Geology and Magnetite Deposits of Dover District, Morris County New Jersey

By PAUL K. SIMS

With a description of

THE GEOLOGIC SECTION AT HIBERNIA MINE

By A. F. BUDDINGTON

GEOLOGICAL SURVEY PROFESSIONAL PAPER 287

Prepared in cooperation with the New Jersey Bureau of Mineral Research, Rutgers University

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1958

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C.

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By Paul K. Sims

ABSTRACT

The Dover district, Morris County, N. J., one of the oldest mining regions in the United States, has been active intermittently since the early part of the 18th century, and has yielded in excess of 26 million long tons of iron ore valued at more than $100,000,000. This is about 70 percent of the total production of iron ore from the State of New Jersey. Since 1940 about 500,000 tons of magnetite lump ore and fine concentrate have been shipped annually from the Scrub Oaks, Richard, and Mount Hope mines—the 3 producing mines in the district.

The Dover district is an area of about 80 square miles in the Dover, Boonton, Mendham, Chester, and Newfoundland 7½-minute quadrangles. It is 18 miles long and 4 to 5 miles wide, and it extends from the village of Ironia on the south to the Pequannock River on the north. The northwest border is the contact of the pre-Cambrian rocks with overlying sedimentary rocks of early to middle Paleozoic age; the southeast limit is arbitrary.

The district is in the New Jersey Highlands, which constitutes a part of the Reading prong of the New England physiographic province. The surface is characterized by northeastward-trending ridges separated by valleys that are 200 to 300 feet below the ridge crests. Altitudes range from about 500 to 1,100 feet. The topography is controlled by the structure and lithologic character of the bedrock and is principally the result of stream erosion. The terminal moraine of the Wisconsin glacial stage, 2 to 3 miles wide, crosses the central part of the district. North of the terminal moraine the topography is moderately rugged and the bedrock is well exposed. South of the moraine the bedrock is covered, except locally on the crests of the hills.

The bedrock consists of a wide variety of pre-Cambrian metasedimentary rocks, migmatites, and intrusive igneous rocks that are intruded locally by small Triassic(?) diabase dikes. The pre-Cambrian rocks are disconformably overlain along the northwestern border of the district by steeply dipping sedimentary rocks of early Paleozoic age. Surficial deposits of the Quaternary form a discontinuous, generally thin cover over the bedrock.

Metasedimentary rocks, the oldest pre-Cambrian rocks in the Dover district, are widely distributed and constitute about 25 percent of the bedrock. They are high-grade metamorphic rocks, derived from calcareous and alumino-siliceous sediments, that have been thoroughly recrystallized and reconstituted. The calcareous rocks have been altered to marble, pyroxene gneiss, skarn, and amphibolite and related rocks; and the alumino-siliceous rocks to biotite-quartz-feldspar gneiss—which contains variable quantities of garnet, graphite, and sillimanite—and oligoclase-quartz-biotite gneiss. The metasedimentary rocks have been isoclinally folded and intruded by igneous sheets and phacoliths; consequently, they crop out both as distinct layers and lenses of different widths and lengths and as generally concordant inclusions within the igneous rocks. Because of the complex structure and the fragmentary record of the metasedimentary rocks and the predominance of igneous rocks, the thickness and the age sequence of the metasedimentary rocks are imperfectly known.

The pre-Cambrian intrusive rocks, in order of inferred age, from oldest to youngest, are [1] quartz diorite and related facies, [2] albite-oligoclase granite and albite-quartz pegmatite, and hornblende granite and related facies. [1] The quartz diorite and related facies contain both clinopyroxene and orthopyroxene, and consist of even-grained granular rocks that have a prominent compositional layering; accordingly, the group is similar to rocks that have been included in the charnockite series. Tentatively they are considered to be of igneous origin and to have formed from a dry magma. [2] Aside from local contaminated facies, the albite-oligoclase granite is alaskitic. Probably the magma that consolidated to form the granite was generated at depth during orogeny by anatexis or differential fluxing of oligoclase-quartz-biotite gneiss, and perhaps other rocks of similar composition, and it moved upward. [3] The hornblende granite and related facies, which include hornblende granite, alaskite, microantiperthite granite, biotite granite, granite pegmatite, and a deformed facies of hornblende granite, formed principally by the differentiation of a magma of granitic composition.

