism of impure calcareous sedimentary rocks, would all produce similar rocks.

To prove the derivation of pyroxene amphibolite or amphibolite by metamorphism of igneous rocks, there must be evidence of relict igneous textures or structures, crosscutting relationships with older rocks, or gradation into unquestioned igneous rocks. No such evidence of the original igneous nature of these rocks has been found in this area.

Conversely, the association of these rocks in some places with skarn and marble supports the conjecture that they were derived from calcareous sedimentary rocks. Rocks of similar composition and mode of occurrence in the Grenville series in Canada have been earlier described by Adams (1909) and Adams and Barlow (1910 pp. 87–127), and in the Adirondack Mountains, N. Y., by Buddington (1939, pp. 166–175). These workers have shown that amphibolite and pyroxene amphibolite have been formed by the alteration of limestone by magmatic solutions and vapors. Differences in conditions and degree of metamorphism, including variations in character of the solutions or vapors, temperature and pressure, as well as compositional differences in the original rocks, were possible factors determining the formation of pyroxene amphibolite, amphibolite, or skarn.

## PROBLEM OF THE TERM "POCHUCK"

In the Franklin Furnace folio Spencer (1908, p. 4) included under Pochuck gneiss "* * * all the gneisses in the Highlands region that contain hornblende, pyroxene, or mica as the principal mineral constituents." Hence, originally the Pochuck included all the "dark gneisses." Spencer recognized the possibility that some of the dark gneisses are of sedimentary origin, "* * * and others may be igneous rocks, but in general they are so completely metamorphosed that their original nature can not be ascertained." He regarded the Pochuck as older than the Losee and Byram gneisses which he believed to be partly responsible for its complete metamorphism.

Bayley, Salisbury, and Kümmel (1914, p. 8), in the Raritan folio, stated that probably the dark gneisses included under the term Pochuck gneiss should be divided into two groups of different age and possibly different origin: the gneisses of possibly sedimentary origin older than the Bryam and Losee, and the dark gneisses of igneous origin possibly contemporaneous with the Bryam and Losee. He did not, however, map the groups separately.

Colony (1923, pp. 49–52) considered the Pochuck to be the oldest of several magmatic units in southeastern New York represented by pyroxenite, hornblendite, peridotite, diorite, soda-syenite, associated pegmatites and "their corelated magmas." He then added two more units: Pochuck-Grenville, a mixed rock due to "soaking" effects on the sedimentary rocks brought about by the syenitic facies of the Pochuck; and Modified Pochuck-Grenville, which is Pochuck-Grenville further modified by the injection of light granitic material.

The Geological Survey (Wilmarth, 1938, p. 1686) uses the term Pochuck gabbro gneiss and restricts it "* * * to the black gneiss of intrusive origin, and the older dark gneisses of sedimentary origin that formerly were included under the name Pochuck gneiss are now included in Pickering gneiss." It is impossible to distinguish between dark gneisses of intrusive and sedimentary origin in this district; therefore, and because of the different ways the name has been used, as well as the impracticability of using a formation name for gneisses of varied composition, the term Pochuck has not been used in this report.

## METAMORPHOSED QUARTZOSE ROCKS

### OCCURRENCE AND DISTRIBUTION

Layers of garnetiferous quartz-biotite gneiss, in places containing significant amounts of sillimanite, and nearly pure quartzite are associated with the metamorphosed calcareous rocks. These siliceous gneisses are considerably less abundant in the area than the amphibolites or skarn.

In most places garnet-bearing biotite gneiss or sillimanite-biotite gneiss constitute distinctive units that can be followed for considerable distances. Where they occur, these layers are useful markers. The least interrupted layers of garnetiferous quartz-biotite gneiss in the area are found on the west side of the Scott mine mineralized zone, and east of the Augusta mine. Some garnetiferous quartz-biotite gneiss, possibly representing the southern continuation of the western layer, crops out south of Sterling Lake near the Lower California mine. A less continuous belt is found in the southern part of the area in the Ringwood district. A few other interrupted layers of garnetiferous quartz-biotite gneiss are shown on plate 19.

Thin layers of quartzite crop out in a few places and a little quartzite has been found in diamond drill holes. Quartzite is interlayered with amphibolite on the west side of the prominent ridge northeast of the village of Greenwood Lake, and a thin quartz-rich layer was cut in a diamond drill hole in amphibolite on the east side of the Scott mine mineralized zone. Some quartzite is associated with amphibolite and interlayered with granite laminae a short distance north of Spruce Swamp east of the Redback mine.

### GARNETIFEROUS QUARTZ-BIOTITE GNEISS

The garnetiferous quartz-biotite gneiss is a light-colored medium-grained gneiss showing a crystalloblastic texture in thin section. In most places the rock is migmatitic. Foliation is well developed and a linear arrangement of sillimanite needles or elongate flakes of biotite is usually visible. A characteristic pink garnet (almandite) is dispersed through the rocks as small individual crystals in amounts as great as 15 percent or as knots and crystalline aggregates adjacent to or in the leaves of injected granitic material. White needles of sillimanite confined more or less to zones are plentiful in some places. The principal accessory mineral is brown biotite, amounting to 10 or 15 percent of the rock. Plentiful quartz and potash feldspar (microperthite) and some plagioclase (oligoclase or oligoclase-andesine) are characteristic, and pyroxene (both hypersthene and diopsidic augite) may accompany the biotite. Minor accessories are magnetite, apatite, and zircon. Graphite occurs in one or two places.

#### QUARTZITE

The quartzites are light-colored, medium-grained, and equigranular. Some have a well-developed gneissic structure, others are essentially massive. In thin section the texture is granoblastic and ranges from equigranular to inequigranular. Recrystallization has completely destroyed all original textures. The boundaries between grains are highly irregular but never sutured. The quartz grains in some specimens are all the same size, and strain shadows are virtually absent, in others the quartz occurs as elongate, strained bodies enclosing patches of other quartz having an equigranular development. Small amounts of biotite may constitute the characteristic accessory mineral. Considerable scapolite and a little plagioclase are present in some of the quartzite near the Redback mine. Part of the scapolite is altered to chlorite and epidote, and slight chloritic alteration of the biotite flakes is visible in all of the quartzite studied under the microscope. Potash feldspar and also plagioclase can be recognized in most specimens.

#### ORIGIN

These quartzose rocks are believed to have been originally siliceous beds in a dominantly calcareous sedimentary series. The quartzose biotite gneiss probably represents a metamorphosed alumino-siliceous sedimentary rock such as sandy shale. The garnetiferous and sillimanitic varieties have abundant granitic material indicating that metasomatic processes were responsible for the formation of the garnet and sillimanite. The thin quartzite layers were probably slightly impure sandstones. Scapolite and possibly the perthitic orthoclase and tongues of late quartz are indicators of modifying magmatic solutions.

## GRANITIC ROCKS

Granitic rocks constitute more than two-thirds of the outcrops in the area mapped. Two major lithologic units, quartz-oligoclase gneiss and hornblende granite and its related facies, have been recognized and mapped. A third less abundant rock type, granite pegmatite, was also mapped because of its wide distribution in the area.

### QUARTZ-OLIGOCLASE GNEISS

#### OCCURRENCE AND DISTRIBUTION

Somewhat more than one-third of the Sterling Lake-Ringwood area is underlain by granitic quartz-oligoclase gneiss, which is generally equivalent to the Losee gneiss in New Jersey (Spencer, 1908, p. 5). In a preliminary report (Hotz, 1945) this same unit was referred to as soda plagioclase granite and soda granite.

Quartz-oligoclase gneiss is present throughout the area. One of the largest bodies is found in the southern part of the area near Ringwood where it is partly covered by alluvium and glacial deposits. Other large bodies occur east of Ringwood and north and west of Sterling Lake. The narrow layer forming the core of the anticline east of Sterling Lake appears to be a continuation of the large body in the southern part of the area.

#### PETROGRAPHY

In part the quartz-oligoclase gneiss is homogenous and so massive that foliation and linear structures are difficult to recognize. Many outcrops, however, have included thin septa, elongated lenses, or schlieren of amphibolite and pyroxene amphibolite. The inclusions are oriented parallel to one another and to the foliation. The contacts of the inclusions are sharp and there is no conspicuous reaction zone between host and inclusion. Where inclusions are folded, the foliation in the host follows the contours of the inclusion in a general way, but the granitic rock is usually not so well foliated as the inclusion. In some places the inclusions appear to have been torn apart by the granitic rock that penetrates between the disrupted layers and fragments. Thin pegmatite veinlets intrude the gneiss, paralleling or rarely transecting the foliation. Weathered surfaces are smooth except where schlieren or inclusions give the surface a slightly ribbed appearance. The rock characteristically weathers white or gray, and, rarely, buff; fresh surfaces are gray with a greenish cast.

Irregular or roughly tabular, striated feldspars intergrown with quartz are clearly evident in hand specimens. In some specimens the lineation is revealed by elongated grains of quartz. Hornblende, biotite, and two kinds of pyroxene are easily recognized where present. The megascopic texture is more or less equigranular and uniform in a given specimen, though it ranges from medium-grained to coarse-grained. The grains are so closely intergrown that the rock has a dense, massive appearance.

Under the microscope (fig. 41) the texture is seen to consist of interlocking anhedral grains. Rarely, some granulation and recrystallization along grain boundaries are visible. A few specimens have typical crystalloblastic textures. Dimensional orientation of the constituents is not apparent in most thin sections, but zones of different mafic composition reveal the foliated structure.

The essential minerals of the gneiss are oligoclase ($An_{28}$) and quartz. Plagioclase ranges from 55 to 80 percent of the rock, quartz from 15 to 35 percent. The plagioclase is clear and well-twinned, and its composition is fairly constant in all specimens. It is commonly antiperthitic and contains a few included beads of potash feldspar.

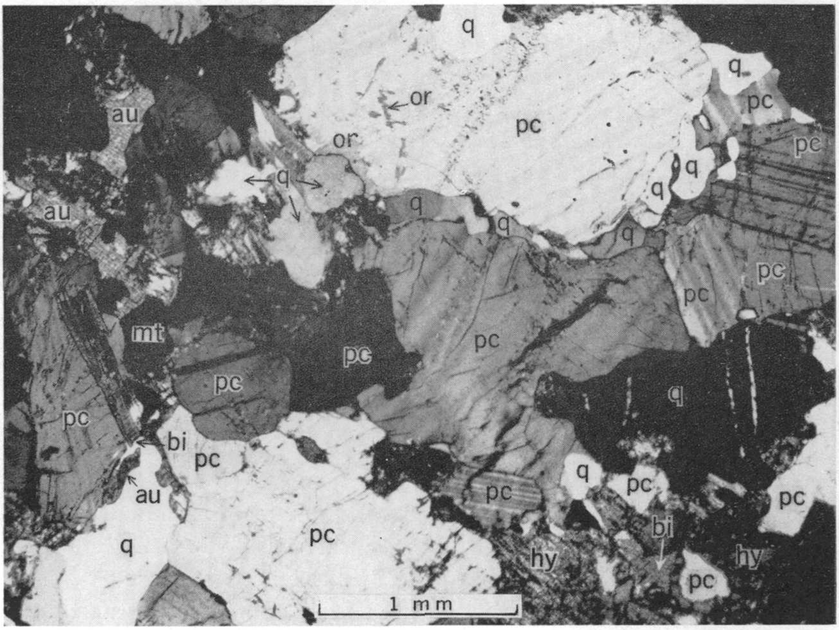


FIGURE 41.—Photomicrograph of quartz-oligoclase gneiss. Plagioclase (pc), quartz (q), orthoclase (or), altered hypersthene (hy), augite (au), biotite (bi), magnetite (mt). Crossed Nicols.

In some specimens small amounts of perthitic microcline are present as small interstitial grains and as partial replacements of plagioclase.

Two types, or generations, of quartz are visible. The first type is of small ovoid, unstrained granules, some enclosed in plagioclase and the others in interstitial positions. The second and more abundant type appears as irregular, somewhat tonguelike bodies that embay and replace the feldspar and enclose other quartz granules. In some thin sections the long dimensions of these granules are roughly parallel.

Hornblende, biotite, and two kinds of pyroxene are the characteristic accessory minerals and constitute from 1 percent to as much as 10 percent of the volume of the rock. Pyroxene is more abundant than hornblende or biotite; both may be absent in some specimens. The pyroxenes are pale-green to colorless diopsidic augite and hypersthene. Hypersthene is more plentiful than augite, and some of it is partly altered to greenish antigorite (?) accompanied by a little secondary magnetite, or partly replaced by biotite. Green hornblende occurs as granules and subhedral prisms. The amphibole replaces pyroxene to a minor extent. Biotite is commonly found in only small amounts in most specimens but is abundant in others. The flakes are pleochroic from reddish brown to pale yellow and, in some thin sections, have a slight preferred orientation.

Subhedral and anhedral grains of magnetite occupy spaces between feldspar crystals, and in some specimens are surrounded by pyroxene or hornblende. Apatite is generally present, but in amounts of less than 1 percent. It is closely associated with the magnetite; some grains may be entirely surrounded by magnetite. Sphene and zircon in small quantities are present in some specimens.

At a few places small masses of a lighter-colored variety of quartz-oligoclase gneiss were found. In thin section (specimen 5, table 2) this variety was observed to be almost devoid of dark minerals and to consist of predominant plagioclase and abundant quartz, with a little magnetite and a trace of sphene. The plagioclase is slightly more sodic than in other specimens of quartz-oligoclase gneiss; it is oligoclase, about $An_{20}$.

### COMPOSITION

The composition of this rock differs from that of normal granite in the abundance of sodic plagioclase, in a lack of potash feldspar, except as minor microcline and antiperthitic growths in the plagioclase, and in a slightly lower quartz content. Approximate modes determined by Rosiwal analyses of typical specimens of quartz-oligoclase gneiss in the Sterling Lake-Ringwood area are presented in table 2.

TABLE 2.—*Approximate modes (volume percent) of quartz-oligoclase gneiss*

| | Specimen | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Plagioclase | 56.0 ($An_{28}$) | 71.0 ($An_{28}$) | 73.6 ($An_{36-40}$) | 56.0 ($An_{28}$) | 61.0 ($An_{20}$). |
| Potash feldspar | 8.0 | 0.6 | | 2.4 | 1.7 |
| Quartz | 32.0 | 23.2 | 18.3 | 33.2 | 35.0 |
| Hornblende | 0.8 | | 0.5 | | |
| Biotite | 0.6 | 1.2 | Tr | Tr | Tr. |
| Clinopyroxene | Tr | 0.6 | Tr | | 1.2 |
| Orthopyroxene | | 1.0 | 2.7 | 3.1 | |
| Magnetite | 0.8 | 0.7 | 1.6 | 2.2 | 1.1 |
| Apatite | Tr | Tr | 0.4 | 0.1 | |
| Sphene | | | | | Tr. |
| Alteration products (mostly after pyroxene). | 1.8 | Tr | 2.7 | 2.0 | |
| | 100.0 | 98.3 | 99.8 | 99.0 | 100.0 |

1. From light, medium-grained gneiss near Whitehead mine.
2. From bold outcrops on Greenwood Lake-Tuxedo highway, Ramapo quadrangle. Massive to weakly foliated, white on weathered surfaces, greenish where fresh.
3. From greenish-gray plagioclase gneiss southeast of Table Rock, Ramapo quadrangle; contains abundant included layers and schlieren of amphibolite.
4. From outcrop on Wanaque-Ringwood highway at entrance to Erskine Lakes. Greenish, massive, medium-grained, containing megascopically visible pyroxene.
5. From white gneiss interlayered with migmatite, north of Crawford mine.

The mineral composition of the quartz-oligoclase gneiss listed in table 2 may be compared with the varieties of Losee gneiss from New Jersey listed in table 3:

TABLE 3.—*Mineral composition in percent of various phases of the Losee gneiss*

[After Bayley, Salisbury, and Kümmel, 1914, p. 8]

| | Specimen | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Quartz | 16.07 | 13.75 | 19.59 | 0.43 |
| Oligoclase | 63.14 | 61.52 | 43.49 | 36.30 |
| Orthoclase | 16.16 | 16.66 | 4.62 | 8.70 |
| Diopside | ---------- | 2.52 | 8.02 | 40.12 |
| Hypersthene | 4.62 | 2.44 | 22.53 | ---------- |
| Hornblende | ---------- | ---------- | ---------- | 3.10 |
| Magnetite | ---------- | 3.06 | 1.82 | 11.35 |
| | 99.99 | 99.95 | 100.07 | 100.00 |

1. Dark-gray variety. From New York, Susquehanna and Western Railroad just east of Smith Mills, Greenwood Lake quadrangle (now Wanaque quadrangle).
2. Very similar to 1; contains bands of Pochuck gneiss. From top, north end of Kakeout Mountain, Passaic quadrangle (now Boonton quadrangle).
3. From small ledge of bronzy rock, northwest of Durham Pond, Passaic quadrangle (now Boonton quadrangle).
4. White variety of Losee gneiss. From ledge few feet from old shaft of Wood mine, near Hibernia, Passaic quadrangle (now Boonton quadrangle).

Variation in the amount of mafic minerals is characteristic of the quartz-oligoclase gneiss. To some extent there is a direct relationship between the abundance of mafic accessory minerals and the number of inclusions. Typical specimens from this area range from a light-colored alaskitic type to a rock relatively rich in mafic minerals closely resembling pyroxene amphibolite in thin section as well as megascopically. Five varieties are tabulated below, and arranged according to the quantity of plagioclase, quartz, mafic minerals, and change in average grain size. Specimen 1 is an intermediate type between pyroxene amphibolite and quartz-oligoclase gneiss; specimens 2–4 are varieties commonly seen in the area; specimen 5 is an unusually light-colored kind that is not often found. The increase in quartz content and the decrease in the amount of mafics are accompanied by an increase in average grain size. There is likewise a slight increase in amount of potash feldspar (not shown here). Most of the potash feldspar occurs as antiperthitic inclusions in plagioclase, but a little microcline can be seen in some specimens.

| Specimen | Plagioclase (percent by volume) | Quartz (percent by volume) | Mafics (percent by volume) | Average grain size (mm) |
|---|---|---|---|---|
| 1 | 70.4 | 5.8 | 21.2 | 0.27 |
| 2 | 76.9 | 12.0 | 8.8 | .26 |
| 3 | 73.6 | 18.3 | 3.2 | .42 |
| 4 | 55.0 | 32.2 | 5.3 | .76 |
| 5 | 56.6 | 32.0 | 1.0 | .65 |

## HORNBLENDE GRANITE AND RELATED FACIES

Two general rock types, hornblende granite and alaskite, are not mapped separately because it was impossible to do the necessary detailed work. The petrographic data indicate that the alaskitic varieties are more plentiful than hornblende granite.

### OCCURRENCE AND DISTRIBUTION

More than one-third of the area is occupied by these granitic rocks that correspond to the Byram gneiss of New Jersey (Spencer, 1908, p. 5; Bayley, 1908, p. 5, 1910). Two large bodies south and southwest of Sterling Lake form the rugged terrain around Cedar Pond and most of the prominent, steep-sided ridge on the western border of the area. A long, relatively narrow body of granite forms a prominent ridge west and northwest of Sterling Lake. Another large oblong body underlies the rugged upland east of Sterling Lake and extends northeast of Cairn Mountain and Warwick Brook. Another smaller body forms the prominent knob on the New York-New Jersey boundary northeast of Ringwood State Park. Smaller sheets of this granite are interlayered with other rocks south of Spruce Swamp and northeast of Sterling Lake.

For the most part, the granite is unaccompanied by other gneisses, but in some places it is interlayered with metasedimentary rocks.

### PETROGRAPHY

A buff to definitely pinkish hue is characteristic of weathered surfaces of the granite and alaskite. Some specimens are brownish-gray to white and, rarely, greenish-gray on freshly broken surfaces, but mostly the buff color predominates. Exposures underground are characteristically pink. Outcrops are commonly rounded and fairly smooth, though where the rock is very coarse grained the surface is rough. Many outcrops have a massive appearance. Foliated structures are more or less rare, and in many places, especially in the central parts of the larger bodies, planar and linear structures are very difficult to recognize. An important feature of this granite is that it contains fewer inclusions than the quartz-oligoclase gneiss.

The rock is medium to coarse in grain, and in places is so coarse that it could properly be called pegmatitic. A medium-grained, distinctly granular variety with visible planar structure is found in a few places.

Unstriated potash feldspar crystals are easily recognized in the coarser-grained varieties. Interstitial, irregular, somewhat elongate white quartz grains also are prominent. A little hornblende and, more rarely, biotite are visible in some specimens, and small concentrations of coarsely crystalline magnetite less than 4 in. long occur locally.

In most thin sections (fig. 42) the granite and alaskite have a granitic texture. In some specimens, however, the intergrowth is granoblastic (fig. 43). An example of this variety is the fine, granu-

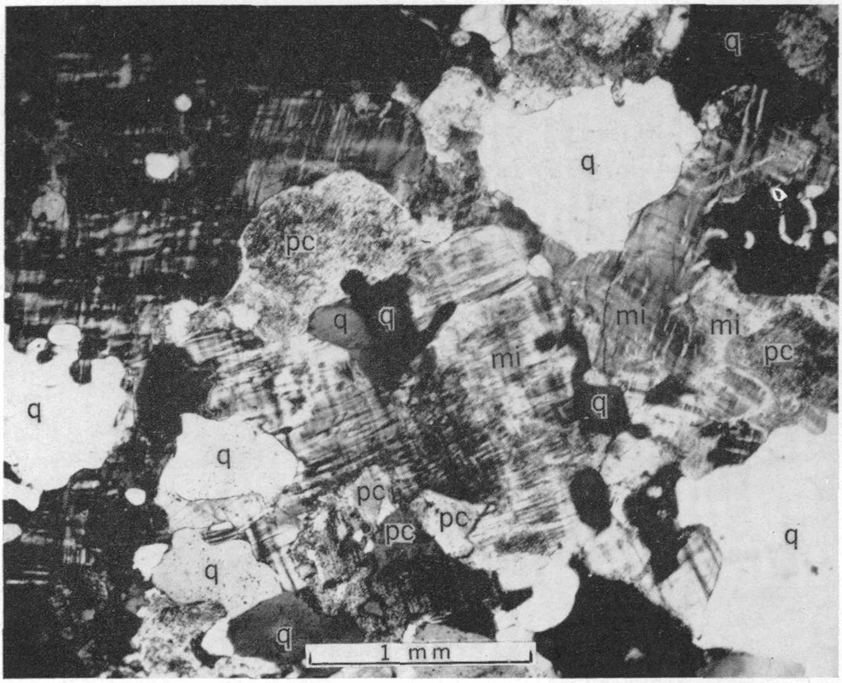


FIGURE 42.—Photomicrograph of granite. Microcline (mi), plagioclase (pc), quartz (q), Crossed Nicols.

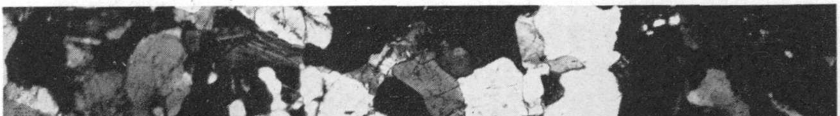


FIGURE 43.—Photomicrograph of granoblastic hornblende granite. Crossed Nicols.

lar granite that crops out south of Sterling Lake lookout tower and in places along the borders of the elongate mass east of Sterling Lake.

The predominant feldspar in most specimens is microperthite. Microcline microperthite is the principal potash feldspar in some of the rocks but generally it is subordinate to microperthite. The amount of plagioclase is small but variable. Its average composition is approximately albite-oligoclase ($An_{12-15}$), somewhat more sodic than in the quartz-oligoclase gneiss.

Quartz is abundant and myrmekite is present in small amounts.

Accessory minerals are green hornblende and biotite, which amount to only a small percentage of the rock at most. Some of the plagioclase is commonly intergrown with these mafic minerals. Minor chloritic alteration of the mafic minerals is fairly common.

Small granules of magnetite, apatite, and zircon, ranging from a trace to 1 or 2 percent, constitute the minor accessory minerals.

A few small, irregular, somewhat skeletal grains of colorless garnet were seen in specimens of potash granite cut in drill holes at the Redback mine. Two small crystals of fluorite were seen in one specimen.

### COMPOSITION

Approximate modes of typical specimens of hornblende granite and alaskite are listed in table 4. For comparison with varieties of Byram gneiss from New Jersey see table 5.

TABLE 4.—*Approximate modes (volume percent) of hornblende granite and related alaskite*

| | Specimen | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Potash feldspar | 53.6 [1] | 65.0 [2] | 57.3 [2] | 37.8 [2] | 46.1 [2] | 33.6 [1] |
| Plagioclase | 21.1 | 1.0 ($An_{12}$) | 7.0 ($An_{13}$) | 8.0 | 9.3 | 21.5 |
| Quartz | 24.4 | 28.6 | 30.8 | 36.5 | 38.8 | 40.7 |
| Hornblende | .6 | 4.2 | 4.9 | 14.7 | 4.9 | 1.0 |
| Biotite | | Tr | | | .5 | |
| Magnetite | .2 | .6 | | 2.6 | .2 | 1.3 |
| Apatite | Tr | <.1 | | <.1 | <.1 | <.1 |
| Sphene | | .1 | <.1 | Tr | | <.1 |
| Zircon | | | | | Tr | |
| Chlorite | <.1 | .5 | | .4 | | 1.9 |
| Epidote | <.1 | | | | | |
| | 99.9 | 99.4 | 100.0 | 100.0 | 99.8 | 100.0 |

[1] Chiefly microcline microperthite.
[2] Chiefly microperthite.

1. Pink, medium- to coarse-grained, foliated granite (alaskite) from end of ridge 0.9 mile south of Sterling Lake lookout tower.
2. Medium-grained, gneissic hornblende granite, from 0.5 mile south of Spruce Swamp, Ramapo quadrangle.
3. Gray, medium- to coarse-grained foliated hornblende granite from exposure on Greenwood Lake-Tuxedo highway about 1.5 miles northeast of village of Greenwood Lake.
4. Coarse-grained massive pink hornblende granite. From top of ridge 0.7 mile east of Little Cedar Pond, Greenwood Lake quadrangle.
5. White medium-grained granite from valley west of Sterling Lake lookout tower.
6. Alaskitic granite from 0.2 mile southeast of Tuxedo-Greenwood Lake road, 0.9 mile west-northwest of Bare Mountain. Specimen taken 15 ft from contact with dark gneiss.

TABLE 5.—*Mineral composition (volume percent) of various phases of the Byram gneiss*

[After Bayley, Salisbury, and Kümmel, 1914, p. 8]

| | Specimen | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Quartz | 24.27 | 27.12 | 30.89 | 35.54 |
| Oligoclase | | | 3.92 | |
| Orthoclase | 31.75 | 12.07 | 16.42 | 4.40 |
| Microperthite | 39.37 | 53.22 | 43.89 | 58.50 |
| Hornblende | 2.31 | | 4.75 | Tr. |
| Magnetite | 2.35 | | | 1.57 |
| Biotite | | 7.68 | | |
| | 100.05 | 100.09 | 99.91 | 100.01 |

1. Medium-grained bronzy variety. From ledge on southwest spur of hill northeast of Powerville, Passaic quadrangle (now Boonton quadrangle).
2. Medium-grained light-colored variety. From ledge on New York, Susquehanna and Western Railroad, west of Riverdale, Greenwood Lake quadrangle (now Pompton Plains quadrangle).
3. Very light colored fine-grained variety. From top of southeast slope of 1169-ft. hill southwest of Durham Pond, Passaic quadrangle (now Boonton quadrangle).
4. Light-yellow medium-grained variety. From south end of knoll on east side of road between Boonton and Taylortown, 1 mile south of Taylortown, Passaic quadrangle (now Boonton quadrangle).

## PEGMATITE

### OCCURRENCE AND DISTRIBUTION

Lenses, sheets, less commonly vein and dikelike bodies, and some irregular bodies of light-colored medium- to coarse grained rock of granitic composition occur in the vicinity of many of the magnetite deposits. These rocks have been classified and mapped as pegmatite because of their generally coarse grain, lack of dark minerals, and mode of occurrence. Some bodies mapped as pegmatite might have been more properly classed as alaskite because they are finer grained than most pegmatites.

Many of the bodies are relatively thin sheets as much as 50 ft thick, but a few attain a maximum of about 200 ft; in length they range from 100–200 ft to more than 1,000 ft. Most of the sheets are within or adjacent to the metasedimentary gneisses and are most abundant near contacts between metasedimentary gneisses and the granitic quartz-oligoclase gneiss. In general, the pegmatite bodies are conformable to the surrounding rock structure. Good examples of this mode of occurrence are found in the vicinity of the Long mine and near the Summit and Upper California mines south of Sterling Lake. In the Ringwood district in the southern part of the area some pegmatite bodies are found in quartz-oligoclase gneiss. Pegmatite is also seen in the mines, where it forms thin sheets and, in places, irregular bodies. These bodies are more or less conformable to the gneissic structure in the wallrocks but locally they exhibit some disconformity where tongues and offshoots extend from larger main bodies. A few pegmatite dikes cut the surrounding rocks at roughly right angles to the gnessic structure. These dikes have been found only in underground exposures.

Pegmatite bodies are found in the quartz-oligoclase gneiss, but they were not mapped because of their small size. These pegmatites are veinlike bodies from less than 1 in. to 1 ft or so in width. Locally, they are slightly discordant to the foliation, but the majority of them parallel the structure. Crosscutting bodies are rare. In places, however, a concordant vein digresses and transects the structure for a few inches, resuming its concordant position within a short distance.

A less common type in the quartz-oligoclase gneiss is the meander pegmatite which resembles a ptygmatically folded body. Further study of more such bodies is necessary to determine whether they were folded after emplacement. In one or two examples, where detailed study was made, the veinlets appear to be following a tortuous fracture across the gneissic structure rather than to have been concordant veinlets subsequently folded.

A large lenticular body of quartz-rich rock is exposed in the central and southern part of the skarn belt southeast of Sterling Lake (shown as pegmatite on the geologic map, pl. 19). The quartz is milky white, more or less massive, and in places looks much like vein quartz. Some of it has a gneissic appearance. It is partly enclosed by skarn, and a little skarn is interlayered with the quartz. In places, however, angular blocks of skarn that have been partly recrystallized to aggregates of coarse green pyroxene are enclosed in the quartz. Large subhedral phenocrysts of sphene and abundant plagioclase occur in a few places. Small bodies of quartz-rich material enclosed in and grading into normal granite pegmatite are exposed elsewhere in the area.

This large quartz body, accompanied by skarn, may be metamorphosed chert that was interbedded with limestone from which the skarn was derived. Yet, the similarity of this quartz mass to others in pegmatite elsewhere, its aggregates of skarn and recrystallized pyroxene, and its crystals of sphene, all suggest that this large body of quartz is genetically related to the pegmatite.

### PETROGRAPHY

A pink or salmon color is characteristic of the pegmatite on fresh as well as on weathered surfaces. Texturally, the rock is coarse-grained to pegmatitic (0.5 mm to 5 cm), with subhedral to euhedral, roughly tabular crystals of pinkish feldspar and irregular bodies of white quartz.

Some small inclusions of amphibolite, pyroxene amphibolite, skarn, and rarely biotite gneiss may occur. These are commonly modified and reconstituted by the pegmatite. No fragments of quartz-oligoclase gneiss or hornblende granite are enclosed in the pegmatite. Most of the inclusions are oriented parallel to the general gneissic structure of the surrounding rocks, but in some outcrops the inclusions lie at random. Some inclusions may be bent, and they appear to be remnants of intricately contorted gneiss.

Foliation and lineation are seldom apparent in the pegmatite, although in some places a faint sheeted structure and some alinement of quartz can be seen. A few thin sections show minor effects of deformation such as strain shadows in quartz and mortar structure between grains, but there has been no complete recrystallization of the rock. The grains interlock in a typical hypidiomorphic texture.

The predominant feldspar in the pegmatite is microcline, but microperthite also has been recognized in some specimens. Minor amounts of plagioclase are present, but the feldspar is so clouded with sericite and other alteration products that its composition is difficult to determine accurately by petrographic methods. Much of it has narrow clear rims of plagioclase. The clouded plagioclase appears to be sodic oligoclase near $An_{12}$; the rims are more sodic and appear to be albite between $An_5$ and $An_8$. The plagioclase is enclosed and partly replaced by the potash feldspar.

A trace of magnetite is the only visible dark accessory mineral in most of the larger bodies. Some of the pegmatite contains subhedral to euhedral xenocrysts and small aggregates of pyroxene derived by the incorporation and reconstitution of amphibolite or pyroxene amphibolite and skarn wallrocks. In places large euhedral crystals of hornblende are enclosed in the pegmatite. A narrow selvage of dark-brown biotite may occur on the contact between pegmatite and wall rocks, and B. F. Leonard (1944, unpublished report) reports garnetiferous selvages in pegmatite that has been injected into garnet-bearing gneisses.

A curious feature observed at several places underground, and in some surface exposures, is a local bleaching of the potash feldspar from pink or salmon to white. At the Cannon mine this bleaching seems to coincide with an abundance of magnetite which replaces feldspar. At most other places the bleaching has occurred where a small body of amphibolite or pyroxene amphibolite is enclosed in the pegmatite; this is especially well exemplified at the 200 level of the Scott mine where a bleached border as much as 4 inches wide surrounds pyroxene amphibolite lenses enclosed in pink pegmatite.

The pegmatites commonly seen in the quartz-oligoclase gneiss are composed of quartz and white or greenish, somewhat perthitic potash feldspar and some sodic plagioclase. In places, a little coarse hornblende, pyroxene, or biotite occurs as xenocrysts and little clots within the pegmatite, probably resulting from reconstitution of mafic minerals from the wall rock. Local concentrations of magnetite have been seen in a few of these pegmatites in quartz-oligoclase gneiss.

### COMPOSITION

The modes of two typical specimens of the pegmatite are:

TABLE 6.—*Approximate modes (volume percent) of pegmatite*

| | Specimen | |
|---|---|---|
| | 1 | 2 |
| Microline | 39.0 | 46.1 |
| Plagioclase | 23.0 | 17.3 |
| Quartz | 35.0 | 34.7 |
| Magnetite | 1.0 | 0.6 |
| Chlorite and epidote | 2.0 | 1.2 |
| | 100.0 | 99.9 |

1. Clean, fresh pegmatite from hanging wall of Summit mine.
2. Typical coarse-grained pink granite pegmatite from hanging wall of Long mine.

## RELATIONS BETWEEN THE GRANITIC ROCKS AND METASEDIMENTARY ROCKS

In most of the area the granitic rocks are interlayered conformably with metasedimentary rocks. Sheets of granitic gneiss and pegmatite alternate with layers of metasedimentary rock. These sheets have little or no apparent change in thickness and do not transect one another. Even the larger bodies are generally conformable with the metasedimentary rocks. In detail, however, slight discordances are discernible.

The contacts of the quartz-oligoclase gneiss with the metasedimentary rocks, though shown as distinct boundaries on the map, are transitional and rarely sharp. In the transition zones the rock is migmatitic. In these zones and in the rock adjacent to them, evidence of strong deformation marked by drag folding or fracturing of the inclusions is mostly lacking. Some examples of deformation, however, have been observed. At the contact between pyroxene amphibolite and quartz-oligoclase gneiss northeast of the Peters mine the granitic rock a few feet from the contact contains inclusions of the metasedimentary rock. Many of the inclusions are intricately drag-folded and some of the flexures are ruptured. Granitic material fills the openings.

While the boundary between quartz-oligoclase gneiss and metasedimentary rock is rarely clean cut, the contact between the potash granite and the metasedimentary rocks appears to be sharp. Migmatitic, or bed-by-bed, transition zones are rare except in a few places where felsic metasedimentary gneisses are at the contact. There may be intrusion of sheets of potash granite 5 to 25 ft thick along a contact.

### RELATIONS BETWEEN QUARTZ-OLIGOCLASE GNEISS AND HORNBLENDE GRANITE

Southwest of Spruce Swamp the hornblende granite and related facies appear to transect the quartz-oligoclase gneiss. The contact, however, is not exposed and one cannot be sure that the boundary is not faulted. Three-quarters of a mile west-southwest of Sterling Lake lookout tower a faulted tongue of coarse-grained alaskite extends into the quartz-oligoclase gneiss. The layer is concordant with the foliation of the quartz-oligoclase gneiss, and it appears to be a continuation of the main body of potash granite to the south. It is not a direct continuation, however, but is separated from the granite by a fault. The relationship, nevertheless, strongly suggests that the hornblende granite is the younger.

Earlier geologists in New Jersey were unable to determine the relations between the quartz-oligoclase gneiss (Losee) and hornblende granite (Byram). Spencer (1908, p. 5), in the Franklin Furnace folio, says, "The structural relationship between it and Losee gneiss is not known." Bayley (1914, p. 9) says, "Its relations to the Losee gneiss are not known, but it is probably practically contemporaneous with that rock, both gneisses possibly being differentiated from one magma." Elsewhere he states (1914, p. 9) that "* * * the Byram gneiss grades into the Losee by introduction of oligoclase * * *." Field relations between the quartz-oligoclase gneiss and the granite in the Sterling Lake and Ringwood area have not positively revealed such a transition. P. K. Sims (personal communication) recently made a detailed study of the Dover district, New Jersey, and has observed replacement of plagioclase by microcline in the quartz-oligoclase gneiss adjacent to some bodies of hornblende granite.

### ORIGIN OF THE GRANITIC ROCKS

The form of the granitic bodies, their structures, and their relationships to the older metamorphosed sedimentary rocks indicate that they were emplaced during or in the waning stages of tectonic activity that deformed the earlier rocks.

The hornblende granite and related alaskite and pegmatite probably formed by crystallization from a magma. There is no indication that the magma was modified or contaminated by the incorporation or assimilation of country rock. Furthermore, little or no replacement of the country rock accompanied the emplacement of the magma. The quartz-oligoclase gneiss has features that make it difficult to say how it originated. The interpretation tentatively held by the author is that the quartz-oligoclase gneiss formed by crystallization of material that was emplaced as a magma; possibly this material was formed by partial fusion of metasedimentary rocks under orogenic stress. Contamination of the magma by incorporation and reconstitution of amphibolite and pyroxene amphibolite was negligible; but locally there was some replacement of the metasedimentary rocks by solutions derived from the magmatic material.

The abundance of inclusions of amphibolite and pyroxene amphibolite in the quartz-oligoclase gneiss might be interpreted as relicts of the country rock that was incorporated in an intruded magma. Yet, at most places, contacts with the inclusions are clean and sharp and there is little evidence of reaction between the granitic material and the inclusions.

The quartz-oligoclase gneiss might be considered to be a contaminated facies of the hornblende granite. It would be difficult, however, to account for the removal or disappearance of the potash in the granite to derive the soda-rich quartz-oligoclase gneiss. Of course, if one wishes to view all these granitic rocks as resulting from "granitization" processes, the quartz-oligoclase gneiss might be considered as an intermediate stage between the original metasedimentary rocks and granite. Under these circumstances, the granite and related alaskite would represent the end stage of the granitization process; that is, the ultrametamorphic rock that has passed through a quartz-oligoclase gneiss stage.

Rocks similar to the granitic quartz-oligoclase gneiss are known in the Adirondack Mountains. They have been described and their origins discussed by Gallagher, Alling, and Buddington. Gallagher (1937) interprets the rock as being formed by a "combination of incorporation of xenoliths and pneumatolytic metasomatism," whereas Alling (1939, pp. 170–171) considered it to be a granite with some assimilated Grenville modified by the introduction of albite-oligoclase of late magmatic or deuteric origin. Buddington (1939, p. 170) thinks that it is "* * * a facies of amphibolite modified by thermal solutions given off by normal granitic magma." The process was accomplished by "the introduction of silica, soda and phosphorus, and the leaching of magnesia, lime, and ferrous oxide." Buddington likewise noted that "* * * the quartz-oligoclase gneiss appears to have formed from material which moved locally as a magma."

Postel (1952, pp. 12–13, 19) has recently described plagioclase granite gneiss from the Adirondacks. He regards it as having formed in several ways: "* * * (1) from local anatexis, (2) from soda-rich solution produced during granitization by a potash-rich magma, and (3) perhaps locally by thermodiffusion-convection at contact zones of the potash-rich magma that produced the microperthite type of granite."

## YOUNGER DIKE ROCKS

A few diabase dikes intrude the gneisses and have been observed at the surface. Lamprophyric rocks have been found in a few drill holes but, except for an isolated boulder, are not exposed at the surface.

### OCCURRENCE

The diabase dikes range in thickness from a few inches to as much as 30 ft, but the majority measure 2 to 3 ft. No dike more than about 50 ft long has been seen.

The prevailing attitude of the mafic dikes is approximately normal to the strike of the foliation. Most of them trend more or less east-west, and dip steeply or are vertical. In these respects they have the same structural relationship to the gneisses as the transverse joints.

The generally fine-grained texture and chilled contacts indicate that the dikes were intruded into relatively cold country rocks. No flow structures were seen in any of the dikes.

### AGE OF DIKES

Small dikes and irregular bodies of mafic rocks like those of the Sterling Lake and Ringwood area have been mapped and described by Spencer (1908, p. 13). Milton (1938; 1947) has recently studied the diabase and lamprophyre dikes in the Franklin Furnace, N. J., area. According to him, the diabase dikes are indistinguishable from the major hypabyssal diabase intrusions of Triassic age elsewhere in New Jersey. The lamprophyres are probably related to the alkalic rocks and camptonites of post-Ordovician age in northern New Jersey. The dikes in the Sterling Lake and Ringwood area may thus be post-Ordovician and possibly Triassic in age.

## GLACIAL AND STREAM DEPOSITS

More than one-third of the mapped area is covered by glacial and stream deposits of Quaternary age. The glacial features in this region have been thoroughly described by Salisbury (1902, pp. 490–494). No attempt has been made to distinguish these deposits on the map, but the bulk of them are of glacial origin. Alluvium is confined to sand and gravels along the streams, much of which is probably reworked glacial material.

The glacial deposits, particularly in the southern half of the area, are widespread and not necessarily confined to drainage channels; they blanket the lower slopes of knobs and ridges at altitudes as great as 500 ft in the southern part of the area and 1000 ft in the northern part. The thickness in any one place is not accurately known. In the lowland east of the Scott mine the overburden is as much as 25 ft thick; it may be thicker in the southern part of the region.