Throughout the Dover district the pre-Cambrian rocks trend northeast and dip steeply southeast, but there is considerable local variation. This prevailing regional pattern is produced by northeast-trending isoclinal and open folds. The structural pattern was developed in Proterozoic time; the direction of principal tectonic motion within the rocks was northwest. Later deformation had little observable effect on the pre-Cambrian rocks, except for the development of some faults and possibly some joints.

The pre-Cambrian rocks have a fair to excellent foliation produced by the dimensional orientation of platy and tabular minerals and by the parallelism of layers, streaks, and lenses. The foliation in the metasedimentary rocks is parallel to the bedding in the original sediments. The dominant foliation in the granitic rocks developed before complete crystallization of the magmas, but in places a secondary foliation was superimposed upon the earlier primary one. Lineation in all rock types is remarkably uniform throughout the Dover district and it has an ave age plunge of 17° N. 52° E. The lineation for the most part is parallel to the fold axes, in the *b* axis of the coordinate system.

The folds in the district range in size from small flexures a few feet in width to large folds a mile or more in width and as much as 7 miles in length. The folds are mostly isoclinal and, without exception, they plunge northeast at moderate to small angles. The largest folds are the Splitrock Pond syncline, Hibernia anticline, Telemark anticline, Cobb anticline, Kinnelon syncline, Mount Hope syncline, and Beach Glen anticline.

The metasedimentary rocks form parallel layers or belts along the limbs of the folds. In general the calcareous rocks tend to

form lenticular bodies and the quartzose rocks long continuous layers. An exception is the hornblende skarn, which forms bodies that extend indefinitely along their plunge.

The igneous rocks occur as conformable bodies and cross-cutting relations are rare. The quartz diorite and related facies forms folded sheets; two bodies have a synclinal structure. The granites occur as sheets and phacoliths. The field relations and the textures of the igneous rocks indicate that they were intruded into deformed country rocks during a period of orogeny; accordingly these rocks are classed as syntectonic intrusives. The emplacement of the intrusives was largely controlled by the preexisting structures in the metasediments. The quartz diorite and related facies was emplaced early in the orogeny and subsequently was folded and recrystallized. Much later albite-oligoclase granite was emplaced and soon afterwards hornblende granite and related facies. The granites consolidated under directed compressive stresses, which ceased, except locally, before complete solidification.

Faults, generally of small displacement and which are later than the ore, constitute serious mining problems in many of the mines. The faults can be classified as transverse, longitudinal, and oblique. The transverse faults are high-angle normal (or gravity) faults that strike northwest and dip steeply southwest. One of the largest faults of this type, the Mount Hope, has a net slip of 300 feet. The longitudinal and oblique faults are, with the possible exception of the Green Pond fault, reverse faults that strike northeastward and dip moderately to steeply northwestward. They are more abundant, but generally of smaller displacement, than the transverse faults.

The principal iron-ore bodies are in (1) oligoclase-quartz-biotite gneiss, (2) hornblende skarn, (3) pyroxene skarn, and (4) albite-oligoclase granite; others occur in reconstituted amphibolite and microantiperthite granite. Low-grade magnetite concentrations are in amphibolite, interlayered biotite-hornblende-pyroxene-feldspar gneisses, and granite pegmatite.

Most of the ore bodies are composed of massive magnetite and contain from 35 to more than 60 percent iron, about 1 percent phosphorus, and low titanium; sulfides are sparse to absent. The deposits in albite-oligoclase granite differ in consisting of disseminated ore; typically they contain 25 to 35 percent iron, and because of their low phosphorus content are of Bessemer grade.

The iron ores consist of a simple suite of metallic minerals. Magnetite constitutes the only ore mineral in the massive ore bodies and is the principal ore mineral in the disseminated deposits; primary crystalline hematite constitutes as much as 15 percent of the ore in the disseminated deposits. Martite occurs in small quantities with the hematite in the disseminated deposits. Ilmenite, as discrete grains and as exsolution lamellae in iron oxides, is widespread but generally negligible in quantity. Pyrrhotite, pyrite, and chalcopyrite constitute more than 1 percent of the ore in the deposits in the Green Pond ore belt, but are sparse to absent in other deposits.

The gangue consists predominantly of irregular, unreplaced fragments of the various host rocks together with minor quantities of minerals that were deposited by the ore-forming solutions—apatite, quartz, carbonate, biotite, sphene, chlorite, pumpellyite, tourmaline, and rutile.