The glacial deposits are composed of sand, gravel, and boulders in heterogeneous arrangement typical of ground moraine. The bulk of the rocks composing the fragments that are coarser than sand are gneisses whose bedrock representatives occur in the district; lesser amounts of sandstone, shale, and conglomerate derived from terrain underlain by Paleozoic strata north and northwest of the mapped area are mixed wilth the pre-Cambrian rock fragments. The most conspicuous Paleozoic rock is a red conglomerate characteristic of the Silurian Shawangunk conglomerate.

## STRUCTURAL FEATURES

### FOLIATION

Most of the pre-Cambrian rocks have a megascopically visible planar structure. This planar structure, usually referred to as the foliation, is due to the parallel arrangement of platy minerals such as mica flakes or of elongate minerals like hornblende. Tabular minerals, such as feldspar, also may be arranged so that their broadest surfaces lie essentially in a plane. Foliation may be due to the parallelism of laminae of different mineral composition representing original compositional differences in sedimentary rocks, to rearrangement and concentration of different minerals into layers by metamorphism, to bed-by-bed injection of igneous material, or to replacement of some strata in preference to others.

The prevailing direction of strike of the foliation at any given place in the area is also the trend of the lithologic units. At no place does the foliation lie athwart the rock layering. In general, the foliation strikes northeast and dips at moderate to steep angles east and southeast. However, systematic plotting of attitudes over the whole area reveals a complex pattern of foliation.

### LINEATION

Linear structures are of several kinds: At most places there is parallel arrangement of the long axes of rodlike minerals such as hornblende or sillimanite, or of the longest crystallographic axes of elliptical plates of mica, or of the prismatic zone of feldspar. In many of the granitic rocks the quartz may be drawn out into elongate blebs. Even where no mineral alinement is megascopically visible, striations and a fluted structure due to slight crinkles on a foliation surface serve to indicate a lineation. The attitude of the lineation is defined by the strike of its horizontal projection and its plunge. Plunge, as used here, is the angle measured from the horizontal in a vertical plane.

The trend of the lineation is very constant over the entire area. At most places the linear structure plunges northeast, the angle measured in the vertical plane ranging from 5° to 60°. Most of the angles are between 10° and 30°, and angles from 35° to 50° are next most common. The strike of the foliation is predominantly northeast, and the trend of the lineation nearly parallels it in many places.

North of Sterling Lake the plunge is very gentle, or essentially horizontal, and the trend nearly north-south. Near the northern limit of the area mapped the direction of plunge is south-southwest. In the southern part of the area of hornblende granite east of Sterling Lake lineation is essentially down dip and hence plunges moderately to steeply east and east-southeast.

The bearing of the lineation is parallel or essentially parallel to the strike of the axial plane of the folds. The folds and the lineation plunge in the same direction and apparently at almost the same angle.

### ORIGIN OF THE GNEISSIC STRUCTURE

Dynamothermal metamorphism has resulted in secondary foliation in the metasedimentary rocks, and this foliation is indicated by a cleavage. So far as could be determined in the field, the cleavage is parallel to the layering, which may be primary in part and reflects original compositional differences that were inherited by the gneisses. Much of the layering is due to bed-by-bed injection, or differential replacement by magmatic material that followed the original stratification of the sedimentary beds or was guided by secondary cleavages and layering formed before the period of magmatic activity.

Some of the foliation in the quartz-oligoclase gneiss is probably inherited from structures in the metasedimentary rocks which it intruded, assimilated, or replaced, and, as such, is to be considered primary. Planar structure exists in quartz-oligoclase gneiss which shows no evidence of recrystallization and hence the foliation is judged to be primary. Some secondary foliation may have been superimposed on older primary structures by recrystallization.

The apparently undeformed structure of the hornblende granite in most places indicates that its foliation also is mostly of primary origin and was formed in the magma before consolidation. A secondary foliation may have been imposed locally by some recrystallization.

The lineation in the metasedimentary rocks was imposed under conditions of dynamothermal metamorphism. In the absence of fabrics of recrystallization in the granitic rocks it must be assumed that the mineral orientation and elongation are primary.

The concordance of foliation and lineation in the granitic rocks with gneissic structures in the metasedimentary rocks may be due in part to inheritance of earlier-developed structures through replacement by magmatic material, and in part to the influence of enclosing rocks by frictional drag on the magma as it was intruded. Or, as seems more likely, they were syntectonic intrusions; in other words, the tectonic forces which caused folding and the development of gneissic structures in the metasedimentary rocks continued during the emplacement of the granitic rocks and imposed similar structures on these unconsolidated granitic rocks. By the time the granitic gneisses had solidified, tectonic activity had essentially ceased, so that they show no recrystallization except locally.

### FOLDS

The attitudes of foliation and the general distribution of the rocks indicate a complex series of folds (pl. 19).

The best-defined structural pattern is in the north-central part of the region mapped. A succession of asymmetric anticlines and synclines, some of which are overturned slightly to the west, can be discerned. Only the most prominent folds, and those involving the magnetite deposits are described in detail. Other folds can be seen on the geologic map (pl. 19).

At the south end of Sterling Lake the southern end of a syncline is well-defined. A northeast-trending fault transects the fold at the Tip Top mine. The structure dies out to the south in the large body of hornblende granite, and northward the syncline disappears beneath the lake. Colony (1923, pp. 76–80) described the Lake mine ore body as occupying the western limb of an asymmetric syncline plunging 16° NNE.

East of the Sterling Lake syncline is a tightly folded asymmetric anticline that has a core of quartz-oligoclase gneiss. The crest of this fold is between the Scott-Cook-Augusta mineralized zone on the east and the Causeway mineralized belt on the west. North of the Scott mine the fold is cut by a cross fault northwest of which the relative displacement has brought up the broader nose of the north-plunging structure. Here, the Long mine is on the east limb, and the Mountain mine and Scott shaft are on the west.

A large area of hornblende granite enclosing long, continuous interlayered sheets of amphibolitic gneiss and skarn is found in the eastern part of the Sterling Lake region. The layers of metasedimentary rock on either side of the central body of granite converge to the south. The junction of the eastern and western layers cannot be seen in the field because of a large swamp, but north of the swamp the gneiss is strongly plicated, as if on or near the axis of a fold. In one or two places toward the central part of the granitic body there is also some plication of the foliation. The foliation also converges toward the south, but the direction of dip of the foliation is the same on both flanks and in the central part of the area. In the belts of metasedimentary gneiss and granite gneiss on the flanks and in the area south of the "nose," the lineation trends in a north-northeast direction and plunges at a low to moderate angle northeast. Linear structures in the gneiss in the south-central part rake at large angles to the strike of the foliation and plunge nearly down the dip, that is, in an easterly direction. At the south near the nose are minor corrugations whose axes plunge south. The significance of this plunge of the lineation to the south and east is not understood, especially as observations on the flanks show a northeasterly plunging lineation. The same kind of lineation, that is, mineral alinement, has been measured in both instances. The writer is not prepared to state positively that this structure is a fold. The outcrop pattern and foliation could be due to the wedging apart of layers of sedimentary rock by a large intrusive body that tapers at the south end and expands toward the north. If the structure is a fold it must have essentially isoclinal limbs and be overturned to the west. Its shape suggests a north-plunging syncline.

Near the Ringwood mines in the southern part of the area mapped, some general structures can be distinguished, but much of the detail is lost because large amounts of quartz-oligoclase gneiss and hornblende granite have engulfed the metasedimentary rocks, leaving only remnants of what appears to have been a complex of small, tight folds. In the southern part of the area the strikes of the foliation converge from the east and west and meet in the vicinity of Ringwood. A series of crenulations or drag folds in this area suggests that this is the crenulated trough of a large synclinal fold.

### FAULTS

Transverse faults cut the igneous and metasedimentary rocks alike. No longitudinal faults were recognized at the surface, and the only known faults parallel to the rock structure are underground at the Ringwood mines and at the Scott mine in the Sterling district.

The most prominent faults in the region are two essentially parallel faults striking about N. 80° E., and cutting obliquely across the strike of the foliation. One, north of Sterling Lake, has resulted in an apparent horizontal displacement of about 800 ft, the northern side having an apparent offset to the east. Along the other cross fault, south of Little Cedar Pond, the direction of offset is the same, and the amount of displacement is more than 1,100 ft near Beach Mountain. So far as could be ascertained, the fault planes are practically vertical. The principal direction of movement could not be determined.

East of Sterling Lake an oblique fault that strikes about N. 45° E. is the boundary between metasedimentary rocks and granitic quartz-oligoclase gneiss in the vicinity of the Scott mine. Underground at the Scott mine the probable extension of this fault dips 50° NW. The apparent horizontal displacement of eastward dipping layers of metasedimentary gneiss is northeast, indicating that the northwest side of the fault has moved upward relative to the southeast or footwall.

A few other small oblique faults have been mapped; one occurs south of Sterling Lake, others offset the contact of hornblende granite with quartz-oligoclase gneiss west and northwest of Little Cedar Pond.

At least part and probably all of the faulting took place after the structures were folded and the granitic rocks consolidated. In the mines the faulting is postore.

### JOINTS

Two conspicuous joint sets have been observed: transverse or regional tension joints, and longitudinal joints. The transverse joints are seen in all exposures and are essentially normal to the trend of the linear structure. Hence the majority of joints of this type strike west-northwest. The dip is from 80° to vertical. The longitudinal joints are slightly less clearly defined. The most common longitudinal joints are parallel to the foliation, but vertical strike joints at an angle to the dip of the foliation also are common.

A third set of joints is seen on broad, flat exposures. The joint surfaces are essentially horizontal or may dip gently in any direction. These joints may be either primary or simply a sheeting due to release of load through erosion.

## MAGNETITE DEPOSITS

### HISTORY

Thirty-five mines and prospects are known in the Sterling Lake and Ringwood area. The discovery and mining of the magnetite deposits began early in the development of the region. The ore deposits at Ringwood were known sometime before 1740, the year a blast furnace was built there. Ore was discovered on the site of the old Sterling mine in 1750; a furnace and forge were later erected. Most of the other deposits in the region were also opened about this time. These mines, furnaces, and forges, as well as many others in New Jersey and New York, played an important role in the production of iron to fulfill the needs of the Colonies and later the Continental Army and finally the young republic.

The mines in the Sterling Lake and Ringwood area continued to be an important source of iron ore until late in the 19th century. About 1880 the market for ore from this general area began to diminish because of the increased use of the Lake Superior ores. As a result, many of the smaller mines throughout New Jersey and New York were shut down and have not been operated again. Only the larger mines continued in operation; the small furnaces were abandoned, and the ore was shipped by railroad to centrally located blast furnaces. None of the mines of the Sterling Lake and Ringwood area was producing in 1950.

The London Company, also known as The American Iron Company (Boyer, 1931, p. 12), owned several mines and furnaces in northern New Jersey and held title to the mines at Ringwood from pre-Revolutionary time until about 1807. The Ringwood property was sold to Martin Ryerson and was held by his family until 1853 when it was acquired by Peter Cooper. Subsequently it was passed on to Cooper Hewitt and Co. and Abram S. Hewitt, Cooper's son-in-law. The property was operated under the name of The Ringwood Company by Abram Hewitt's son, Erskine Hewitt, and his heirs until 1931. In 1942 the property was purchased by the U. S. Government (Defense Plant Corporation) and reconditioned by the Alan Wood Steel Company, which placed the mines in standby condition in World War II. This company did considerable work on underground improvement and development, and erected a new mill. The property was leased by a private company in 1947 and a small tonnage of ore (46,900 tons) was produced. Since then, the property has been returned to the U. S. Government which still held it in 1950. Except for the small tonnage in 1947 no ore has been produced since the early 1930's.

The history of ownership of the mines in the Sterling Lake district is not so well known as that of the mines of the Ringwood district. The land on which these mines are located is owned by the Sterling Iron and Railway Company. For many years during the operation of the mines the property was leased by the Sterling Iron and Railway Company to the Ramapo Ore Company. From June 1918 until the mines were finally closed in 1921, the Bethlehem Steel Company was in charge of the operations. The Lake and the Scott-Cook mines, the largest in the area, are abandoned and the workings flooded. None of the smaller but once active mines is now accessible.

## DISTRIBUTION

### STERLING LAKE DEPOSITS

Colony (1923) subdivided the deposits of the Sterling Lake district into the Sterling group and the Scott group (fig. 44).

The Sterling group at the south end of Sterling Lake includes the old Sterling and Lake mines, the Tip Top mine, and several small mines and prospects distributed in an arc at the base of a small hill directly south of the lake. The Scott group is 1 to 2 miles northeast of the Sterling and Lake mines.

In the Sterling group the deposits occur along two zones or mineralized belts, a stratigraphic distance of about 200 ft apart at the south

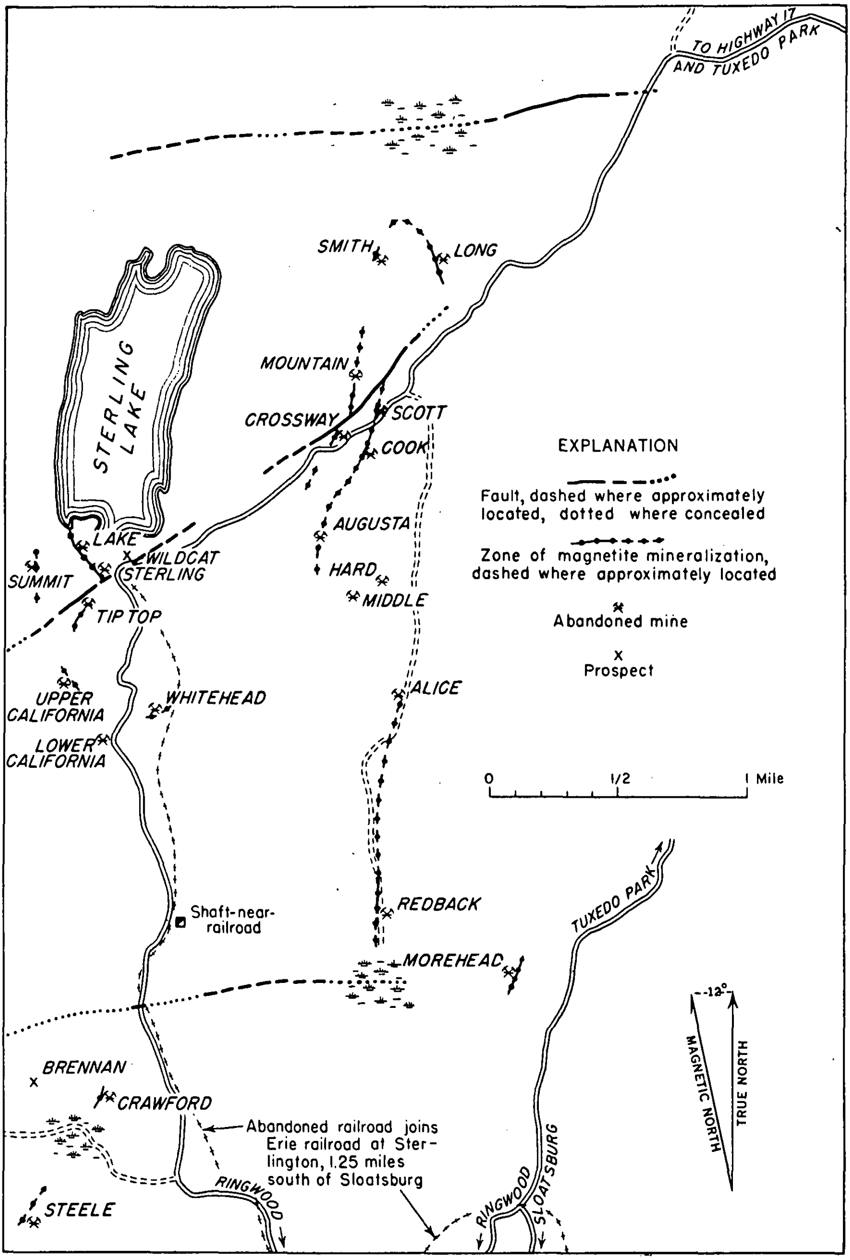


FIGURE 44.—Index map of the Sterling Lake district, Orange County, N. Y.

end of the Sterling Lake syncline. The underground workings of the Lake and Sterling mines, now flooded, are beneath Sterling Lake (fig. 45) and are on the upper mineralized zone. The Tip Top mine, less than 1000 ft south of the Lake mine shaft, is on a segment of the upper zone that has been displaced by a fault. The Summit, Upper California, Lower California, and Whitehead mines are on the lower zone. The zone is barren north of the Whitehead mine but the magnetite deposits of the Scott group may be on the northward extension of this lower zone.

The deposits of the Scott group (fig. 44, pl. 20) are in two nearly parallel zones that are actually parts of one belt of pyroxene amphibolite and amphibolite. This belt is on the western and eastern limbs of a tight anticline. The eastern part of the belt may be continuous with the lower zone of the Sterling group.

From north to south the mines on the eastern zone are the Long, Scott-Cook, and Augusta; on the western zone they are the Smith mine, Mountain, and Crossway.

### RINGWOOD DEPOSITS

The ore deposits in the Ringwood district are in several discontinuous zones (fig. 46). Nason (1895, p. 514) was of the opinion that they were once all in the same ore zone and subsequently were folded to their present positions. No evidence was found by the author to support this interpretation of the structure. With the possible exception of the Ward-Bush zone, which may be a continuation of the zone in which the Cannon mine lies, the ore zones apparently are separate and probably were never continuous. Furthermore, there is no indication that they are faulted segments of a single zone. The principal deposits are within a northeast-southwest strip not much more than a quarter of a mile wide and about 1½ miles long. The mineralized zones trend northeast-southwest and are relatively short. The Peters-Hope Mountain zone, in which the Peters mine is located, is at the north end. Several pencillike shoots of ore, at least five of which are included in the Peters mine, occur in this zone. The Cannon mine at the south end of the district includes several closely spaced ore shoots that were mined separately at an earlier period. The geology is complex, but apparently this cluster of shoots lies in the trough of a northeast-plunging syncline. Between the Peters and the Cannon mines are three ore zones that were mined by the Cooper, Keeler-Miller-St. George, and Ward-Bush mines, about which little is known.

### OTHER DEPOSITS

Other deposits of lesser importance occur elsewhere in the area. They include the Crawford and Steele mines, which are on a zone of mineralization just north of the New Jersey boundary, the Redback

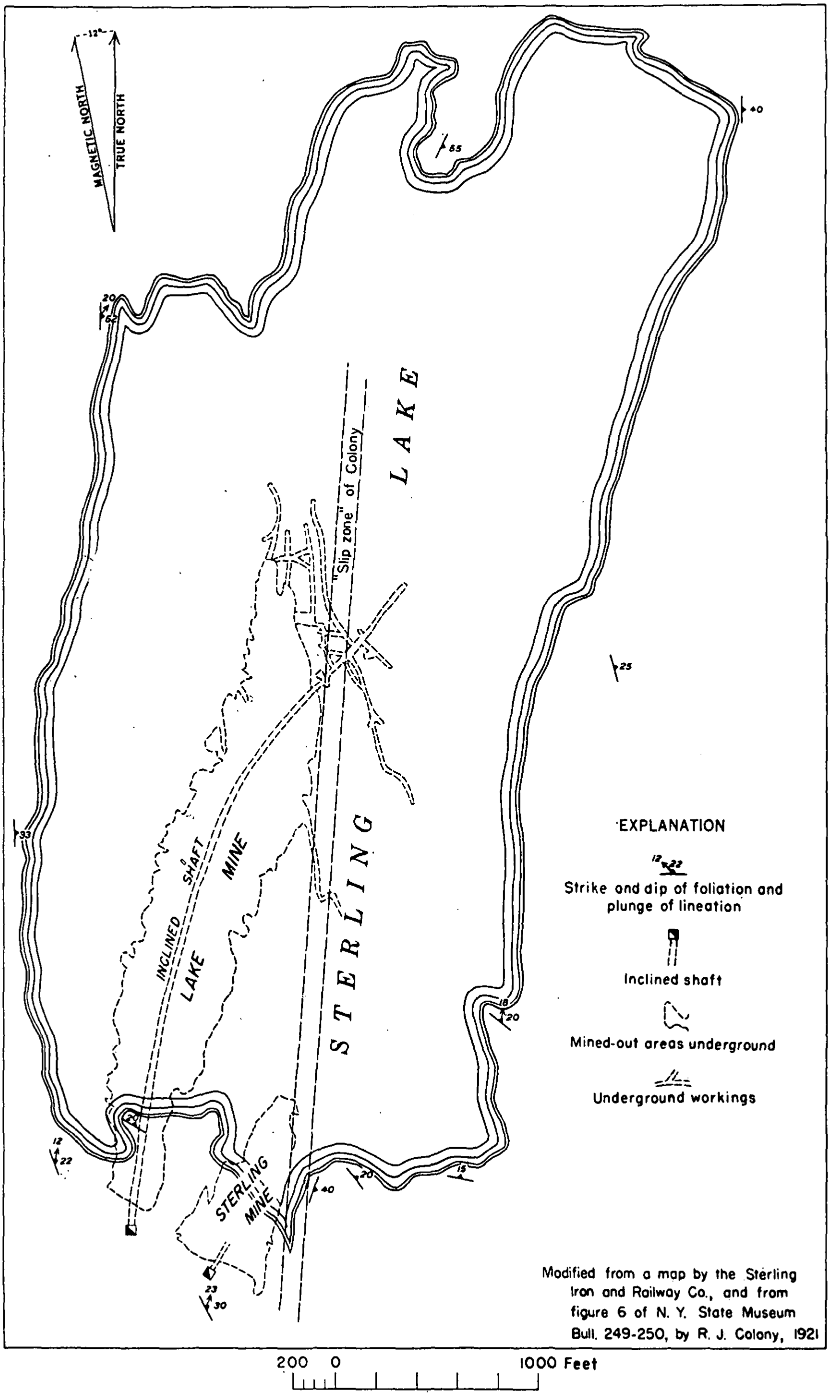


FIGURE 45.—Sketch map showing location and extent of underground workings in the Lake and Sterling mines, Orange County, N. Y. Modified from a Sterling Iron and Railway Company map and from figure 6 in Colony, 1921, New York State Mus. Bull. no. 249–250.

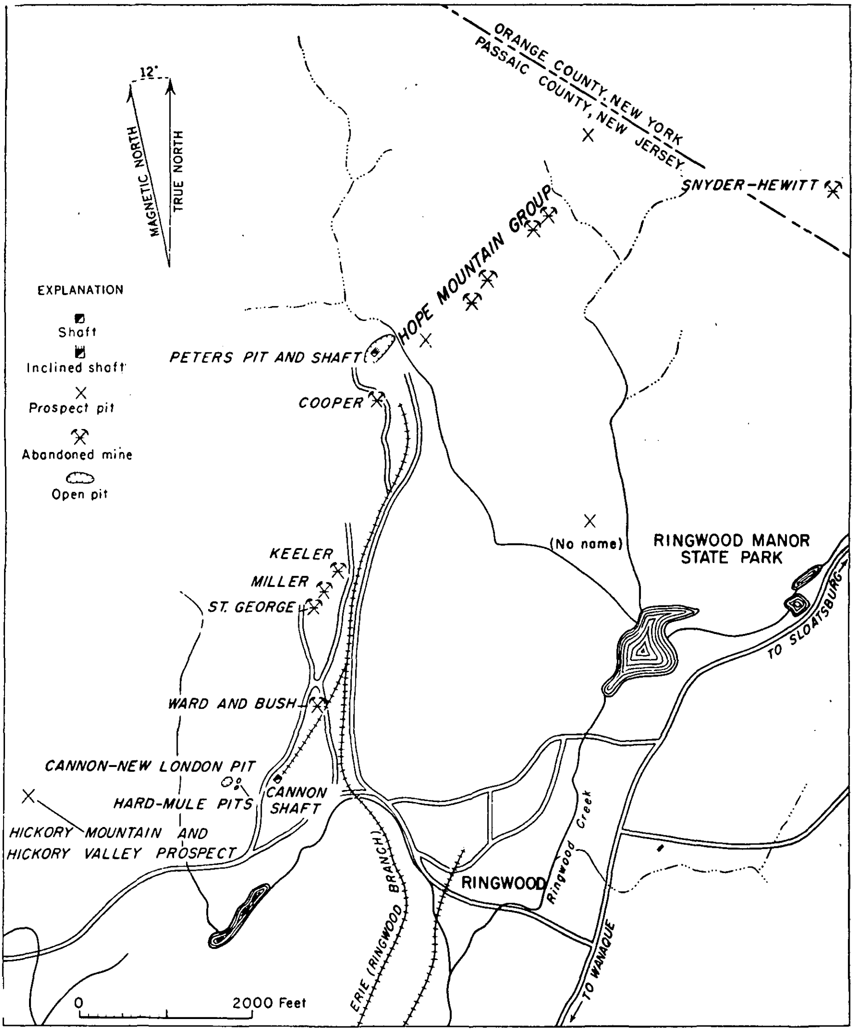


FIGURE 46.—Index map of the Ringwood district, Passaic County, N. J.

mine east of the Sterling Lake district, and several others described in the section on mines and prospects, whose locations are shown on plate 19.

## PRODUCTION

The record of production from the mines in the Sterling Lake and Ringwood area is incomplete. The available data are given in tables 7 and 8.

TABLE 7.—*Production of iron ore from the Sterling Lake district*

[No data for Sterling, Tip Top, Summit, Upper California, Lower California, Whitehead, Smith, or Augusta mines]

| Mine | Tons | Dates | Reference |
|---|---|---|---|
| Lake | 1,254,283 | 1750 (?)–1917 | Colony, 1923, p. 80. |
| Long | 37,500 | 1761–1839 | Colony, 1923, p. 93. |
| Mountain | 7,000 | 1831–1839 | Colony, 1923, p. 94. |
| Crossway | 128,000 | 1793–(?) | Colony, 1923, pp. 95–96. |
| Scott-Cook | 497,500 | (?)–1921 | Estimated from mine maps. |
| | 1,924,283 | | |

TABLE 8.—*Production of iron ore from the Ringwood district*

[No data on individual mines available; most of production probably from Cannon and Peters mines]

| Dates | Tons | Reference |
|---|---|---|
| Production to June 1880 | 896,000 | Bayley, 1907, p. 478. |
| Production from June 1880 through 1907 | 325,000 | Do. |
| Production from 1908 through 1910 | 84,596 | Records of the New Jersey Department of Conservation and Economic Development. |
| Ore shipped from 1911 through 1931 | 1,365,523 | |
| Total 1880–1931 | 2,671,119 | |

## GENERAL CHARACTER

The principal iron mineral is magnetite ($Fe_3O_4$), the magnetic oxide of iron. In some places a small amount of the nonmagnetic iron oxide, hematite ($Fe_2O_3$), is intimately associated with magnetite. The hematite in a few specimens has the outward form of magnetite and is called martite.

The best grade of ore consists of compact, coarsely crystalline magnetite and a gangue of sparsely disseminated grains of silicate minerals. It is usually structureless except for a distinct blocky appearance due to closely spaced joints. Much of the material is a crystalline magnetite rock containing some silicate minerals as granules interstitial to the grains of magnetite. Some of the material has a banded or foliated appearance due to alternating layers of magnetite-rich and essentially barren rock. With a decrease in the amount of magnetite and a corresponding increase in the proportion of gangue minerals, the low-grade material passes gradually into gneiss or skarn containing disseminated granules or irregular masses of magnetite.

The chemical composition of pure magnetite is Fe=72.4 percent, O=27.6 percent, but, except perhaps in selected specimens, this concentration of iron is never attained in the deposits. Ore ranges in grade from about 35 percent to as much as 68 percent Fe. Most of the mines have furnished material ranging in grade between 40 and 60 percent Fe. The magnetic properties of the ore permit beneficiation with magnetic concentrators to raise the grade. Most of the ore is so consistently low in sulfur that it is not necessary to sinter it. Titanium is generally low, but phosphorus tends to run high. The phosphorus is present as the mineral apatite, which can be partly removed by grinding and concentrating the magnetite. Titanium is mostly locked up in the magnetite and cannot be removed by concentration, but the titanium content is not high enough to be objectionable.

## MODE OF OCCURRENCE

In the Sterling Lake and Ringwood area magnetite deposits occur in pyroxene amphibolite and amphibolite and in skarn. No deposits of economic value are found in the granitic rocks, although in the vicinity of some of the ore bodies disseminated magnetite occurs in pegmatite.

### DEPOSITS IN PYROXENE AMPHIBOLITE AND AMPHIBOLITE

The larger and more important deposits are in zones of pyroxene amphibolite and amphibolite. The deposits most commonly are at or near the contact with quartz-oligoclase gneiss. Pegmatite is commonly associated with the deposits and in places it forms the walls, and a body of magnetite may be completely enclosed in pegmatite. Ordinarily, however, the pegmatite has the form of sheets, tongues, and irregular bodies (rarely dikes) partly or wholly enclosed by the magnetite. A rock type seen at many places underground but not observed in surface exposures is an intimate mixture of pegmatite, pyroxene amphibolite, and, at some places, quartz-oligoclase gneiss. Locally the pegmatite contains clots and aggregates of green pyroxene and some hornblende, or biotite-rich streaks due to nearly complete reconstitution of the pyroxene amphibolite by the solutions that formed the pegmatite.

### DEPOSITS IN SKARN

Magnetite deposits in pyroxene skarn are neither plentiful in this area, nor do they have the persistence and continuity of the deposits in the pyroxenic and amphibolitic gneisses. Possibly this is because the greater volume and persistence of the gneisses offered more sites that were favorable for deposition of magnetite in quantities of economic value.

The skarn may be accompanied by remnants of marble that are partly replaced by magnetite. More or less serpentine may accompany the deposits in skarn and at some places chlorite, tremolite, and actinolite are abundant. The magnetite is commonly accompanied by some sulfides, principally pyrite and pyrrhotite, which partly replace magnetite and the silicates.

The wallrocks may be skarn, marble, pyroxene amphibolite or amphibolite and some of the deposits are enclosed in quartz-oligoclase gneiss. Pegmatite has the same intimate relations to the ore occurring in skarn that it has in ore bodies in the amphibolitic rocks.

## STRUCTURE OF THE MAGNETITE DEPOSITS

### GENERAL STRUCTURE OF THE ORE BODIES

The magnetite deposits occur in well-defined zones along which there may be one or more bodies of minable size. Commonly these are pod-shaped or lenticular bodies or shoots whose greater cross sectional dimension and longitudinal axis are in a plane parallel to the foliation of the enclosing rocks. The dip corresponds rather closely to the dip of the rock foliation, and the plunge corresponds to the plunge of the linear structure of the enclosing gneiss. (The plunge of a shoot is the vertical angle measured between the horizontal and the line of maximum elongation of the body.) The lean or barren rock overlying the crest of a shoot in the plane of the foliation is commonly spoken of as the "cap rock" or "top rock," and that beneath the shoot is called the "bottom rock." (The top and bottom rock are not to be confused with the hanging wall and footwall.) The shoots pinch and swell somewhat along the plunge but in general their cross section is rather constant. Figure 47 illustrates these relationships.

The comparatively barren rock between shoots lying more or less in the same plane are known as "pinches." Commonly these pinches are not entirely barren, for thin veinlets or stringers of magnetite connect the shoots. In some deposits the pinch is merely a narrower and hence uneconomic part of a tabular body of magnetite. In some other deposits where the shoots thin completely out, the intervening rock is so impregnated with scattered grains and clots of magnetite that it constitutes a low-grade ore.

In the Sterling Lake district the larger and more important magnetite bodies are essentially tabular and veinlike. Certain parts of the bodies are thicker than others and constitute the shoots. The thinner parts of the veins, or pinches, were mined with the shoots. A good example of the tabular type of ore body is found at the Scott mine (pl. 23). In contrast, the Ringwood district deposits are pencillike plunging shoots separated from one another by essentially barren pinches. The shoots of the Peters mine (pl. 21), and the Hard-Mule "vein" of the Cannon mine are typical.

The ore bodies are not solid masses of magnetite or magnetite-bearing gneiss but contain blocks, or "horses," and veinlike sheets of barren rock that split and divide the ore and in some places are remarkably persistent. In most places the barren rock is pegmatite or granite and less commonly granitic quartz-oligoclase gneiss. Some small bodies of magnetite are surrounded by barren rock.

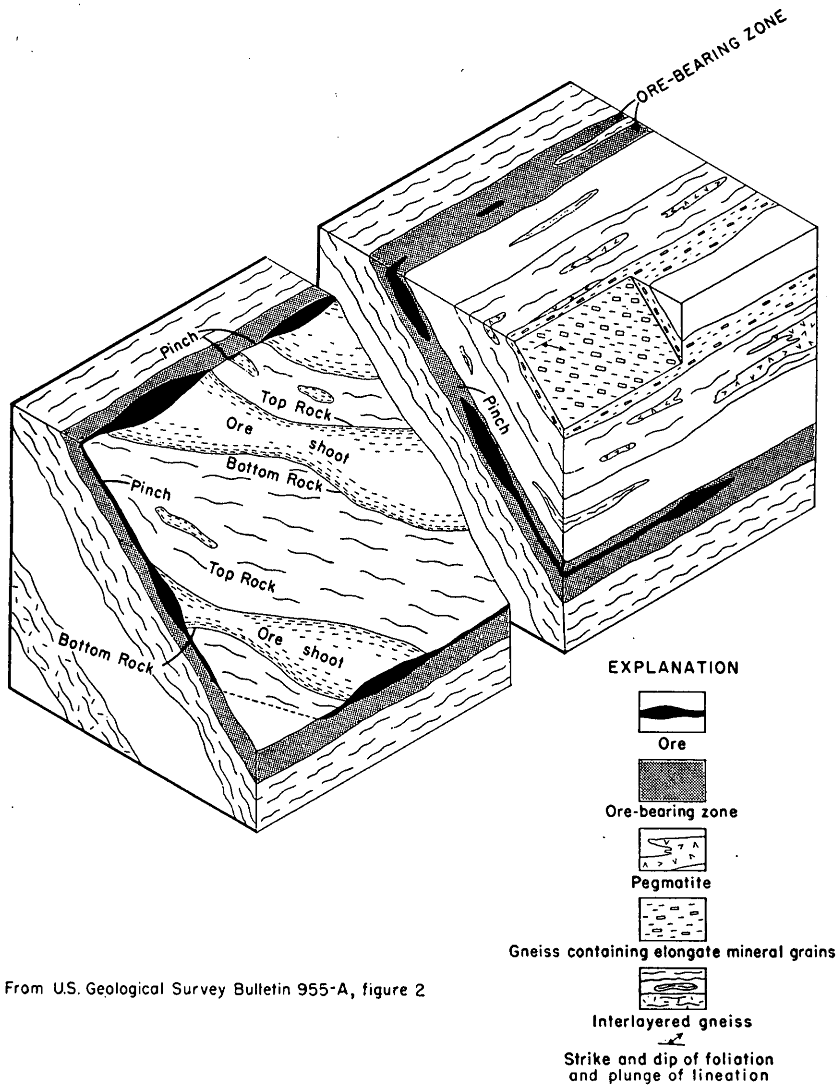


FIGURE 47.—Idealized block diagram showing the structural relations of country rock to ore. From Hawkes and Hotz, 1947, U. S. Geol. Survey Bull. 955–A, p. 5.

The relation of the ore bodies to the enclosing wallrocks is in general one of conformity. Where the details of the contact between ore and country rock are examined, however, it is evident that the relationship is not always a strictly conformable one. In places the boundary is sharp and parallels the foliation of the gneiss; locally little tongues and veinlets of magnetite split off from a main body of ore and cut the wall rocks for short distances. Elsewhere the boundary is abruptly gradational. Boundaries are sharpest where the wall rock is pegmatite or granitic gneiss.

### FOLDS

In the Sterling Lake and Ringwood area many of the magnetite deposits occupy zones that are involved in folds but there is no positive evidence that the ore bodies have been folded since their formation. Rather, apparently folds exerted some control on the localization of magnetite deposition. Thus two of the larger deposits, those of the Lake and Cannon mines, occur in the trough of synclines, and many of the mines in the Sterling Lake district are on the limbs of folds. Furthermore, in a few places there is some evidence that minor crenulations or flexures parallel to the plunge of the lineation in the gneisses controlled the position of individual ore bodies.

### FAULTS

Faulting after the magnetite was deposited has affected the ore bodies to various degrees. For the most part the displacements are small, but in places postore faulting has caused important offsets of the magnetite bodies. Faults that affect the ore cannot ordinarily be recognized at the surface, but they have been seen underground. Their number and importance vary from mine to mine. Most of the faults are steep, and intersect the ore at large angles to the strike of the ore bodies; the displacement is commonly only a few feet and is probably normal. Some reverse faulting has been seen at the Cannon mine at Ringwood and at the Scott mine in the Sterling Lake district. Most observations of striae on slickensided surfaces reveal a marked horizontal component of movement. Minor zones of slippage between the ore and the wallrocks parallel to the gneissic structure are fairly common.

### RELATIONSHIP TO PEGMATITE

The relation between pegmatite and the magnetite deposits is somewhat obscure. The occurrence of small pods and sheets of ore completely enclosed in pegmatite has been cited by some as proof of the postore introduction of pegmatite. However, at places where pegmatite apparently cuts the ore magnetite has replaced the feldspar of the pegmatite along the contact. In a few places magnetite extends from the ore body into the pegmatite where it almost completely replaces the feldspar, leaving unreplaced quartz in a matrix of magnetite. Thin veinlets and stringers of magnetite can be seen in the pegmatite extending a foot or so beyond the contact (fig. 48). The writer believes the evidence shows that pegmatite emplacement preceded the deposition of magnetite.

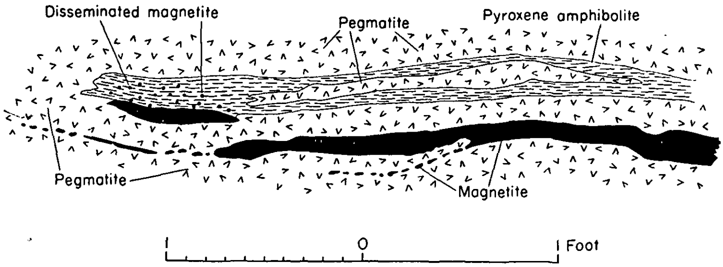


FIGURE 48.—Field sketch of hanging wall at Augusta mine. Magnetite has replaced an inclusion of pyroxene amphibolite in pegmatite. Veinlets of magnetite replace the pegmatite for a short distance beyond the replaced inclusion.

Colony (1923, p. 71) emphasizes the constant association of magnetite ore and pegmatite as evidence of the igneous origin of the magnetite. The association is certainly a constant relationship in the Sterling Lake and Ringwood area, but work by Sims (personal communication) in the Dover area has shown that pegmatite is much less abundant there, and that the magnetite deposits are not necessarily accompanied by pegmatite. Therefore, in the Sterling Lake and Ringwood area the magnetite may not necessarily be genetically related to the pegmatite except in so far as the pegmatite was formed in structural environments that were also favorable for the introduction of magnetite, which locally replaced the pegmatite.

## MINERALOGY AND PARAGENESIS

Thin sections and polished ore specimens collected by the writer, as well as a suite of thin sections and polished specimens collected by R. J. Colony in southeastern New York and made available by the geology department of Columbia University, have been studied under the microscope.

### MAGNETITE

The ore is composed of intergrown anhedral grains of magnetite ranging from microscopic dimensions to as much as 0.2 in. across. The best grade material consists of solid masses of intergrown magnetite grains, with here and there an included gangue mineral (fig. 49). In lower grade ore the magnetite aggregates are in veinlets and irregular bodies enclosing larger masses and groups of the normal minerals of the host rock. The magnetite in the poorest grade ore occurs as small grains or clusters of grains surrounded by the rock minerals.

The magnetite has replaced minerals of the host rock (figs. 50 and 51). It penetrates along grain boundaries and has smooth but irregular contacts with the minerals of the host. Under the microscope

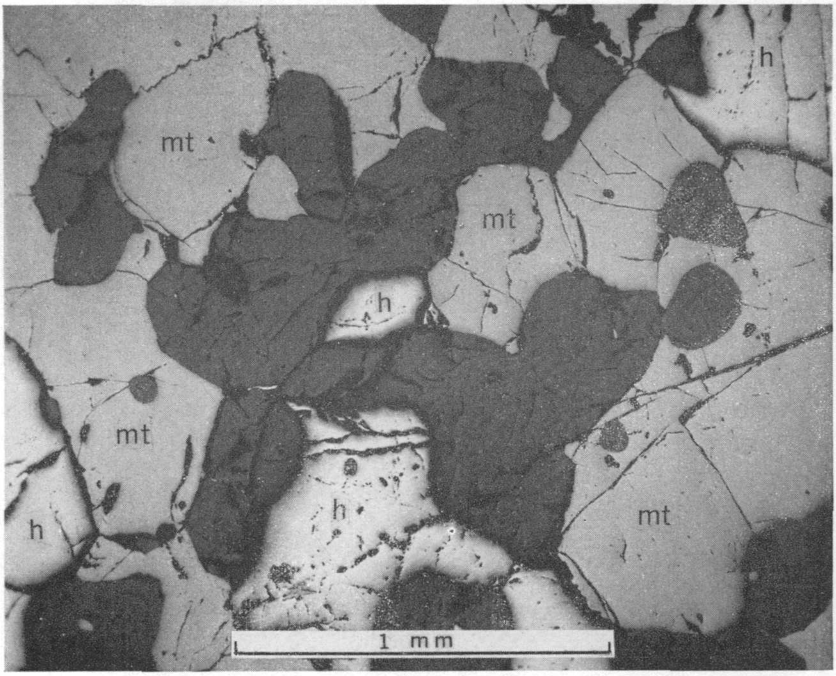


FIGURE 49.—Photomicrograph of polished specimen showing unreplaced silicate gangue in magnetite. Pyroxene (dark), magnetite (mt), hematite (h). Cannon mine.