The ore minerals were deposited during a single period of mineralization. After the deposition of these minerals there was local fracturing and crackling of some of the massive ore and subsequent deposition of small quantities of quartz and carbonate. The quartz and carbonate cement breccia fragments of the ore.

The iron-ore deposits are veinlike bodies that essentially conform to the gneissic structure of the wall rocks. At the surface they appear to be tabular, but when observed in three dimensions they are seen to be either lath-shaped or pod-shaped; they strike and dip parallel to the foliation and plunge parallel to the lineation of the enclosing rocks. The lath-shaped deposits are the most important sources of ore in the district. They are as much as 2 miles long (surface length) and average between 10 and 20 feet in thickness. The breadth of the deposits ranges from somewhat less than 100 feet to 2,400 feet. These ore bodies are unique among iron deposits because they extend along their longitudinal axes (pitch length) for indefinite distances; the end of an ore body has never been reached although several have been mined for more than a mile along their pitch length and to vertical depths of more than 2,000 feet. The ore bodies dip at angles greater than 45° and plunge 10° to 40° NE. The plunge of an individual deposit is remarkably constant along its length.

The pod-shaped deposits, which are much less common and occur only in pyroxene skarn, are, on the other hand, lenticular and pinch and swell along their longitudinal axes. Most are small, and they have not been important sources of ore.

The iron deposits are concentrated into ore belts or ranges that parallel the rock units and foliation. As most of the ore belts are on the limbs of major folds, they trend northeast, but one ore belt is on the nose of an anticline and accordingly has the shape of a fish hook.

Aside from the ore bodies in albite-oligoclase granite and the local concentrations in granite pegmatite and microantiperthite granite, all the deposits are in metasedimentary rocks. The ore minerals embay and corrode the minerals of the host and are interpreted to replace them. Microbrecciated zones formed by preore cataclastic deformation were favorable sites for the deposition of ore.

The magnetite deposits are believed to be high-temperature metasomatic replacement bodies formed by emanations from the alaskite magma, a differentiate of the magma that consolidated to form the hornblende granite of alaskitic composition. They were formed after the orogeny that deformed the pre-Cambrian metasedimentary rocks and after the emplacement of the youngest granitic rocks in the pre-Cambrian complex. The ore is believed to belong to the older Proterozoic, but the absolute age is not known.

The future of the district is promising. Although the district is an old one, and many of the deposits have been intermittently worked for more than 200 years, the reserves are adequate to provide iron ore for many generations at the present rate of exploitation.

INTRODUCTION

The Dover district, one of the oldest mining regions in the United States, has provided about 70 percent of the total iron-ore production of the State of New Jersey. Through 1950 it had yielded about 26 million long tons of iron ore valued at more than 100 million dollars (table 1). During the past decade an average of about 500,000 tons of lump ore and magnetite concentrate have been shipped annually from the 3 operating mines—the Scrub Oaks, Richard, and Mount Hope—in the district. This ore has been produced from magnetite-rich skarn, gneiss, and granite in pre-Cambrian gneisses and granites.

Despite the economic importance of the district and the fact that the deposits have been mined intermittently for more than 200 years, there has been no previous systematic geologic investigation of the region. The iron deposits in the Dover district, and in the other mining districts in the State, were studied by several geologists during the 1800's and the early part of this century, but these studies for various reasons were of local extent or of a reconnaissance nature; no geologic investigations have been carried on in the Dover district since the work of Bayley (1910). The present investigation—a systematic detailed geologic study—was undertaken as part of the U. S. Geological Survey's iron program in the northeastern United States. The geology of an area of about 80 square miles was mapped (pl. 1) and is presented in this report with a description of the magnetite deposits of the individual mines and prospects.

LOCATION AND ACCESSIBILITY

The Dover district is in Morris County, N. J., and includes parts of the Dover, Boonton, Mendham, Chester, and Newfoundland 7½-minute quadrangles. The district is 18 miles long, extending from the village of Ironia on the south to the Pequannock River on the north, and 4 to 5 miles wide. The northwest border of the district is at the contact of the pre-Cambrian rocks with the overlying sedimentary rocks of early to middle Paleozoic age; the southeast limit is established arbitrarily. (See fig. 1.)

Dover, population 11,210 (1950 census), is in the central part of the district. Other principal towns include Denville, Rockaway, Mine Hill, and Wharton, all of which are on or near the Rockaway River. New York City is 35 miles southeast; and Franklin, N. J., is 20 miles northwest of Dover.