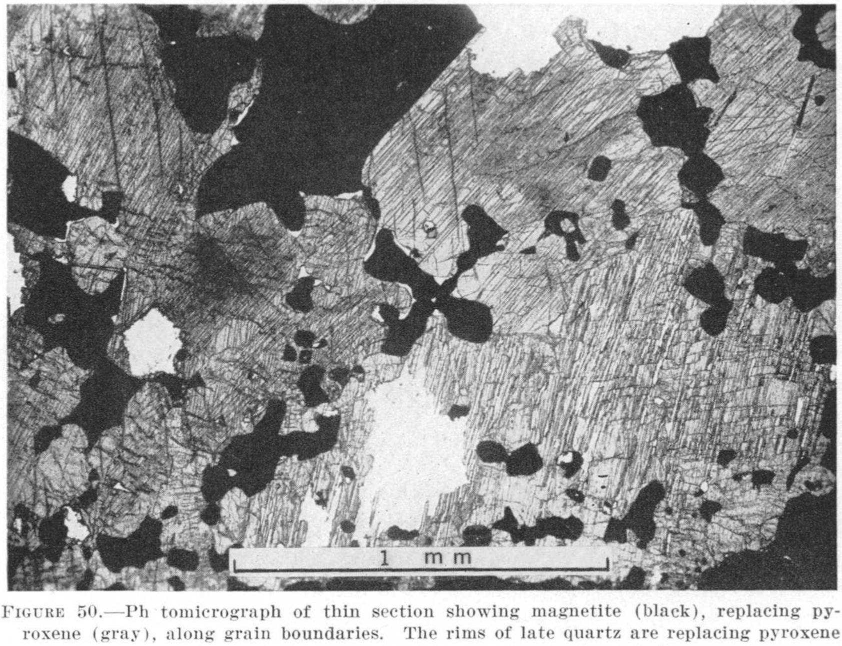


FIGURE 50.—Ph tomicrograph of thin section showing magnetite (black), replacing pyroxene (gray), along grain boundaries. The rims of late quartz are replacing pyroxene along some of the magnetite-pyroxene boundaries. Scott mine. Ordinary light.

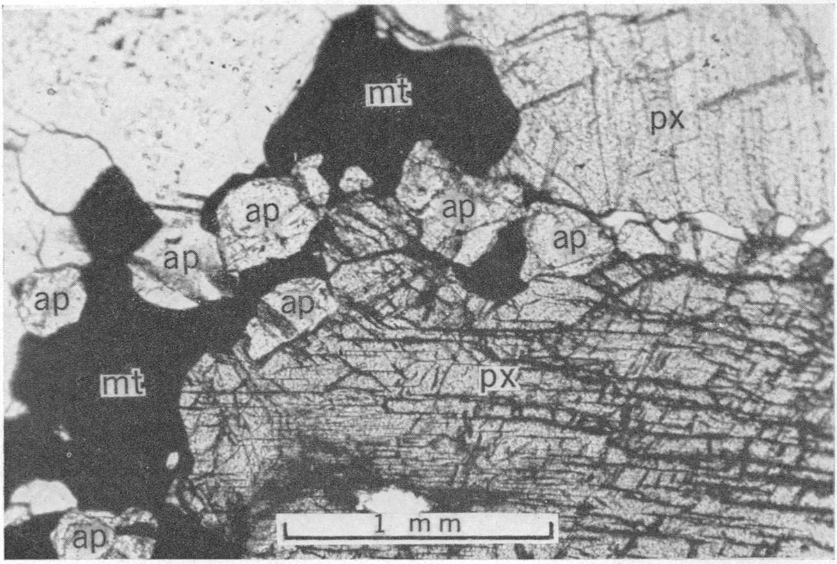


FIGURE 51.—Photomicrograph of thin section showing magnetite and apatite replacing pyroxene. Magnetite follows path taken by apatite along grain boundaries. Magnetite replaces apatite, as well as pyroxene. Pyroxene (px), apatite (ap), magnetite (black). Steele mine. Ordinary light.

all variations in abundance of magnetite can be seen from that in which small amounts occur along grain boundaries or are enclosed by the silicates, to that in which isolated grains of relict host minerals are completely surrounded by magnetite. Magnetite replaces all the usual minerals of the gneiss, including feldspar, pyroxene, and hornblende, but a certain degree of selective replacement is exhibited, the effect being more pronounced in the poorer types of ore. In a given specimen containing plagioclase, pyroxene, hornblende, and apatite, the pyroxene and feldspar are in greatest degree replaced by magnetite, hornblende is considerably less replaced, and apatite is generally largely preserved.

A very small amount of the magnetite contains microscopic exsolved blades of ilmenite. A few irregular grains of ilmenite can be seen in some specimens. When highly magnified, some polished specimens of magnetite show minute oriented rods of nonmetallic material, possibly spinel.

### HEMATITE

Some hematite is associated with the magnetite in the Sterling Lake and Ringwood area. Scattered small granules have been seen in polished specimens of ore from the Lake and Scott mines, Sterling Lake district. It is more abundant in some of the ore from the Ringwood mines where, in places, conspicuous amounts of hematite are associated with the magnetite as granules intergrown with the magnetite, and less commonly, as solid masses surrounded by magnetite. The hematite in a few specimens has the outward form of magnetite and hence has been called martite. The steel-gray color, reddish-brown powder, and nonmagnetic character of the hematite distinguish it from magnetite.

Polished specimens of material from the Cannon mine, Ringwood district, contain about 20 percent hematite as subhedral granules intimately intergrown with magnetite. The hematite has the same relationships to the gangue minerals (fig. 52) as the magnetite and

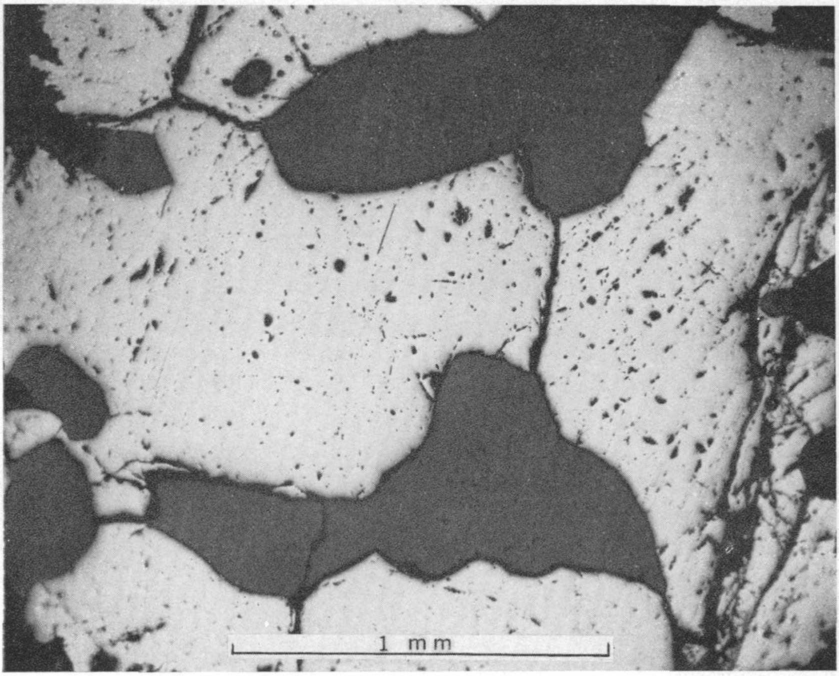


FIGURE 52.—Photomicrograph of polished specimen showing hematite (light gray) enclosing silicate remnants (dark gray). Cannon mine.

appears to have been formed almost simultaneously with the deposition of magnetite. Some of it, however, appears to have replaced magnetite (fig. 53).

### GANGUE MINERALS

Unreplaced minerals of the host rock are associated with the magnetite ore. They are the usual minerals in the gneiss, skarn, or limestone, such as pyroxene, hornblende, plagioclase, or calcite. Also there are those related to the magnetite mineralization. They are, in approximate order of greatest abundance and persistence of occurrence: apatite, quartz, biotite, chlorite, actinolite, serpentine, albite, epidote, calcite, rarely spinel (pleonaste?), and some tourmaline.

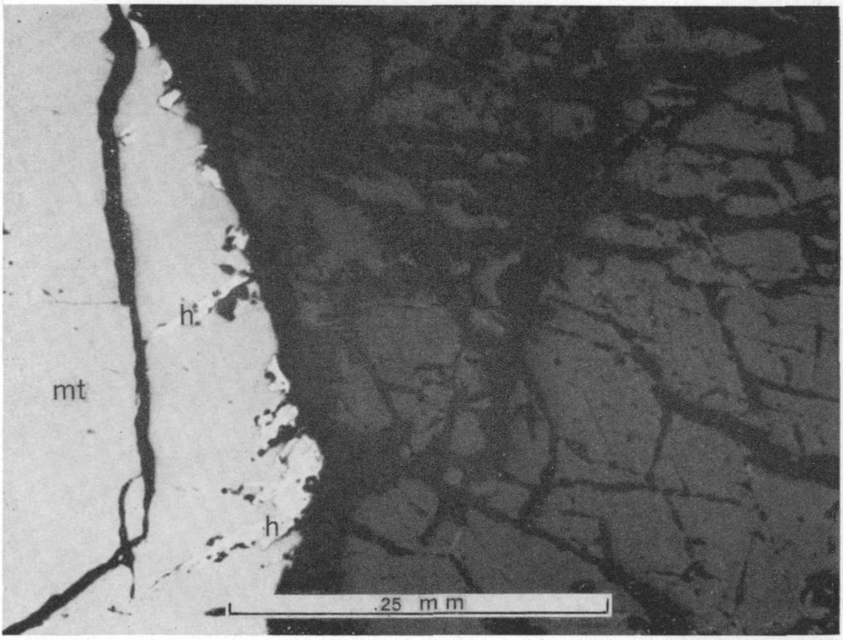


FIGURE 53.—Photomicrograph of polished specimen showing hematite replacing magnetite along the contact with a pyroxene grain. Hematite (h), magnetite (mt), pyroxene (dark gray).

Sulfides in varying but for the most part minor amounts include pyrite, pyrrhotite, and chalcopyrite, intimately associated with the ore. Molybdenite is represented by a few small scattered flakes.

Excepting pyroxene, only gangue minerals related to the magnetite mineralization are described here because the preore minerals of the host rock have been described in a previous section.

#### PYROXENE

Pyroxene is the most abundant gangue mineral. In addition to its occurrence as unreplaced grains of the host rock, laminae and layers of pyroxene occur parallel to the foliation. Some are partly replaced by magnetite. Layers of magnetite parallel these layers of pyroxene, and many of the magnetite layers have a border of granular pyroxene. Some of the thin pyroxene layers contain no magnetite. Rounded crystals of plagioclase are enclosed in the pyroxene. Although the pyroxene mostly is a medium- to fine-grained aggregate, here and there larger crystals enclose feldspar granules and closely resemble the large poikilitic pyroxenes found in pegmatite along the contact with pyroxene amphibolite.

The pyroxene is optically different from that in the dark skarn, which it outwardly resembles. It is an augite like that in the pyroxene amphibolite. It may be of magmatic origin deposited along channels ahead of the magnetite, but the writer's interpretation is that these pyroxene layers or "veinlets" are recrystallized from pyroxene amphibolite and preceded the magnetite or was formed almost simultaneously with it.

### APATITE

The constant association of apatite with magnetite suggests that the two minerals have been introduced together. This hypothesis is borne out by the evidence seen in thin sections where the apatite is surrounded and enclosed by the magnetite (fig. 54). In some speci-

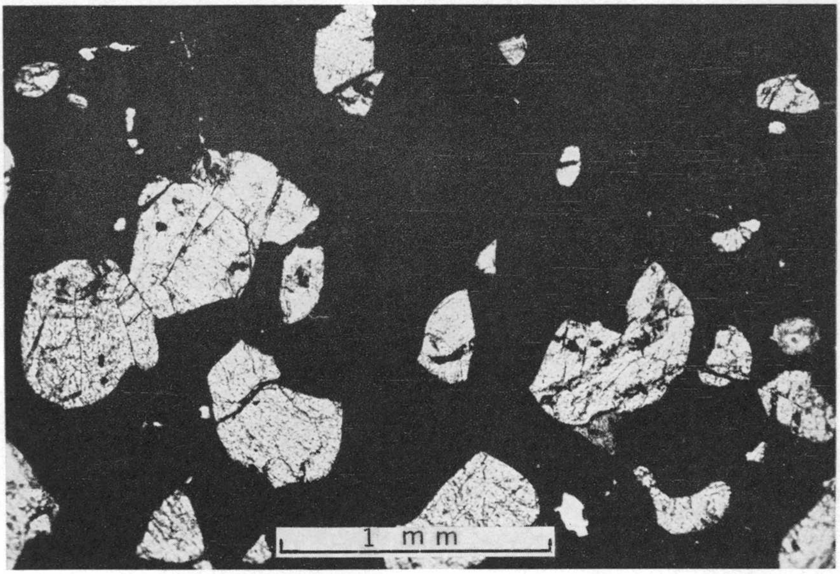


FIGURE 54.—Photomicrograph of thin section showing apatite granules (gray) enclosed in magnetite (black). Ordinary light.

mens the apatite granules are more or less alined within the solid magnetite, and one thin section of ore from the Steele mine shows a veinlet of granular apatite entering along grain boundaries in pyroxene amphibolite (fig. 51). The pyroxene and plagioclase are partly replaced by apatite which in turn is enclosed and partly absorbed by magnetite which follows the same path taken by the apatite.

### QUARTZ

Small but rather persistent amounts of quartz accompany most of the ore. Quartz with magnetite has been seen on a larger scale as small masses within the ore and also as small veins in the wallrocks. Microscopic examination of thin sections definitely shows that quartz accompanied the introduction of magnetite though it was deposited slightly later than the main influx of iron. The quartz occurs as small, rounded inclusions in magnetite and, less commonly, as rims around pyroxene. It enters along the grain boundaries and replaces the pyroxene and, to a slight extent, the apatite. The magnetite appears to be unaffected, and retains its boundaries which were developed against the pyroxene and apatite (fig. 55). Some of the quartz inclusions have remnants of pyroxene that have not been completely replaced.

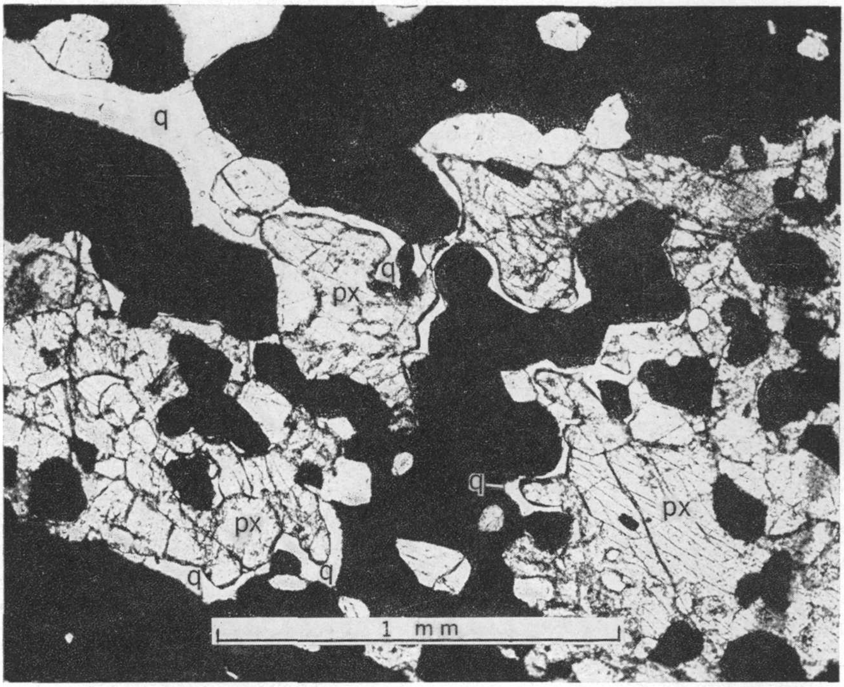


FIGURE 55.—Photomicrograph of thin section showing quartz (q), replacing pyroxene (px) (and magnetite?) along magnetite-pyroxene boundaries. Magnetite (black). Ordinary light.

## BIOTITE

A few flakes of deep reddish-brown biotite have replaced the magnetite, as well as the hornblende and pyroxene, in many specimens of ore, and leaves of biotite occur in the ore and adjacent rock. Some of the biotite was formed before the magnetite, but a specimen from the footwall of the Lake mine contains abundant biotite that has replaced the magnetite and also the earlier mafic minerals.

## CHLORITE AND ACTINOLITE

Some of the mafic inclusions in the ore are mostly chlorite (fig. 56). In part the chlorite is an alteration product of pyroxene; some of it has formed around the quartz along boundaries with magnetite. Some specimens are cut by microscopic veinlets that are chloritic where they

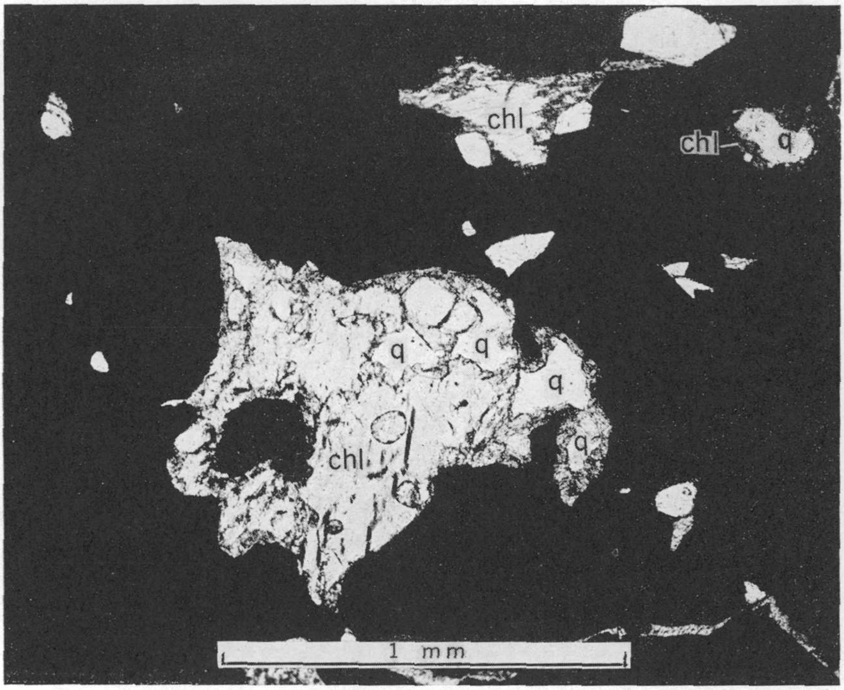


FIGURE 56.—Photomicrograph of thin section showing chlorite inclusions in magnetite. May be replacements of pyroxene. Chlorite (chl), quartz (q). Ordinary light.

are in magnetite and are filled with actinolite where they traverse pyroxene. Fibrous actinolite may form as the product of pyroxene alteration.

SERPENTINE

Some of the magnetite is associated with serpentine, which is the alteration product of chondrodite (or olivine) and pyroxene. Serpentine is confined to deposits in pyroxene skarn; the occurrences are restricted to some of the ores of the Redback belt, the Morehead mine, and the Snyder mine (fig. 57).

In some specimens serpentinization appears to have taken place after the introduction of magnetite, for alteration starts along the boundaries between magnetite and silicate grains; in other specimens the change to serpentine seems to be simultaneous with the introduction of magnetite. In either occurrence magnetite deposition and serpentinization preceded the introduction of sulfide minerals.

ALBITE

In some specimens the earlier plagioclase is partly replaced by rims and microscopic veinlets of albite. More commonly, the plagioclase is partly altered to sericite.

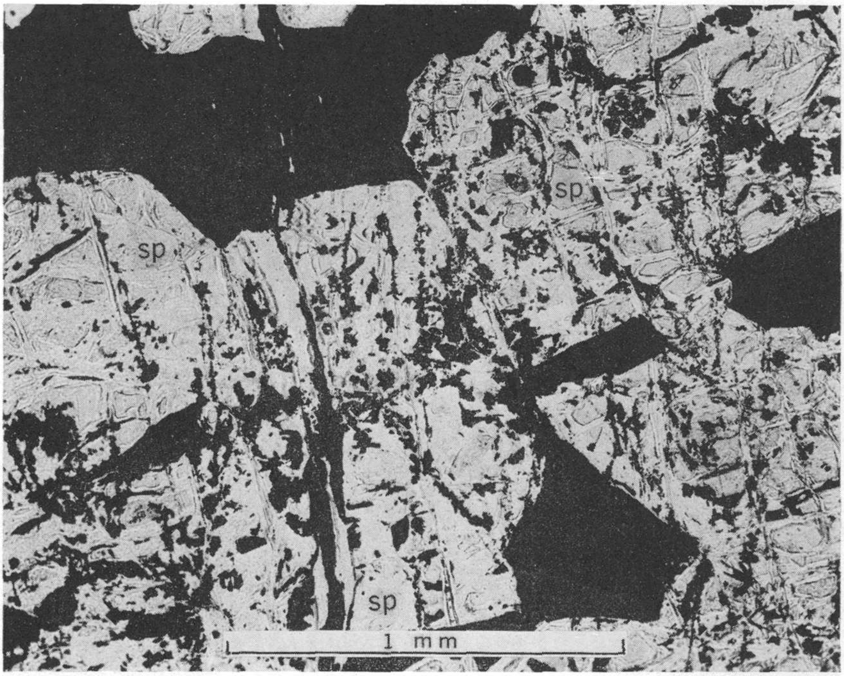


FIGURE 57.—Photomicrograph of thin section showing magnetite (black) in serpentine (sp) (pseudomorphing pyroxene[). Two kinds of magnetite: coarse primary, and fine-grained secondary resulting from serpentinization. Morehead mine. Ordinary light.

### EPIDOTE

Veinlets and coatings of epidote and clinozoisite are fairly common on joint surfaces. Epidotization, however, is not restricted to the ore deposits but occurs throughout the whole gneissic complex. In some of the ore from the Patterson mine prismatic epidote forms aureoles around inclusions of quartz and feldspar in the magnetite.

### CALCITE

There is little evidence of introduction of calcium carbonate. Most of the calcite present is in unreplaced limestone. Some specimens of ore contain calcite, however, which microscopic study shows to be replacing the mafic minerals.

### SULFIDES

Sulfide mineralization affecting all of the rocks is not restricted to the limits of the mineralized zones. The observed species of sulfide minerals are almost exclusively pyrite, pyrrhotite, and chalcopyrite. Molybdenite amounts to no more than a trace.

Pyrite occurs as individual crystals, irregular bodies, and less commonly, as veinlets. The most plentiful of the sulfide minerals, pyrite, may occur alone or with other sulfides and magnetite, or with magnetite alone. Where it is in conjunction with the ore, it was formed later than the magnetite.

Pyrrhotite and pyrite are similar in occurrence and association. Pyrrhotite is more restricted than pyrite in its distribution and is more or less confined to the ore zones. Their relative paragenetic positions are uncertain; pyrrhotite may be later than the pyrite and is certainly younger than the magnetite.

Transecting threadlike veins of chalcopyrite definitely postdate the other sulfides. Chalcopyrite never occurs alone but is always associated with pyrrhotite and is commonly associated with pyrite.

Molybdenite is rare and its position in the sequence of formation is not known. None has been found in the magnetite ore, but only in pegmatite in the vicinity of the magnetite deposits.

## COMPOSITION

Several partial analyses of ore from the Ringwood district are available and are listed in table 9. Data on the composition of ore from the mines in the Sterling Lake district are very fragmentary, but a few analyses are presented in table 10.

## ORIGIN OF THE MAGNETITE DEPOSITS

The magnetite deposits probably were formed by metasomatic replacement of preexisting rocks in favorable structural environments. The metasomatic origin of the New York magnetite deposits was first

TABLE 9.—*Analyses of ore from the Ringwood district, New Jersey*

| Mine | Sample | Percent | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | Fe | P | S | Mn | Ti | |
| Cannon | 1 | 46.30 | 2.43 | | | 0.49 | Bayley, 1910, p. 96. |
| | 2 | 53.41 | 2.88 | | | .43 | Do. |
| | 3 | 67.44 | Tr. | | | .43 | Do. |
| | 4 | 63.53 | Tr. | | | 1.66 | Do. |
| | Shipment, 1880 | 55.25 | 1.567 | | | | Do. |
| | Dump | 58.61 | .296 | 0.026 | | | Do. |
| Cooper | | 59.72 | 2.71 | Tr. | 0.15 | | Bayley, 1910, p. 97. |
| Hope | Hillside pit | 62.66 | .458 | | | | Bayley, 1910, p. 99. |
| | Bottom of hill | 63.20 | .448 | | | | Do. |
| | Old mine | 66.03 | .20 | | .19 | .18 | Do. |
| | New mine | 68.30 | .21 | | .27 | .32 | Do. |
| Keeler | | 54.96 | 1.48 | .01 | .19 | .88 | Bayley, 1910, p. 100. |
| Miller | | 59.36 | 2.07 | | .19 | .31 | Bayley, 1910, p. 101. |
| Peters | | 63.96 | .39 | | .19 | .18 | Bayley, 1910, p. 102. |
| | Shipment, 1880 | 55.56 | 1.556 | | | | Do. |
| Snyder | | 49.61 | .06 | .20 | | | Bayley, 1910, p. 103. |
| St. George | | 66.45 | 1.09 | | .15 | .40 | Do. |

TABLE 10.—*Analyses of ore from the Sterling Lake district*

| Mine | Percent | | | Reference |
|---|---|---|---|---|
| | Fe | P | S | |
| Crawford | 57.66 | 2.004 | 0.178 | Colony, 1923, p. 85. |
| Lake | 57.25 | 1.205 | .088 | Colony, 1923, p. 80. |
| Redback | 52.93 | .028 | 3.603 | Colony, 1923, p. 87. |
| Sterling | 61.01 | .284 | .371 | Colony, 1923, p. 76. |
| Tip Top | 54.03 | 1.751 | .173 | Colony, 1923, p. 80. |

recognized by Colony (1923, pp. 69–73). Bayley (1910, p. 149) considered the deposits in New Jersey to be of igneous origin, but he postulated a kind of ore magma and iron-rich solutions or vapors that deposited magnetite. All this is in contrast to the view held by earlier geologists working in the Highlands that the magnetite deposits were of sedimentary origin, subsequently metamorphosed. No doubt this theory was based on the belief that all the country rocks associated with the deposits were metamorphosed sedimentary rocks. It was probably Spencer (1905) who first recognized that many of the gneisses in New Jersey were of igneous origin.

Evidences that the magnetite deposits were formed by solutions from igneous sources that replaced minerals of the host rock are:

1. Associated with the magnetite are minerals ordinarily found with rocks and mineral deposits of igneous origin. These minerals include apatite and the sulfides: pyrite, chalcopyrite, pyrrhotite, and molybdenite. Chlorite, biotite, actinolite, and serpentine are closely related paragenetically to the magnetite and occur elsewhere in mineral deposits that are considered to be of hydrothermal origin.

2. All the textural and structural evidence clearly shows that the magnetite has been introduced by replacement of preexisting minerals of the host rock. No evidence of forceful injection with accompanying displacement has been seen.

3. Locally, the magnetite bodies cut across the foliation of the enclosing gneisses.

4. The magnetite deposits are closely associated with pegmatite and hornblende granite which are believed to be of igneous origin.

And indirectly:

5. In other regions magnetite deposits occur in conjunction with intrusive igneous bodies to which they are genetically related. The deposits of the Cornwall type in the Triassic belt of Pennsylvania are associated with diabase intrusions from which iron-rich emanations issued (Spencer, 1908b). Monzonite intrusions are responsible for the magnetite deposits of the Iron Springs and Bull Valley districts, Utah (Mackin, 1947; Mackin and Switzer, 1948; Wells, 1938), and those of southeastern California (Lamey, Hadley, and others, 1945). Buddington and Leonard (personal communication) believe that the pre-Cambrian magnetite deposits in the Adirondack Mountains of New York originated from a magma, a facies of which is represented by widespread bodies of gneissic granite. Gallagher (1937, pp. 74–77), and Postel (1952) believe the Adirondack deposits to be of igneous origin. According to Sims (in preparation), magnetite in the deposits of the Dover district, New Jersey, is genetically related to alaskite intrusions.

The systematic occurrence of the deposits in zones of restricted dimensions probably can be attributed to control exerted by the structure in the rocks during mineralization. Barren gneisses of a composition apparently just as favorable for replacement as those of the ore zones are plentiful in the district.

Lack of evidence of deformation of the ore shoots and the conformable relations between the plunge of the shoots and the plunge of the lineation in the wall rocks indicate that the shoot structure is inherited. The magnetite may have been localized in zones of crinkling or complex minor folding. Sims' work in the Dover district has shown definitely that microbrecciation of the host rock prepared favorable sites for the introduction of the iron-bearing solutions. Microbrecciation probably was an important controlling factor in the Ringwood-Sterling Lake area also, though direct evidence for it has not been recognized by the writer.

The mineralizing agencies are not exactly known, but probably they were in part pneumatolytic and in part hydrothermal. Colony (1923, pp. 70–71) postulated that the iron was transported in "aqueo-igneous solutions"; Gallagher (1937, pp. 74–77), Alling (1939), and Postel (1952, pp. 44–45) believe that the principal mineralization at Lyon Mountain, New York, is the result of pneumatolytic metasomatism.

The ultimate source of the solutions or vapors that deposited the magnetite is largely a matter of speculation. Bayley (1910, p. 149) concluded that the source was

> * * * deep-seated molten magmas, which upon being intruded into the overlying rocks solidified as the various gneisses now constituting the principal rocks of the Highlands ridges. After the partial cooling of the gneisses these in turn were intruded by ferruginous portions of the same magma that gave them birth, and these intrusions were later enriched by iron-bearing solutions or vapors originating in the same subterranean source.

Colony's (1923, p. 70) view is somewhat different. He ascribes the evolution of the ferruginous products to

> * * * (1) long continued magmatic differentiation of a basic magma of great extent, with the concentration of extremely mobile end-phase products rich in those elements which ultimately formed the pegmatites; rich in magnetite, rich in quartz and gaseous concentration products, all in aqueo-igneous solution. (2) Subdifferentiation of the concentrate itself, into pegmatite-rich and magnetite-rich fractions * * *.

The writer believes that the iron-rich vapors or solutions that deposited the magnetite in the rocks of the Sterling Lake and Ringwood area were derived from the magma that formed the hornblende granite and alaskite and related pegmatite. Possible, however, the iron was derived from a magma having no representatives among the rocks, at least none that have been recognized.

## MINES AND PROSPECTS

### RINGWOOD GROUP

#### GENERAL GEOLOGY

The Ringwood district is in northern Passaic County, N. J., near the New York-New Jersey State line in the southern part of the map area. The mines and prospects, about 12 in all, occupy a relatively small area about 1 mile long in a northeast-southwest direction, and three-quarters of a mile wide. The two principal mines, neither of which was in operation in 1950, are the Peters and the Cannon. They have rather extensive underground workings and could be put into operation fairly easily. Both are equipped with electric hoists and had some underground equipment in 1950. A mill and magnetic concentrating plant situated near the Peters shaft were constructed during World War II. The other mines were abandoned long ago and little is known about them.

Exposures of bedrock are plentiful in the northern and western parts of the Ringwood district (fig. 46 and pl. 19), but much of the central and eastern parts are lowlands covered with glacial and stream deposits.

Pyroxene amphibolite, amphibolite, and garnetiferous and sillimanitic quartz-biotite gneiss constitute the metasedimentary rocks. Of them, only the pyroxene amphibolite and some amphibolite occur in conjunction with the ore. A distinctive layer of garnetiferous quartz-biotite-sillimanite gneiss is exposed southeast of the Peters mine and north and northwest of the Cannon mine. This rock does not appear in any of the underground workings.

Much of the country rock is granitic quartz-oligoclase gneiss. A large body of this gneiss makes up Hope Mountain and occupies the area west of the district; it is exposed also in the eastern part of the district around the Cannon mine. Some quartz-oligoclase gneiss is exposed underground, but its occurrence is sporadic.

Hornblende granite is less plentiful in the Ringwood district although there are a few surface exposures and it is fairly common underground.

A few lenses of pink or salmon-colored pegmatite crop out near the magnetite deposits. Pegmatite is very plentiful underground where it is intimately associated with the ore shoots. Mixed rocks consisting of quartz-oligoclase gneiss and pegmatite containing inclusions of amphibolite or pyroxene amphibolite are common at many places underground.

In general the gneissic foliation strikes northeast and dips steeply southeast. The lineation plunges consistently east-northeast. The plunge is somewhat steeper in the southern part of the district than it is in the north and central parts.

The complexity of the rocks and the lack of surface exposures in critical places make it difficult to determine the structure, but the pattern of rock distribution and the attitudes of the gneissic foliation indicate a complex pattern of folds involving the granitic rocks. South of the Cannon mine attitudes of the foliation indicate a northeast-plunging syncline with the Cannon mine ore bodies in its trough. The Keeler-Miller-St. George zone apparently occupies the southeast limb of a tight anticline. The Peters-Hope Mountain mineralized zone also may be on the southeast flank of an anticline whose crest is to the northwest on Hope Mountain. The steep eastern slope and trench-like feature at the base of the hill northwest of the Cannon shaft are possibly the surface expressions of a north-south zone of faulting.

### PETERS MINE

The Peters mine was opened before the Revolution and worked by the London Company through several shafts and adits (Bayley, 1910, p. 483). The mine was included in the purchase of the Ringwood property by the U. S. Government in 1942. The inclined shaft and underground workings were improved and development work was begun on level 17. No ore was mined, however.

An inclined shaft about 2,000 ft long serves the 17 levels of the Peters mine which, in its deepest part, is more than 1,500 ft below the surface. The upper levels and stopes are dangerous and inaccessible, but it was possible to study the geology at some of the lower levels (pl. 21).

The host rock for the ore is pyroxene amphibolite and amphibolite. Some massive to migmatitic quartz-oligoclase gneiss is found at each level and appears to be confined to the footwall of the ore zone. Pegmatite and granite are plentiful near the ore bodies.

The pencillike shoot structure is especially well developed at the Peters mine (pl. 21). The exact number of individual shoots is not known, but five are recognized on the lower levels of the mine, and there were probably other smaller ones that were abandoned during earlier operations or did not continue in depth. In cross section the shoots are more or less elliptical and have nearly constant dimensions, though there is minor pinching and swelling. Individual shoots are very persistent down the plunge, and they maintain their relative positions on all levels. Some of the larger shoots have been followed continuously for lengths of 1,500 to 2,000 ft down their plunge. They range in thickness from 15 to 60 ft as mined, the average being 30 to 40 ft. The breadth, measured in the plane of the ore body at right angles to the plunge, ranges from 30 to 160 ft. Within a given ore shoot the tenor of the ore is relatively constant. There is scarcely any low-grade disseminated ore except that within a few feet of the shoots.

Most of the ore is massive granular magnetite with some disseminated gangue. Hematite, occurring as irregular masses within the ore bodies, is present in small quantities.

The gneissic foliation of the wallrocks strikes northeast and dips steeply southeast. The ore shoots, which are more or less localized in a zone 150 to 200 ft wide, plunge 30°–35° slightly north of east.

Faulting is negligible at the Peters mine, though a few small faults along which there has been very slight displacement were observed. The faulting, which is post ore, is normal to the strike of the foliation.

No ore has been mined below the 16th level, and with the exception of a crosscut that intersects one of the shoots, the 17th level has not been developed. There is every reason to suppose, however, that the ore shoots on the 16th level continue to the 17th. On the 9th level an exploratory tunnel called the Hope Mountain drift was driven northeast beyond the shaft, and a small amount of ore was exposed in a short raise at the end of this drift. The Peters shoots are in an ore zone which extends along the southeastern slope of Hope Mountain for about 2,500 ft. Several lenses of ore have been mined along this zone; these lenses may extend in depth and could be explored and mined from the Peters shaft.

### CANNON MINE

The Cannon mine was formerly the most important of the mines in the Ringwood group (Bayley, 1910, p. 480). The mine is an old one. It is not known when it was opened, but by 1855 large quantities of ore had been mined from extensive pits. The mine was worked almost continuously between 1855 and 1879. In later years a vertical shaft was sunk northeast of the original openings, and from it the Cannon and New London shoots and also the Hard and Mule shoots were mined.

With the exception of a few stopes, all the workings at the Cannon mine are accessible. Except the Mule shoot and some smaller bodies in the Cannon-New London ore zone, the shoots have been more or less completely mined down to the 3d level, about 450 ft vertically below the surface openings. Development work has been done on the 4th level, 500 ft below the collar of the shaft. Plate 22 shows the workings and geology on levels 1 to 4. The ore occurs in pyroxene amphibolite. Pegmatite and granite are plentiful and are most abundant in and near the ore zones, and some quartz-oligoclase gneiss also is present. Where there has been extensive intermingling of the granite (and pegmatite) with pyroxene amphibolite or quartz-oligoclase gneiss, a mixed rock like that at the Peters mine has been the result.

Two ore zones containing several shoots occur at the Cannon mine. The largest is the Cannon-New London zone: about 200 ft southeast of it is the Hard-Mule zone.

The Cannon ore bodies are more complex structurally than those of the Peters. In the Cannon-New London zone, 4 or 5 shoots lie close together and plunge down as a cluster of massive ore bodies separated from one another by thin zones of disseminated magnetite. Everything has been mined between the 1st level and the surface, a vertical distance of about 200 ft, leaving a large open pit 200 ft long and 150 ft wide.

The Hard-Mule zone has two distinct shoots lying one above the other and separated by barren rock. Seven small openings are found at the surface but the shoots represented by these openings apparently were not all followed in depth. Some of them may have been lost or were too small to warrant further mining or may have pinched out altogether. Possibly the Hard and Mule shoots are actually two or more of these small bodies that came together at depth or were sufficiently close together to permit mining the intervening rock.

Although there is considerable variation in the strike of the foliation, the average trend is between N. 30° E. and N. 40° E. Dips are steep to vertical. The predominant direction of dip is to the southeast. On the 3d and 4th levels, however, the foliation dips northwest on the Hard-Mule side of the mine, whereas on the Cannon-New London side the rocks are inclined to the southeast, indicating a synclinal structure. The direction of plunge of the ore shoots is about N. 70° E. and between 45° and 50° from the horizontal.

Faulting is more common at the Cannon mine than at the Peters. A strong persistent northeast-southwest fault zone dipping about 80° SE. lies about midway between the Cannon-New London and Hard-Mule zones. This fault can be followed from the 1st down to the 4th level. It does not intersect either ore zone. A complicated fault system, possibly subsidiary to the major northeast-southwest fault, intersects the Cannon-New London ore zone between the 1st and 4th levels. Some minor faulting shows up in the Hard-Mule zone, but displacements are small and unimportant, and the effect on the ore is negligible.

The faults affecting the Cannon-New London ore zone strike about N. 20° E. to N. 20° W. Their dip is steep and ranges from east to west. Also, especially on the 2d level, there are minor zones of slipping between the ore and the wallrock. Striae on fault surfaces plunge moderately to the southwest or northeast, but the relative movement could not be ascertained in most places. The only relative displacement that could be determined with any certainty was on the northwest-trending fault against which the ore terminates in the 3d and 4th levels. This fault dips about 60° SW., and a reverse movement has displaced the southwest, or hanging wall, a score or so feet upward, relative to the northeast side. Thus the ore is on the southwest side of the fault on the 3d level and on the northeast side on the 4th level (pl. 22). The general effect is as if the ore shoots in their extension downward from the surface encountered a zone of cross faulting that disrupted their continuity between the 2d and 3d levels, whereas on the 4th level the ore zone is beyond the faulting.

In the Hard-Mule ore zone the Hard shoot has been completely mined out down to the 3d level; development has shown that it continues to the 4th level. The Mule shoot, which lies northeast of and above the Hard, has been followed down to the 2d level. The geology strongly suggests that the Mule ore shoot extends in depth and will be found in the lower levels.

Ore from the Cannon mine is similar in appearance to that of the Peters. However, a good deal more medium- to low-grade material is present. In places the pegmatite contains magnetite in sufficient quantities to constitute low- to medium-grade ore. In the Cannon-New London shoot system layers of good grade massive magnetite ore 1 to 4 ft wide are separated by leaner material. Hematite intimately associated with the magnetite is common in the Cannon-New London ore zone.

### HOPE MINES

A zone of mineralization in which about 10 ore shoots have been opened occupies the southeast slope of Hope Mountain for a distance of about 2,500 ft northeast of the Peters mine pit. Exploration and mining began here around 1760, and continued with several interruptions until about 1868.

The magnetite is in a layer of pyroxene amphibolite 250 to 400 ft wide near the northwest contact with quartz-oligoclase gneiss. The shape and size of the openings indicate that the shoots averaged 15 ft wide and 20 to 30 ft long horizontally. According to Bayley (1910, p. 484), one of the larger pits was 100 ft long. The plunge length of the shoots is not known. The general dip is 75°–85° SE.; the plunge is 30°–35° NE. Pegmatite, pyroxene amphibolite, and migmatite form the wallrocks. The magnetite-bearing material on some of the dumps looks as good as that in the Peters shoots.

About 200 ft southwest of the New York-New Jersey boundary and 1,000 ft northeast of the northeasternmost opening on Hope Mountain there is a shallow prospect from which pyroxene amphibolite containing a little magnetite has been removed. It is probably the northeast end of the Peters-Hope Mountain mineralized zone. A short distance farther north the layer of pyroxene amphibolite pinches out.

### COOPER MINE

The Cooper mine is about 500 ft south of the Peters pit. Nothing much is known about it, and the opening is no longer visible. The shoot was opened a few years before 1868 and worked for a length of 80 ft horizontally. It was abandoned soon after 1873.

### KEELER-MILLER-ST. GEORGE MINES

The Keeler pit is on the west side of the railroad tracks 2,500 ft south of the Peters pit. The opening was originally 70 ft long, 20 ft wide, and 15 ft deep. It is now filled with water. At the upper end of the opening pegmatite can be seen on both walls. Some quartz-oligoclase gneiss and epidotized amphibolitic gneiss also are exposed on the hanging wall (northeast side), and a little massive magnetite is visible on the footwall. There appear to have been originally two parallel ore shoots at the surface separated by a pegmatite lens 5 to 10 ft thick. The dip of the foliation is about 60° SE. and the plunge of the lineation 40° NE.

The Miller shaft is 375 ft southwest of the Keeler. This shaft, which is flooded, is probably what Bayley (1910, p. 481) refers to as the New Miller opening. The original Miller pit was opened in 1867 on a vein 12 ft wide. The New Miller was opened about 1881 on a large shoot 300 ft long and 20 ft wide. The ore body pinched at a depth of 150 ft, where it decreased to a thickness of 5 ft. Apparently no attempt was made to explore the shoot beyond the pinch.