The region is traversed by a good network of primary and secondary roads, and all parts are reasonably accessible. U. S. Highway 46 and State Highway 10 cross the central part of the district from east to west; U. S. Highways 202 and 206 extend north and south on the east and west sides, respectively, of the district.

Dover is on both the Delaware, Lackawanna & Western Railroad and the Central Railroad of New Jersey. Ore from the operating mines is shipped via the Central Railroad of New Jersey, a branch line of which, the Mount Hope Mineral Railroad, extends to the Richard and Mount Hope mines.

TOPOGRAPHY

The Dover district, in the New Jersey Highlands, a part of the Reading prong of the New England physiographic province, is characterized by northeastward-trending accordant ridges—part of the Schooley peneplain—that are separated by broad valleys that are at the elevation of the Harrisburg peneplain, 200 to 300 feet below the ridge crests (pl. 1).

Altitudes in the district range from about 500 to more than 1,100 feet. The highest point, altitude 1,156 feet, is north of Lake Kinnelon; the lowest points are along the valleys of the Rockaway and Pequannock rivers. The local relief in the district averages about 300 feet, but in places it is as much as 500 feet; the relief is greater in the region underlain by rocks of Paleozoic age, to the northwest of the district.

The topography in the region, as elsewhere in most of the New Jersey Highlands, is controlled by the structure and lithologic character of the bedrock. The northeastward-trending ridges and valleys are principally the result of stream erosion and reflect to a marked degree the structure of the gneisses. In places the more prominent fold structures are reflected by the topography. In general the ridges tend to be developed on the more massive and resistant rocks and the valleys on the less resistant rocks. Eastward-trending valleys and topographic saddles, which transect the prevailing trend of the topographic land forms, are in part formed along crushed zones in prominent transverse faults. (See pls. 1 and 15.)

The present topography, to different degrees, shows the effects of Pleistocene glaciation. The terminal moraine of the Wisconsin glacial stage (Salisbury, 1902, p. 252; Darton and others, 1908; Bayley and others, 1914) mantles the central part of the Dover district, forming a belt from 2 to 3 miles wide that in general is parallel to the Rockaway River. The terminal moraine completely obscures the bedrock in the region between Dover and Mount Hope where it locally is more than 150 feet thick; the moraine is considerably thinner, however, on the hill crests in the vicinity of Wharton and Mine Hill, where it is generally slightly less than 50 feet, and in places is less than 10 feet thick. The terminal moraine, where normally developed, is characterized by a distinctive hummock and sink topography that contrasts sharply with the topography developed on bedrock. The striking differences in the topography can be seen in plate 15. North of the stream that drains White Meadow Lake the topography is marked by northeastward-trending ridges and valleys controlled by bedrock structure; south of the stream the topography has the typical irregularity of terminal moraines.

North of the terminal moraine the topography is moderately rugged and the bedrock is well exposed, except in the valleys. The upland surfaces are somewhat rounded and smooth and frequently have bare precipitous south slopes. Glacial striae, which are evident in places, always strike nearly south. The valleys commonly are filled with alluvium, and rock exposures are sparse; swamps and lakes, many of which are artificial, are abundant. The valleys of Beaver

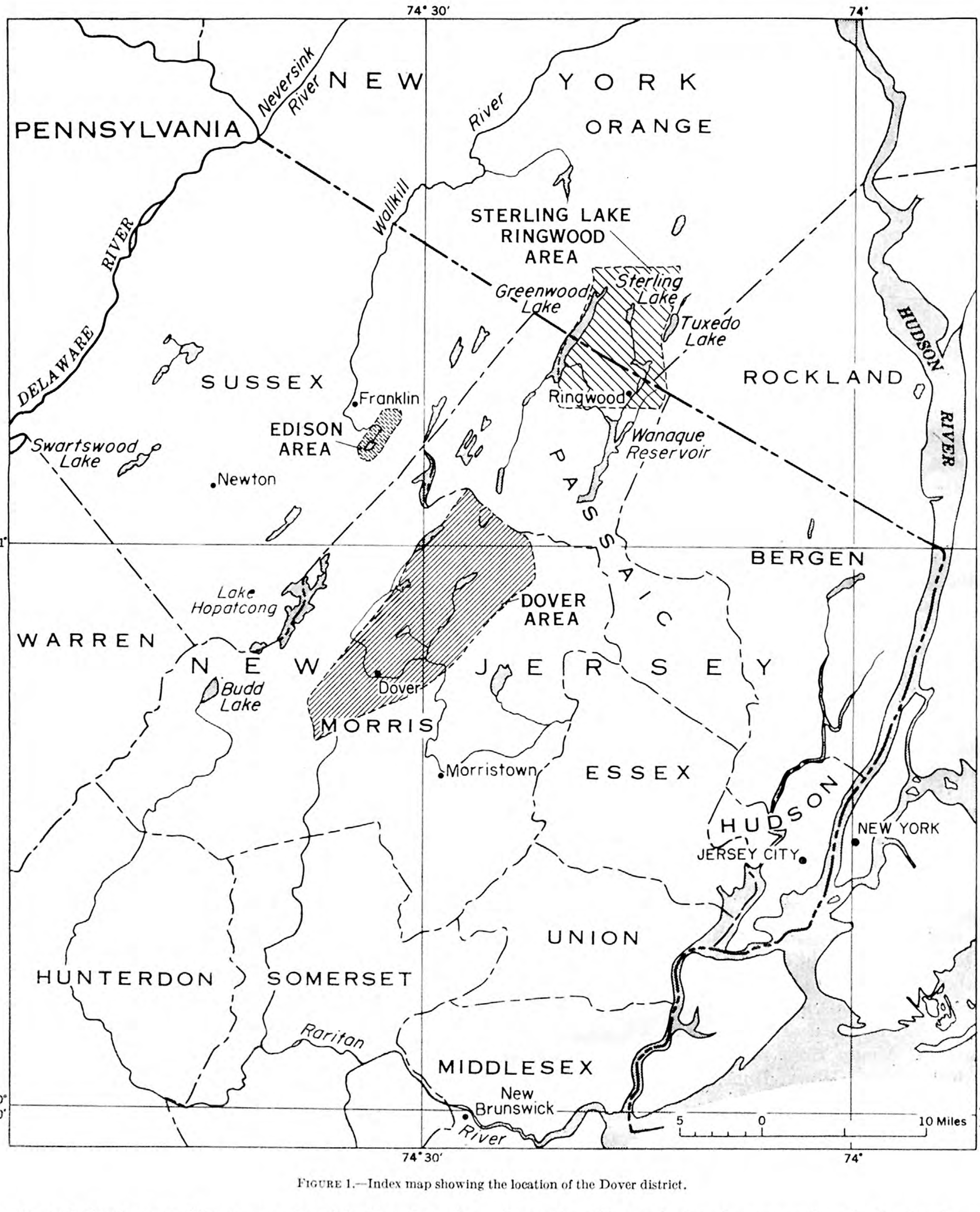


FIGURE 1.—Index map showing the location of the Dover district.

Brook and Rockaway River contain wide flat deposits of stratified drift and alluvium.

South of the terminal moraine another distinctive type of topography is developed. In this area outwash from the Wisconsin ice sheet mantles the lowlands, and drift of pre-Wisconsin age largely mantles the uplands (Bayley and others, 1914; MacClintock, 1940). Exposures of bedrock are sparse and are confined for the most part to the crests of the higher hills. The rocks are moderately weathered and a residual rubble characteristically mantles many of the ridges.

CLIMATE AND VEGETATION

The climate is similar to that throughout the Highlands and is marked by cold winters and warm summers. Excessive extremes of temperature rarely occur. The mean annual temperature at Dover is about 49° F.

The average annual rainfall at Dover is about 50 inches, and the average annual snowfall is 47 inches. Most of the precipitation falls in the spring and fall, and the summer months may be relatively dry, although thunder showers are not infrequent.

Most of the region is covered by dense vegetation. The country has been cut over at least once, and many parts several times, so there is a great variation in the density and type of vegetation. The central and northern parts of the district are heavily wooded; the southern part is partly cleared and extensively cultivated. In upland areas deciduous trees predominate over evergreens. In swamps small shrubs and scrub trees form a tangle that in places is almost impenetrable. The trees are chiefly oak, poplar, birch, maple, hickory, beechnut, cottonwood, and chestnut. Rhododendron is common in swampy areas and on many slopes.

PREVIOUS WORK

The literature contains numerous references to the geology of the magnetite deposits and associated rocks of the Dover district and the New Jersey Highlands. The early reports have been reviewed by Bayley (1910, p. 156–182) in his excellent volume on the iron mines of New Jersey, but because this volume is not widely available a summary of the more important earlier studies is given here, together with a discussion of the more recent investigations.