Southwest of the Miller, in line with the Keeler and Miller pits and some 250 ft distant from the Miller, is the St. George pit. Though flooded and partly filled in, it is still about 30 ft deep, 35 ft wide, and 60 ft long.

Pegmatite and dark amphibolitic gneiss are on both walls of the pit, and some high-grade magnetite can still be seen on the southeast or hanging wall. The foliation dips steeply to the southeast and the plunge is 40° NE.

There is some confusion between what the local inhabitants call the St. George and the St. George mine briefly mentioned by Bayley (1910, p. 481). Bayley reports the St. George as being a small deposit "on the trend of the Cannon vein and very close to the mine." The ore body "was reported to be 30 ft wide, and * * * was supposed to be connected with the Cannon mine shoots." The opening now called the St. George is the one mentioned above as being southwest of the Miller.

The Keeler, Miller and St. George ore shoots are in a layer of pyroxene amphibolite striking N. 45° E. Garnetiferous biotite-sillimanite gneiss is on the northwest side, and quartz-oligoclase gneiss to south and southwest.

### WARD-BUSH MINES

Two narrow, shallow openings 1,250 ft south of the Keeler-Miller-St. George group are on the site of the old Bush and Ward mines. The Bush had a pit 100 ft long and 70 ft wide. Quartz-oligoclase gneiss containing dark inclusions and some pegmatite forms the walls of the openings, and some thin veinlets of magnetite cut the rock parallel to the foliation. The dip ranges from 70° SE to vertical. The plunge is about 30° NE.

### SNYDER AND HEWITT MINES

The Snyder and Hewitt mines are in New York a little more than a mile east-northeast of the Peters mine and just north of the New Jersey-NewYork boundary. Here are several shallow pits, a partly flooded opening 150 ft long and 20 ft wide, and another flooded pit 60 ft long and 20 ft wide. The Hewitt mine was on the site of the shallow pits south of the larger openings.

The ore bodies appear to have been 5 to 10 ft wide, lying in echelon. Foliation in the surrounding gneiss dips very steeply east to vertical, and the lineation plunges 20°–25° NNE. The deposits differ from the rest of the Ringwood deposits, for they are a replacement of pyroxene skarn by magnetite. The skarn, some of which has been serpentinized, occurs as a thin, elongate lens surrounded by pink granite; fragments of pegmatite were seen on the dump. Magnetite-bearing material on the dump ranges from low to medium grade, and the magnetite is moderately coarsely crystalline with dark-green pyroxene and serpentinous gangue. Sulfides are associated with the ore and may constitute 2 or 3 percent of it. Pyrite and some chalcopyrite and pyrrhotite are the most common sulfides.

### PROSPECTS

Some shallow openings called the Hickory Valley and Hickory Mountain mines are found about half a mile west of the Cannon mine. A little lean magnetite-bearing rock occurs in amphibolitic gneiss surrounded by quartz-oligoclase gneiss. Pegmatite is rare. No published data on these mines are available.

A mile northeast of the Cannon is another prospect. A lean vein of magnetite about 20 ft long and 3 to 5 ft wide was opened and apparently abandoned after little or no exploration in depth.

There is no substantial area of magnetic attraction at either of these prospects.

### STERLING LAKE GROUP

The magnetite deposits in the Sterling Lake district are in Orange County, N. Y., in the north-central part of the area shown on the map. Included in this district are 14 mines and prospects northeast and south of Sterling Lake (fig. 44). The principal mine was the Lake mine which is now flooded. All the other mines have been abandoned also, but the Scott mine could be put in operation.

During 1944 and 1945 the Jones and Laughlin Ore Company undertook an intensive program of diamond-drill exploration in the Sterling Lake district. Eighteen holes totaling more than 9,000 ft were drilled. Through the courtesy of L. P. Barrett, chief geologist, and R. E. Comer, geologist in charge of the exploration, the author was permitted to examine and log all the core. Drilling was done on several properties in the Scott group: 7 holes on the Scott-Cook ore zone, 4 at the Long mine, 2 at the small area of magnetic attraction at the Smith shaft, and 5 in the Mountain mine ore zone. The positions of these holes are shown on pl. 20.

## GENERAL GEOLOGY

The Sterling group of deposits south of Sterling Lake occupies two mineralized zones at the south end of a syncline plunging gently north-northeast (figs. 44 and 45). The Lake and Sterling mines are in the upper zone on the west and southwest limbs of the fold. The hanging wall, which is also the core of the fold, is quartz-oligoclase gneiss; the footwall, which is the hanging wall of the lower zone, is pyroxene amphibolite. The upper zone terminates east of the Sterling and Lake mines where it is cut off by a fault. Its underground termination is not known. The Tip Top mine is on part of the upper zone, which has been displaced by movement along the fault. There is no apparent continuation of this upper zone to the northeast in the Scott group.

The Summit, Upper California, Lower California, and Whitehead mines are on the lower mineralized zone, about 200 ft stratigraphically below the upper one. This zone swings around the base of the hill south of Sterling Lake. The hanging wall is amphibolite and pyroxene amphibolite, and the footwall is quartz-oligoclase gneiss. The zone is barren north of the Whitehead mine, but the magnetite deposits of the Scott group are believed to represent its northward extension.

The magnetite bodies in the Scott group are in pyroxene amphibolite near the contact with quartz-oligoclase gneiss. The quartz-oligoclase gneiss is on the west or footwall side of the eastern zone and on the east, or hanging-wall, side of the western belt.

Outcrops of pegmatite are plentiful and are closely associated with the magnetite deposits. They are especially common in the vicinity of the Long mine where they occur as large, comformable, lenticular masses separated from one another by thin layers of metasedimentary gneiss.

At the Scott group of deposits two belts of garnetiferous biotite and biotite-sillimanite gneiss, one on each limb of an anticline, lie a short distance west of the western zone and east of the eastern belt of deposits (pl. 19). Although they cannot be followed continuously, the garnetiferous belts are sufficiently persistent to be used as markers indicating the probable position of the mineralized zones.

The zones along which deposits of the Scott group are found are on the western and eastern limbs of a tight, somewhat asymmetrical anticline which in places is overturned slightly to the west (pls. 19 and 20, fig. 44). The axis of the fold trends north-northeast to almost due north and plunges gently northward (pl. 19). The west limb dips very steeply to the east or is essentially vertical, and the east limb dips consistently to the east at a lower angle. The inclination of the foliation on the east limb becomes progressively gentler from south to north.

North of the Long mine the contact of the quartz-oligoclase gneiss with the metasedimentary gneisses curves around the nose of the fold (pl. 20, fig. 44), and magnetic data indicate that the mineralized zone also is continuous around the end of the structure.

North of the Scott mine a major diagonal fault striking N. 45° E. crosses the structure, raising the northwest side and apparently offsetting it to the northeast. The fault is not sufficiently well-exposed at the surface to enable its dip to be determined, but underground at the north end of the drift on the 200 level of the Scott mine a prominent fault, which is believed to be the continuation in depth of the cross fault, strikes N. 45° E. and dips 55° NW. (pl. 23). Quartz-oligoclase gneiss is in fault contact underground with pegmatite and the gneiss of the mineralized zone.

### STERLING AND LAKE MINES

Ore was discovered at the Sterling mine in 1750, and the first iron produced in the State of New York came from a furnace erected on the property. In 1778 the great chain that was extended across the Hudson River at West Point to impede the progress of British warships during the Revolution was made at Sterling Furnace. The Sterling mine was closed about 1902, according to Colony (1923, p. 76).

It is not known exactly when the Lake mine began to produce ore, but it was at sometime after the opening and development of the Sterling. The Lake mine was in operation when Colony examined the district in 1921, but soon afterward it was closed down and the workings were flooded. Up to 1918 the total output of the Lake mine was 1,254,283 tons of magnetite (Colony, 1923, p. 80). According to data kindly given to the author by the Sterling Iron and Railway Company, development had revealed a considerable body of ore to be present at the time the mine was closed.

The Sterling mine was developed for 1,000 ft along a slope of approximately 28°. The ore ranged in thickness from 10 to 30 ft and consisted of granular magnetite containing more or less apatite. A pinch separated the Sterling from the Lake mine by a distance of 250 to 400 ft.

According to Colony (1923, pp. 76–80), the Lake ore body

> * * * about 500 ft in width * * * is a long, relatively narrow and thin, obscurely lenticular mass * * * gently pitching * * * to the northeast. The ore zone emerges from Sterling Lake at the south end near the western shore and strikes west-northwest and dips from 15° to 20° east of north.
>
> [The workings were extended] through an inclined shaft * * * sunk at an angle varying from 12° to 25° * * * following the length of the ore body * * *. Drifts have been driven in either direction from the slope at various levels. The slope has been sunk 3,800 ft on the incline which places the bottom of the mine * * * roughly between 1,000 and 1,100 vertical ft below the level of the lake * * *. [The ore has] not yet been exhausted, nor have the limits of the ore body been determined.

The hanging wall of the Lake mine is "granite" for a distance of 2,300 ft along the slope. The "granite" described by Colony is probably the quartz-oligoclase gneiss that crops out at the south end of Sterling Lake. At the surface the footwall is pyroxene amphibolite which, judging from Colony's description, continues underground to the bottom of the mine. Colony states that from the 2,500-ft level the hanging wall gives way to "granitized Pochuck-Grenville" which continues to the lowermost workings. According to Colony's description and the present author's recent examination of thin sections collected by Colony, granite pegmatite is closely associated with ore and in places intrudes, modifies, and reconstitutes the pyroxene amphibolite.

The ore is massive magnetite containing remnants of unreplaced silicate minerals. Apatite granules are present in most specimens and are abundant in some. Apparently, sulfide mineralization has been negligible, inasmuch as pyrite is scanty and no chalcopyrite or pyrrhotite was observed.

According to Colony's report, first-class shipping ore contained 61.34 percent Fe, 0.60 percent P, and 5.20 percent S, and the average was 57.25 percent Fe, 1.205 percent P, and 0.088 percent S.

The Lake ore body is an elongate lens plunging about 16° NNE. and occupying the gently dipping western limb of an asymmetric syncline. Colony describes a series of cross corrugations or rolls that strike more or less at right angles to the strike of the rocks and the ore zone. These rolls, which are of short extent, give an undulating character to the ore zone, the ore being thinnest at the crest of a roll. They are possibly due to cross folding of the metamorphosed sedimentary rocks and antedate the period of ore deposition. A typical roll is exposed at the foot of the hill just south of the dump of the Lake mine.

The surface trace of the mineralized zone disappears beneath the lake about 500 ft northwest of the portal of the Lake mine slope. A layer of dark pyroxene amphibolite, apparently unmineralized, crops out at the north end of Sterling Lake and is possibly the northern continuation of the layer which was replaced by the Lake mine ore body. An old exploratory drill hole put down on the north shore of the lake revealed ore only at a depth of 1,170 to 1,705 ft, according to data furnished by the Sterling Iron and Railway Company. Two areas of low to moderate magnetic attraction were discovered in 1917 beneath the ice about 80 ft from shore and between 1,300 and 2,200 ft north of the southwest shore of the lake. There is no apparent relation between these anomalies and the Lake mine zone at the south.

The belt of gneiss in which the mineralized zone occurs apparently does not reach the surface on the east limb of the syncline. South of the Sterling and Lake mines the ore pinches out on the east side of the Tip Top mine, which is in the faulted segment of the upper ore zone. (See section B–B′, pl. 19.)

The synclinal structure that is evident south of the lake is not clearly defined at the north end. It possibly continues as a tight overturned structure west of the anticline in the Scott mine area.

Colony described a "slip zone" that cuts the northeast edge of the Lake ore body and the east edge of the Sterling ore body (fig. 45). This is a zone of "mixed rock and disseminated ore approximately 150 ft in width." The slip zone contains pegmatite, garnet, epidote, and occasionally tourmaline, and Colony believes that the slip zone is a "pre-Cambrian crush zone * * * possibly serving as a channel for the magmatic end stage products * * * responsible for the deposition of the magnetite." According to Colony's observations the slip zone "does not apparently offset the ore." He says that there are "evidences of its [the slip zone] emergence at the south end of the lake; its northerly extension has not been determined." The slip zone was not recognized at the surface during the present survey.

### TIP TOP MINE

The Tip Top mine is an opening on the northern slope of the hill immediately south of Sterling Lake about 1,000 ft from the Sterling and Lake mines. According to Colony, the mine ceased operation between 1880 and 1889.

Much of the ore was close to the surface and was mined from an open cut. The hanging wall is a light, medium-grained quartz-oligoclase gneiss; the footwall is dark pyroxene amphibolite and amphibolite. Lenticular bodies of pink pegmatite intrude the hanging wall and footwall adjacent to the ore zone. The ore shoot was a sheet 10 to 12 ft thick, which dipped gently to the northeast. It rapidly became thinner in depth and pinched a short distance below the surface. On the northwest side the ore terminated against an almost vertical fault striking northeast. This same fault truncates the upper ore zone southeast of the old Sterling mine. The south side has been displaced southwest, and thus the Tip Top mine is on the offset continuation of the Lake mine ore zone.

A few hundred tons of massive ore remains as pillars in the short openings on the northeast side of the mine, and near the top of the open-cut near the southeast wall some ore is still in place. Judging from the rapidity with which the ore pinches on the northeast side and from the results of reconnaissance magnetic work, the author believes there is little hope for finding any additional ore.

### SUMMIT, UPPER CALIFORNIA, LOWER CALIFORNIA, AND WHITEHEAD MINES

The mineralized zone along which these mines are located lies in an arc around the base of the hill south of Sterling Lake and is the south end of a syncline plunging north to northeast at an angle of about 18°. The direction of strike and dip of foliation shifts in accordance with the position on the structure, and the attitude of inclination ranges from 20° to 35°.

The zone is narrow and confined to pyroxene amphibolite overlying quartz-oligoclase gneiss. In places, especially where magnetite mineralization has occurred, the rock is reconstituted to a green granular pyroxene aggregate occurring in thin layers and streaks. Pegmatite sheets and lenses are plentiful in the hanging wall for a vertical distance of about 50 feet above the ore zone.

None of the old mine openings is accessible, but the material on the dumps indicates the ore was massive, granular magnetite and occurred in thin sheets and layers accompanied by pegmatite. A little solid ore may have been found but it is doubtful that any sizable shoots were discovered. According to Colony, the ore seldom exceeded a few feet in thickness.

There is no information available on the extent of operation of any of these old workings or on the character and amount of ore mined. The Upper California seems to have been the most extensively worked, the slope reportedly having been sunk to a depth of 350 ft on the incline. It is possible that more ore can be found in depth along this zone.

### SCOTT-COOK MINE

The most recently operated mine in the Scott group is the Scott-Cook mine which once was two mines in the same mineralized zone. The two mines are now connected underground (pl. 23). The dates of discovery and development are not known, but the Scott mine was last operated in 1921 when, after it had been closed down in 1917, the workings were dewatered and some development work was done by the Bethlehem Steel Company. When the Geological Survey examined the mine only some of the Scott workings were accessible.

The mine was worked through two levels, 180 and 345 ft below the collar of the vertical shaft in the footwall of the Scott mine. South of the shaft, two large stopes nearly 300 ft high and 500 to 800 ft long extend almost up to the surface from above the 2nd, or 400 level. The shoots are estimated to have had a thickness of 20 to 40 ft. No mining beyond that necessary for development has been done on the 400 level. In the Scott mine the 200 and 400 levels were driven 1,000 and 1,200 ft, respectively, north of the vertical shaft.

The ore as exposed in the drifts in the Scott mine ranges from stringers and veinlets less than 1 ft thick to a more or less solid body of magnetite more than 10 ft wide. The ore is almost continuous throughout the explored length of the zone, though in places an ore layer pinches out and another, separated from the first by a thin layer of pegmatite or barren gneiss, comes in parallel to it (pl. 23). No shoots comparable in size to those mined in the old Cook and Scott stopes have been discovered in the drifts north of the vertical shaft, but in one or two places the ore swells to a thickness which, if continuous in depth, might be mined profitably.

Drilling has also shown that the mineralized zone occupies a very constant stratigraphic position. Over a strike distance of more than 1,400 ft from hole S–15 to S–8 and S–12 (S–8 and S–12 are in the same section) (pl. 20) the distance from the top of the mineralized zone to the bottom of the skarn and marble zone east of the mine is between 500 and 550 ft. The intervening gneiss becomes thinner southwest of hole S–15 and in the section through holes S–9 and S–14. The distance from the skarn and marble belt to the mineralized zone is between 350 and 400 ft.

Unlike the pencillike shoot structure of the ore bodies in the Ringwood mines, the shoots at the Scott and Cook are swells in a more or less tabular zone. Along their strike the shoots terminate by gradually becoming thinner and fraying out in two or more thin layers or veins. The plunge of the shoots appears to be around 30° NE. Diamond-drill exploration has demonstrated that the Scott-Cook mineralized zone exists in depth below the 400 level of the mine.

The magnetite zone is parallel to the foliation which strikes from nearly north to N. 25° E.; the dip ranges from an average of 40° E. on the 200 level to as much as 65° on the 400 level (pl. 23). Dips on the lower level of the Scott are generally steeper than on the upper level and at the surface. Colony (1923, p. 92) observed that the ore body in the Cook mine is almost vertical. An indication of structural control is found in the 200-level drift where a marked change in strike of the foliation is accompanied by thinning and discontinuity of the ore. Furthermore, the steepest dips are found in the northern third of the 400-level drift where the magnetite zone becomes thinner. The dip of the foliation of the gneiss and mineralized zone as measured on drill cores increases from 45°–50° SE. at the northeast (holes S–3 and S–12), to 60°–70° in the southwestern part under the old Cook mine workings.

Faulting is uncommon at the Scott mine. With the exception of a prominent fault, which lies at the north end of the 200-level drift, there are only a few minor postore breaks of negligible displacement. An exception can be seen on the 200 level south of the vertical shaft where in part of the Scott stope a tight strike fault dips 70° W. and appears to have had a reverse movement of about 15 ft. On the 200 level the fault is the west boundary of the ore, but in the stope above it intersects the shoot, bringing ore against ore.

Colony (1923, p. 93) states that the major fault at the end of the 200-level drift cuts off the ore, but underground mapping has shown that this has not been proved by development. The ore goes into the wall of the drift near the fault but cannot be seen to be cut off by it. However, if the fault and the ore continue their strike, the fault should intersect the ore about 40 ft beyond the end of the drift (pl. 23).

The walls of the ore body are pyroxene amphibolite and pegmatite. The contacts of the mineralized rock with the wallrocks are generally sharp, though in places the contact may be more or less gradational within a foot or so. Pegmatite is plentiful and occurs as fairly continuous thin sheets. It intrudes the gneiss, and in places the ore splits around it. Nowhere was pegmatite seen cutting the ore, but veinlets of magnetite crosscut pegmatite in places. The important magnetite bodies occur only in pyroxene amphibolite, though a few small local occurrences in skarn and pegmatite were noted in some of the drill core.

The ore varies in quality from massive granular magnetite, with only a few grains of unreplaced silicates, to material which has a banded appearance due to parallel seams and veinlets of magnetite alternating with unreplaced amphibolite or pyroxene amphibolite laminae. Some apatite and small amounts of sulfides—mostly pyrite, a little pyrrhotite and traces of chalcopyrite—also are present. According to Colony (1923, p. 92), shipping ore analyzed from 58.50 to 61.0 percent Fe, and from 0.35 to 0.61 percent P.

### AUGUSTA MINE

The Augusta mine is about 1,400 ft south-southwest of the Cook mine and on the same mineralized zone. The workings are caved, flooded, and completely inaccessible. Two large, flooded open-cuts and three flooded shafts are all that can be seen on the site of the old mine, though a few other shallow, trenchlike openings are found along the zone as far as 1,500 ft south of the main workings.

The magnetite-bearing zone is in pyroxene amphibolite, and quartz-oligoclase gneiss is on the footwall. The hanging wall (east of the zone) is pink pegmatite, which is also plentiful as sheetlike bodies in the gneiss and skarn east of the zone. The mineralized zone and the foliation in the adjacent gneiss strike about N. 10° E. and dip 40°–50° E.; the plunge is 21° NNE.

According to the old maps and sections of the Ramapo Ore Company, two ore shoots were worked at the Augusta mine. The shoots ranged from only 8 to 10 ft in the widest places. The larger shoot is represented by the most northerly of the elongate surface openings. This shoot was about 400 ft long measured horizontally; the smaller body, some 275 ft to the south, was about 250 ft long. These bodies were worked to a vertical depth of 100 ft and 75 ft, respectively. An old map shows a 400-ft drift 200 ft below the surface under the first shoot. Apparently this was an exploratory drift so situated that it cut across both ore shoots. Old records show six diamond-drill holes put down to explore the underground extension of the Augusta shoots, which become thinner at depth. A magnetic survey conducted by the Sterling Iron and Railway Company showed that the belt of attraction continues for almost half a mile south of the main workings, but the attraction becomes progressively weaker in that direction and no other important shoots are indicated.

### LONG MINE

The Long mine is about 4,000 ft northeast of the Scott mine shaft (fig. 44; pl. 20). An open-cut about 700 ft long and several small shallow cuts constitute the visible workings. All of them are flooded and so badly caved that it is impossible to determine the extent of the underground development. According to Colony, 37,500 tons of ore were removed between the time of discovery (1761) and 1839 (1923, p. 93).

The magnetite at the Long mine is in pyroxene amphibolite near the contact with the quartz-oligoclase gneiss that occupies the core of a plunging anticline. The mineralized zone is on the east limb of the fold and the belt of magnetic attraction swings around the north end of the fold and appears to be continuous with the Smith-Mountain mine ore zone on the west flank.

Many large conformable granite pegmatite sheets or lenses intrude the gneiss in the vicinity of the Long mine; a pegmatite sheet about 15 to 20 ft thick constitutes the hanging wall. The footwall is dark pyroxene amphibolite and, in places, pegmatite. The magnetite occurs as veinlike stringers and layers, ranging in thickness from a fraction of an inch to several feet, lying parallel to the foliation. The ore is 3 to 4 ft thick in some of the pillars, and the old openings indicate that the ore was not more than 10 to 15 ft thick at most. At the north end the ore thins rapidly from a solid body 4 or 5 ft thick to stringers of a fraction of an inch. The host rock also thins and in turn gives way to pegmatite. Where the pyroxene amphibolite is finally displaced by pegmatite, the magnetite veinlets end abruptly or, less commonly, extend into the pegmatite for short distances. Colony (1923, p. 93) reported that the ore was split by a "horse of country rock, making two parallel bodies." Because of the present condition of the workings, exposures are not good enough to show this feature.

The magnetite zone and the foliation of the gneisses strike nearly north at the south end of the workings and become progressively more westerly as one goes north, until in the most northerly exposures of the zone the strike is about N. 50° W. In contrast to the moderate to steep dips along the Scott-Cook zone, the dips of the gneissic foliation and mineralized zone are consistently gentle to the east and northeast, averaging about 30°; the dip becomes even more gentle in the northernmost exposures, where angles as low as 8° and 10° to the northeast were measured. The plunge of the lineation and of the ore is 15° to 18° north to northeast.

The depth to which the ore was mined is unknown, but it was probably 100 ft or less.

The four drill holes northeast of the openings (pl. 20) showed that the magnetite zone is very thin and probably too low in grade for profitable mining. The ore shoot that was mined probably pinches out at a relatively short distance in depth.

The lenticular shape of the pegmatite layers in the gneiss above the ore zone is well shown in the drill core. In the eastermost holes, S–2 and S–4, pegmatite occupies only about a third of the drilled section; 300 ft west southwest in holes S–5 and S–7, which are in the same plane as S–2 and S–4, about 70 percent of the rock is pegmatite.

## SMITH MINE

The shaft of the old Smith mine west of the Long mine (fig. 44; pl. 20) is flooded and caved, and because it is near a large swamp there are no exposures. Colony (1923, p. 94) states that "* * * a body of magnetite about 2 ft thick was encountered at the bottom of this shaft." The mine is at the north end of the western mineralized zone on which the Mountain and Crossway mines are situated, and is on the western flank of the anticline described on pages 191 and 223–224. A belt of magnetic attraction continues around the nose of the fold and joins the Smith mine with the Long mine.

Two holes, S–6 and S–10 (pl. 20), were drilled from one location in order to explore the zone a little north of the Smith shaft between 100 and 250 ft below the surface. Hole S–6, inclined at 30°, cut about 2.5 ft of magnetite of good grade at a vertical depth of about 100 ft. In the steeper angled hole (S–10, 50°) about 16 ft of low-grade material was found at 150 ft, and 18 ft of medium- to high-grade material between 225 and 260 ft in depth. This lower body may be the extension of the body of magnetite which causes high dip-needle readings over an area 250 ft long at the Smith shaft.

## MOUNTAIN MINE

The Mountain mine is about 2,000 ft south of the Smith shaft (fig. 44; pl. 20). Ore was discovered here in 1758 (Colony, 1923, p. 94) but development was not begun until 1831. The workings consist of a series of deep, narrow openings extending over a distance of about 1,100 ft along the strike. The southermost openings are on the discovery site, and were originally known as the Patterson mine. The northern openings constitute the Mountain mine. The depth of the workings is not known.

The mineralized zone is in pyroxene amphibolite and, like the eastern belt, is situated close to, but not at, the contact with quartz-plagioclase gneiss. Leaves of granite pegmatite are common in and adjacent to the zone. The zone is on the steep overturned western limb of an anticline and the dip is about 80° SE. to vertical. The plunge could not be satisfactorily determined but it appears to be north-northeast at a moderate angle.

Specimens from the dumps range from massive granular magnetite to material containing considerable pyroxene gangue. As mined, the ore ranged in thickness from 10 to 20 ft and apparently was in a tabular body. It is reported that the ore in the shaft averaged 9 ft in thickness.

Five holes were drilled as shown in plate 20. The holes were planned to penetrate the ore zone between 100 and 150 ft vertically beneath the surface. Magnetite-bearing rock of medium grade was cut in the northeasternmost hole, S–11, about 625 ft south of Smith shaft, and in holes S–13 and S–16 about 650 ft south of S–11. Its thickness averages about 25 ft, and its position in the holes indicates that all of it is probably from one mineralized zone. The ore body may or may not be continuous. Holes S–17 and S–18 are nearly 1,100 ft south of S–13 and S–16 and about midway between the northern and southern limits of the old surface workings of the Mountain mine. Only a few feet of medium-grade ore was cut here.

#### CROSSWAY MINE

The Crossway mine (also called the Causeway mine) is about 1,000 ft south of the south end of the Mountain mine, and about 800 ft west of the Cook mine (fig. 44; pl. 20). It is also situated on the western mineralized zone which is offset south of the Mountain mine by the diagonal fault described on pages 192, 224.

A flooded open-cut, 10 to 15 ft wide, extends about 300 ft north-northeast from the Sterling Lake road. The workings went to a depth of 100 ft, and Colony (1923, pp. 95–96) says that about 78,000 tons of ore has been removed since the discovery in 1793.

The ore is in pryoxene amphibolite close to the hanging wall of quartz-oligoclase gneiss. Several large conformable sheets of pink pegmatite intrude the dark gneiss on the footwall side. The pegmatite bodies, the gnessic foliation, and the ore strike approximately N. 20° E. and dip very steeply southeast. Apparently the ore became thinner with depth, for it was about 14 ft wide where first opened and the later operations were in a body 5 to 8 ft wide (Colony, 1923, pp. 95–96).

A small prospect pit judged to be on the site of the old Fletcher mine was found about 100 ft southwest along the strike from the Crossway. South of the prospect pit no other deposits of magnetite are known, but in places there is weak magnetic attraction as shown by a dip needle. The geology indicates that this western mineralized zone may be continuous with the lower mineralized zone south of Sterling Lake.

### OTHER MINES AND PROSPECTS

In addition to the Sterling Lake and Ringwood deposits there are other concentrations of magnetite, some of them in groups and others of isolated occurrence. The geological features observed in the Sterling and Ringwood districts are found also in these deposits.

#### CRAWFORD AND STEELE MINES

About 2,000 ft northwest and southwest, respectively, of old Sterling Furnace are the Crawford and Steele mines (fig. 44; pl. 19) at the north and south ends of what is believed to be a more or less continuous zone of mineralization. A dip-needle survey made by the Sterling Iron and Railway Company shows an almost continuous belt of magnetic attraction joining the Steele mine with the Crawford mine.

The zone is more than 3,600 ft long and strikes N. 35° E., beginning about 1,100 ft northeast of the New York-New Jersey State line. About 1,500 ft west of the Crawford mine another magnetite body was opened up at the Brennan prospect (fig. 44; pl. 19).

The Steele-Crawford zone is probably on the east limb of a small syncline plunging 15°–20° NE. The fold is fairly open at its south end but farther north it becomes tighter and overturned to the west. The belt of amphibolitic gneiss containing the zone of magnetite deposits can be followed around the end of the fold near the Steele mine. Although the Crawford and Steele mines appear to be on the same zone, there is no evidence that the Brennan is a continuation of the zone on the opposite limb of the syncline. Its position relative to the contact with the quartz-oligoclase gneiss is, however, similar to that of the Steele and Crawford.

A large open-cut 375 ft long, 15 to 20 ft wide, and 40 ft deep, and several other smaller pits constitute the present workings of the Crawford mine, which was opened in 1792. At the north end of the open-cut a drift continues along the strike of the zone for an unknown distance.

The ore was in an elongate lens as much as 35 ft thick and probably averaging 15 to 20 ft. It dipped 80° to the southeast and plunged about 20° NNE. Colony (1923, p. 86) estimated the shoot to have been 125 ft high, measured in the plane of the lens. At the north end a small fault striking N. 75° W. and dipping 80° S. cuts the ore and displaces the north side 15 or 20 ft east. A short distance north of the fault at the end of the open-cut the top of the ore shoot plunges gently beneath the cap rock. Apparently this was a fairly large body of ore, and, judged from material that can now be seen on the dump, was of good quality. Colony (1923, p. 85) states that the ore averaged 57.66 percent Fe, 2.004 percent P, and 0.178 percent S. No data are available concerning the depth to which the ore was mined and, so far as known, there has been no adequate exploration to determine the continuity of the ore shoots at depth. A few shallow openings north of the large cut do not show any ore.

No extensive mining operations have been conducted at the Steele mine, but the mineralized zone has been explored for a distance of 800 or 900 ft along the strike by several pits and trenches. In their present condition none of the openings clearly expose the ore.

The magnetite-bearing rock where exposed is seldom more than 5 or 6 ft wide and is of poor quality. It tends to be layered, but some is massive and granular. Examination of Colony's specimens shows an incomplete replacement of pyroxene amphibolite by magnetite. The magnetite layers are parallel to the gneissic structure of the rock. Many apatite granules are enclosed in the magnetite.

A map furnished by the Sterling Iron and Railway Company shows moderate to high dip-needle readings at the Steele mine between 1,000 and 3,000 ft S. 30° W. of the southern end of the Crawford open-cut.

### BRENNAN PROSPECT

Four shallow pits and one flooded shaft constituted the workings at the Brennan prospect (pl. 19). It is reported that a shaft 20 ft deep exposed a layer of ore 10 ft thick. Colony (1923, pp. 86–87) says that excavation to the south revealed no ore, and a dip-needle survey did not indicate the presence of magnetite. Hence, he postulated a fault to explain the abrupt termination. Efforts to follow the ore north of the shaft were unsuccessful also. Possibly the Brennan deposit was only a small lens whose pitch carried it below the surface.

The magnetite has replaced pyroxene amphibolite, much of which is migmatite grading to quartz-oligoclase gneiss. Granite pegmatite is not plentiful in the vicinity of the mine. The foliation of the surrounding gneiss dips steeply to the east and the linear structure plunges about 21° NNE. The material on the dump is mostly veinlets and thin layers of magnetite in pyroxene amphibolite, though it contains a few pieces of fairly massive granular magnetite, with a small amount of pyroxene gangue.

### THE REDBACK BELT

The old Redback mine is situated at the south end of a mineralized zone, the north end of which was explored by shallow pits of the Alice mine. The Redback mine is 1¾ miles southeast of Sterling Lake. Ore was discovered here in 1780, and by 1880 a total of 3,600 tons of ore had been mined. The mine was abandoned soon afterwards.

The mine was worked through surface openings for 500 ft along the strike, and an inclined shaft about 300 ft long followed the ore down the dip (Colony, 1923, pp. 87–88). Except for shallow, trench-like openings the workings are inaccessible because of caving and flooding. In 1943–44 the U. S. Bureau of Mines and the U. S. Geological Survey conducted a diamond-drill exploration program of the Redback zone. A detailed unpublished report by B. F. Leonard of the Geological Survey has been used in this report to supplement observations made by the writer. A report by Millar, Hammond and Sanford (1949) contains data resulting from exploration by the Bureau of Mines.

The Redback belt deposit differs from most of the Sterling Lake and Ringwood deposits in that the magnetite has replaced pyroxene skarn. The skarn is associated with a series of metasedimentary gneisses, which include amphibolite, pyroxene amphibolite, garnetiferous biotite gneiss, remnants of impure marble, and some thin layers of scapolitic quartzite. Sheets of granite pegmatite are plentiful in the skarn and are interlayered with the other metasedimentary rocks. The belt of metasedimentary rocks is about 400 ft thick, has an outcrop width of about 600 ft, and strikes N. to N. 10° E., dipping from

40° to 50° E. Linear structures measured on outcrops and on drill cores plunge north at angles from steep or vertical at the south end of the belt to very gentle at the north end.

The rock containing magnetite ranges from 2 or 3 ft of low-grade material to 17 ft of intermediate-grade ore. The average composition, according to Colony (1923, p. 87), is 52.93 percent Fe, 0.028 percent P, and 3.603 percent S. The Bureau of Mines investigation showed a somewhat lower iron content; samples range from 14 to 50 percent iron. The magnetite replaces pyroxene skarn, and to a lesser extent, associated layers of marble. Some of it is associated with serpentine. Pyrite, pyrrhotite, and chalcopyrite, in descending order, account for the high sulfur content.

A belt of magnetic attraction extends from the south end of the open-cut at the Redback mine 4,300 ft north along the strike of the rocks to the Alice mine. Apparently most of the magnetite concentrations occur as rather thin tabular bodies and small lenses.

Leonard, by carefully noting and logging the lithologic features in the drill core, was able to establish characteristic units and markers that were sufficiently persistent to enable correlation of rock units from hole to hole (Hawkes, 1947, pp. 13–17). Knowing the position of the units relative to the zone in which ore occurred in some of the holes, Leonard was able to predict rather successfully during the course of the drilling the approximate position at which the ore should be found.

### MOREHEAD MINE

The Morehead mine is about 2,750 ft southwest of the Redback mine (fig. 44). It was worked through an open-cut and two shafts, one at each end of the mine. The present visible workings are an open-cut 425 ft long at the north end, a shaft at the south end, and an open-cut 45 ft long, about 30 ft north of the shaft. The workings cover a distance of about 600 ft and appear to have been connected underground by a drift. The depth to which the ore was mined is not known, but judged by the size of the dump, it was not great.

The magnetite zone was a more or less tabular body about 10 ft thick, striking about N. 30° E. and dipping from 65° to 70° SE. Five to 6 ft of magnetite remain in some of the openings. The mineralized zone cannot be followed magnetically much beyond the southernmost workings, and to the north it apparently has been largely removed by erosion.

The magnetite is more or less massive and occurs in almost completely serpentinized pyroxene skarn. Much of the magnetite is medium- to coarse-grained, but some of it is fine-grained to microscopic secondary magnetite released by the serpentinization of the skarn. Sulfides, mostly pyrite and some pyrrhotite, make up about 2 or 3 percent of the magnetite-bearing rock.

### BERING MINE

The Bering mine is near the eastern edge of the mapped area about 1½ miles southeast of the Morehead. It is not in Rockland County, N. Y., as Colony described it, but in Orange County, N. Y., near the Orange-Rockland County line. The mine is badly caved and flooded and all that is visible of the old workings is an open-cut 300 ft long.

The body of magnetite was more or less tabular; its maximum thickness was 15 ft, and its thickness probably averaged between 5 and 10 ft. The magnetite occurs in pyroxene skarn intruded by some thin sheets of pegmatite. The wallrocks are amphibolite and migmatitic amphibolite. The rocks strike N. 35°–40° E. and are inclined to the northwest at steep angles. Apparently the Bering is situated on the east limb of a small syncline because 1,000 ft to the west the foliation dips southeast. In the open-cut the foliation on the east, or footwall, side is essentially vertical or dips very steeply west; on the west wall the foliation rolls, changing from a steep dip east at the upper edge of the cut, through vertical, to a steep westerly dip near the bottom of the exposure. The lineation plunges 10° or less NE.

### MIDDLE AND HARD MINES

The Middle and Hard mines are little more than prospects. The Middle is about 1,000 ft southeast of the main Augusta pits; the Hard is about 500 ft east-northeast of the Middle (fig. 44). Nothing is known of the past history of these properties; probably neither produced more than a token amount of ore.

The Middle mine is near the center of the large body of light-colored pyroxene skarn east of the Augusta mine, probably the southeast continuation of the skarn and marble belt cut in drill holes east of the Scott-Cook mine. Workings consist of a small open-cut and a very small dump. A little magnetite-bearing rock of poor grade can be found on the dump, but none can be seen in place.

The Hard mine was developed somewhat more extensively than the Middle. A small pit exposes a 10-ft thickness of disseminated magnetite in dark gneiss. A small open-cut 25-ft long shows 4 to 5 ft of rock containing disseminated magnetite. The magnetite-bearing zone is in a very thin layer of gneiss on the eastern edge of the belt of light skarn. It is between the skarn and a narrow band of quartz-oligoclase gneiss. The rocks dip moderately to the east and trend N. 15° E. No linear structure was observed.

### SHAFT-NEAR-RAILROAD

About 2.5 miles south of Sterling Lake on the east side of the old Sterling railroad is an unnamed prospect (fig. 44) marked by a small flooded shaft. The wallrocks are quartz-oligoclase gneiss containing a few thin leaves of dark, pyroxene amphibolite that strike about

N. 10° E. and dip 80° E. A few thin veinlets of magnetite replacing the inclusions of pyroxene amphibolite can be seen in the outcrop. Apparently a small body of magnetite replaced a lens of dark gneiss enclosed in the granitic gneiss. No pegmatite can be seen.

A small area of magnetic attraction was found less than 50 ft north of the shaft and another lies 450 ft west-southwest of the shaft.

### PATTERSON MINE

A small prospect called the Patterson mine is 0.75 mile southwest of Beach Mountain and about 1 mile northeast of the old settlement of Hewitt. It is in Passaic County, N. J., and is briefly mentioned by Bayley (1910, p. 420) as having been worked about 1903, though no ore is known to have been shipped. Two flooded shafts and several shallow pits exist. A considerable amount of fair- to good-grade material containing sparse amounts of pyrite has been dumped about the openings.

Because of the absence of outcrops at the mine, the exact occurrence of the magnetite body is not known. The deposit is in the midst of a large body of quartz-oligoclase gneiss that commonly has dark inclusions. In the nearest outcrops the foliation of the gneiss strikes N. 40° E. and is vertical to steeply inclined southeast.

The magnetite is seldom massive but consists of grains of magnetite intergrown with pink potash feldspar and quartz. Under the microscope it can be seen that magnetite has replaced the feldspar and quartz. Conspicuous amounts of epidote and colorless zoisite are likewise present. A little pegmatite and some barren pyroxene skarn are also on the dump.

### BOARD (SCHERMERHORN) MINE

The Board mine, described by Bayley (1910, pp. 459–460), is about 1.25 miles due west of Ringwood. It is considered by some, who call it the Schermerhorn, as being in the Ringwood mining district.

The mine was opened in 1872, and 11,000 tons of ore was shipped before the close of 1873. Intermittently operated after that, the mine was finally closed in 1884. Little is to be seen except two caved pits and a small dump, though Bayley (1910, p. 460) states that a 9-ft vein dipping 30° SE. was worked for a distance of 100 ft and to a depth of 70 ft. A parallel vein of unknown dimensions was found 50 ft east of the first.

Judged by Bayley's account and by the material on the dump, the ore was lean and consisted of a magnetite replacement of pyroxene amphibolite. It contains traces of apatite and pyrite.

## SUGGESTIONS FOR PROSPECTING

Although none of the mines of the Sterling Lake and Ringwood area is producing at present, they are by no means exhausted. Undoubtedly they are still capable of producing a considerable tonnage of ore and may sometime be mined again. The lower workings of the Peters and Cannon mines and the Scott mine are still in ore. Similar deposits in New Jersey have been traced several thousand feet along the plunge of the ore shoots.

The chances of finding a new large deposit of magnetite in the Sterling Lake and Ringwood area are believed to be slight, inasmuch as individuals and private concerns have searched most of this region with dip-needles. Furthermore, the most promising places where known concentrations of magnetite might be expected to continue in depth have been drilled by private interests. There are, however, a few deposits that seem to warrant further investigation and offer possibilities for the devolopment of new reserves.

One of them is the Hope Mountain ore zone in the Ringwood district. Here are several ore shoots in an environment similar to that of the Peters mine. Exploration and mining probably could be carried on from the Peters shaft. Accurate location of the shoots at the surface would first be necessary. This step would be followed by projection of the shoots in depth, based on observations of strike, dip, and plunge at the surface, followed by an intensive drilling program to check the underground position and size of the shoots. Relatively short crosscuts made from the southeast slope could be used to explore the more promising shoots, which then could be developed from the Peters workings.

The Keeler-Miller-St. George group in the same district merits consideration. Diamond drill holes from the surface would probably reveal whether the shoots extend in depth. Some underground exploration may be possible from the Miller shaft.

One of the most promising areas for exploration appears to be at the Crawford mine. An old dip-needle map belonging to the Sterling Iron and Railway Company shows a well-defined anomaly here. The highest dip-needle readings are over the old workings, but a belt of high dips, averaging about 100 ft in width, continues to the north for about 450 ft beyond the north end of the pit. A drill hole was put down by the Ramapo Ore Company to explore the Crawford ore body at depth, but no ore was found. This hole was started more than 1,000 ft from the ore zone at an angle of about 55°. The hole was 1,487 ft long and should have almost reached the vertical projection of the Crawford ore zone. In order to verify the presence of the ore at depth, the first holes should be drilled closer to the zone and should cut the ore within a few hundred feet of the surface. Once something is known of the subsurface structure, a more extensive drilling program could be outlined.

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