The first references to the geology of the New Jersey Highland region are contained in a series of papers published in the early 1800's. Pierce (1822) described the rocks of the Highlands as granites and schists and he also mentioned two of the mines—the Copperas and Dickinson—in the Dover district. Later Rogers (1836, 1840) gave a more detailed description of the geology of the Highlands. He recognized that the gneisses associated with the ore deposits were unconformably overlain by sedimentary rocks of Paleozoic age. Also he proposed an igneous origin for the magnetite ore bodies, stating "that they are real veins of injection, and not true beds, contemporaneous with the adjoining gneiss, as some have supposed" (Rogers, 1840, p. 22). There were no significant papers for 15 years, but in 1855, Kitchell (1855, p. 28–38) discussed in some detail the geology of Sussex County, as typical of the northern part of the State. He divided the pre-Cambrian rocks into a metamorphic series that included gneiss, hornblende, slate, and white limestone; and an igneous series that included granite, syenite, and a quartzose feldspathic rock that cut the metamorphic series. He described the ore as consisting of magnetite and admixed quartz, mica, hornblende, and feldspar. In the following year Kitchell (1856, p. 111–248) presented a more detailed description of the magnetite deposits. In refutation of Roger's theory of an igneous origin, Kitchell concluded that the deposits are of sedimentary origin, mainly on the argument that they are associated with rocks which at the time of his studies were widely regarded as metamorphosed sedimentary rocks. In addition, he described the form and structure of the ore bodies; and presented a detailed description of the magnetic properties of the ore, the field procedure for investigation, and the interpretation of the survey data. In a third report, Kitchell (1857, p. 11–13) presented additional details of the deposits.

Some 10 years later, Cook (1868) compiled all previous data on the geology and magnetite deposits of the Highlands into a single excellent reference, which still is an important source of information not only for the Dover district but also for the entire State. He described each known mine in some detail and discussed the origin of the ores, essentially agreeing with Kitchell that the ores are metamorphosed sediments.

For several years after the publication of Cook's important report practically all of the studies in the New Jersey Highlands were devoted to individual mines, in an attempt to show some constant relation between the ore bodies and the associated rocks; little advance was made on the origin of the ore deposits. In 1883 a summary of these studies was given by Cook (1883). Following popular usage he referred to the deposits as "veins" and for the first time clearly described the structure of the deposits (Cook, 1883, p. 75–76).

In 1883 the State Survey began a systematic study of the geology of the New Jersey Highlands, which was continued through several years. Britton and Merrill (1885, p. 36–55) considered all the crystalline rocks as Archean in age, but they were unable to subdivide them into suitable mappable units. They agreed with the earlier opinions that the magnetite was sedimentary in origin, but they believed that there had been considerable segregation of iron during metamorphism. About this time the Tenth Census Report (for 1880) was published (Pumpelly, 1886), which contained many reliable chemical analyses of magnetite but little data on the geology.

In 1890 a report by Nason (1889, p. 12–65) contested the widely held opinion that all the rocks of the Highlands are metamorphosed sedimentary rocks. He did not subdivide the pre-Cambrian rocks into units that could be mapped, but he recognized 4 characteristic rock types: Mount Hope, Oxford, Franklin, and Montville.

In 1892 a summary of the pre-Cambrian geology of New Jersey was presented by Van Hise (1892, p. 414–415) and at about the same time geologists of the U. S. Geological Survey began a number of studies in the New Jersey Highlands. In the first report on these investigations Wolff (1894, p. 359–369) discussed the structure of the region near Hibernia, primarily concerning himself with the northward extension of the important Hibernia ore body. He mapped for the first time the foliation and lineation of the pre-Cambrian rocks and demonstrated by use of mappable units that large-scale folds occur in the Highlands. His map of the syncline at Splitrock Pond is an excellent one. An important petrologic report was published by Westgate (1896, p. 21–62) in which he described a sequence of intercalated calcareous rocks and quartzose gneisses on Jenny Jump Mountain, in Sussex County. Wolff and Brooks (1898) proved the White Franklin limestone to be pre-Cambrian, thus concurring with Kitchell, Cook, and Westgate. The white gneisses that cut the limestone were considered to be intrusives.

In 1905 Peck (1905, p. 161–186) described the gneisses near Phillipsburg and the associated limestones and talc, but he did not discuss the origin of the gneissic rocks.

In the same year Spencer (1905, p. 247–253), in the first of several important publications, proposed that all the gneisses of the Highlands are igneous in origin. He found that the magnetite was associated with all types of country rocks but that it was always found near pegmatites. In another paper Spencer (1904, p. 377–381) described the rocks further, and he proposed that the structure of the gneisses is original; the banding being the result of fluxion. Spencer (1904, p. 381) concluded that

> instead of being bog ores or carbonates deposited in sedimentary rocks and later changed to magnetite by metamorphism, as formerly suggested, they [the magnetite deposits] apparently have been introduced as products of igneous activity.

The results of the first regional studies in northern New Jersey were published in 1908 (Spencer and others, 1908; Darton and others, 1908). Spencer (1908) proposed 3 new formation names—the Pochuck, Losee, and Byram gneisses—in his report on the Franklin Furnace quadrangle, and these names have been widely used. Bayley applied these names to similar rocks in the Passaic quadrangle (Darton and others, 1908) and in the Raritan quadrangle (Bayley and others, 1914). Both Bayley and Spencer considered that the magnetite ores were of igneous origin. In 1910 an excellent volume by Bayley (1910) summarized the geology of the iron deposits and presented all the data available on the mines and prospects in the State. This report has been the most important source of detailed information on the individual mining properties.

In an important petrologic paper Fenner (1914) discussed the origin of certain gneisses in the New Jersey Highlands, but then nothing of significance was published until 1919 when Berkey and Rice (1919) described the geology of the West Point quadrangle, New York. Shortly afterwards Colony (1923) described the magnetite deposits of southeastern New York, and he presented the first clear statement for a metasomatic origin of the magnetite.

In 1933 Smith (1933, p. 658–677) described briefly the magnetite ores of northern New Jersey, particularly emphasizing the deposits at the Washington mine near Oxford; and in 1941 a report, based on work done in the early 1900's, was published on the pre-Cambrian geology of the Delaware Water Gap and Easton quadrangles, New Jersey and Pennsylvania (Bayley, 1941).

During World War II, the U. S. Geological Survey, as part of its northeastern United States iron program, began a study of most of the principal iron ore districts in the New Jersey Highlands. The first of these studies to be completed was the Ringwood, N. J. and Sterling Lake, N. Y. magnetite districts (Hotz, 1953). Later the Survey (Hotz, 1954), in cooperation with the U. S. Bureau of Mines, studied several widely scattered magnetite deposits in the western part of the New Jersey Highlands. These investigations indicated that the pre-Cambrian rocks of the Highlands are of both igneous and sedimentary origin and that the ore deposits are of metasomatic origin. During the early part of World War II the Survey began the investigation of the low-grade iron-ore deposit in the Edison mining district, but because of the pressure of other more urgent work this project was temporarily abandoned; it now is being completed and a report is being prepared on it by Buddington and others. In 1952 a report was published on the iron deposits in the Andover mining district, Sussex County, N. J. (Sims and Leonard, 1952), that compared the deposits to certain Swedish iron deposits. Later, a preliminary report on the Dover district (Sims, 1953) presented a summary of the geology and ore deposits of the district, and a brief discussion of the Mount Hope, Richard, Scrub Oaks, and Hibernia mines, and the Hibernia magnetic anomaly.

FIELD WORK

Geologic mapping and study of the magnetite deposits in the Dover district by the writer and other geologists of the U. S. Geological Survey, in cooperation with the New Jersey Bureau of Mineral Research, was started in June 1947 and continued through the 1948 and 1949 field seasons. An additional week was spent in the field during the spring of 1951. In all a total of 14 months was devoted to field work and an equal time to the preparation of reports. The field work was carried out under the general supervision of A. F. Buddington. The district (pl. 1) which is about 80 square miles in extent, was mapped on 7½-minute quadrangle maps prepared by Army Map Service (scale: 1:25,000). The locations of many mine shafts and opencuts were plotted on contact prints of aerial photographs, having a scale of approximately one inch equals 1,700 feet, and later were transferred to the topographic base maps. About 25,000 feet of underground mine workings was mapped and several thousand feet of drill core was logged at the Mount Hope, Richard, and Scrub Oaks mines. The mine mapping was done on company base maps. The mapping at Mount Hope mine was on a scale of 1 inch equals 30 feet, at Richard and Scrub Oaks mines on a scale of 1 inch equals 50 feet. Planetable maps or sketch maps were made of several small mines and prospects; a detailed geologic map of part of the surface at Mount Hope mine was made with a planetable in the spring of 1948. Six hundred fifty thin sections and 25 polished sections were studied in the laboratory.

In 1953, subsequent to the completion of this report, several long diamond-drill holes were put down at Hibernia mine. Because the cores provided a long, continuous section through a group of complexly interlayered rocks, they were studied in detail by A. F. Buddington, and the results of his studies are given on pp. 147–156.

ACKNOWLEDGMENTS

During the field work the writer was ably assisted by several members of the U. S. Geological Survey. P. E. Hotz spent 2 weeks in the field with the writer during June 1947. E. S. Davidson assisted for 9 weeks during 1947 and for 16 weeks during 1948; L. Pavlides assisted for 6 weeks during 1948; G. S. Koch, Jr., assisted for 16 weeks during 1949; and L. Carswell assisted for one week during 1951. Mr. Davidson did independent areal mapping in the southeastern part of the district; Mr. Koch also did independent areal mapping in the northwestern part of the district and was largely responsible for the mechanical construction of the block diagram of a part of the Mount Hope mine; and L. Pavlides prepared the topographic map of the Mount Hope mine.

In the course of the survey the writer had the advantage of constant advice from and discussion with A. F. Buddington. Professor E. Sampson of Princeton University aided in the study of ore deposits and in the preparation of the photomicrographs of polished sections.

The personnel of the mining companies in the district cooperated fully in every way possible. Although it is impossible to list all the individuals who have been helpful, the writer wishes to acknowledge especially the contributions pertaining to the Mount Hope mine made by Harry Davenport, F. G. Woodruff, T. J. Holland, and Allan James of the Warren Foundry and Pipe Corp.; to the Scrub Oaks mine by W. P. Schenck and W. Keats of the Alan Wood Steel Co.; and to the Richard mine by M. J. Brophy, M. T. Hoster, Richard Dockeray, and A. J. Getz of the Colorado Fuel and Iron Corp. R. C. Baker of the Baker Holding Corp. kindly offered data pertaining to the abandoned Baker mine.

Meredith Johnson, State Geologist of New Jersey, fully cooperated in every way, and supplied some of the production data. The Graduate School of Princeton University generously provided office and laboratory facilities and many thin sections prepared by C. Sadlon, of Princeton, N. J., and 3 chemical analyses made by E. Chadbourn, Rock Analysis Laboratory, Department of Geology and Mineralogy, University of Minnesota.

HISTORY AND PRODUCTION

The Dover district was providing iron ore as long ago as 1710, when both the Mount Hope and Dickerson mines were in operation. Possibly the district is even older, for the first smelting furnace for converting iron ore into bar iron was built at Tinton Falls, N. J., in 1682 (Roche and Stoddard, 1915, p. 171), and it seems certain that some iron ore was being mined in the Highlands at that time. The first forge built at Dover was the John Jackson forge, completed in 1722; shortly afterwards, in 1730, the Job Allen forge was completed at Rockaway. A number of other forges and furnaces were built in northern New Jersey during this period, and for an interesting account of these, the reader is referred to Boyer (1931).

The district has been the principal source of iron ore in New Jersey since the beginning of this industry, and it has contributed about 70 percent of New Jersey's iron-ore production. Through 1950 it had yielded in excess of 26 million tons of iron ore valued at more than $100 million. The production figures by years are given in table 1.

The district, as well as the State, attained its maximum production in the early 1880's, before the widespread utilization of the Lake Superior hematite ores. In 1882 New Jersey produced 932,762 gross tons of iron ore, the maximum for the State, and in that year it ranked second to Michigan in total production. Previously, New Jersey had for many years produced more iron ore than any other State. The magnetite-pro-

TABLE 1.—*Iron-ore production, in long tons, from Dover district, New Jersey*

[Production prior to 1900 from annual reports of the New Jersey Geological Survey, Bayley (1910), and estimates by Sims; production since 1900 from private companies; M. E. Johnson, New Jersey State Geologist; and Bayley (1910)]

Year	Production, in long tons, from indicated mines											
	Mount Hope [1]	Richard [2]	Scrub Oaks [3]	Beach Glen	Hibernia	Hurd	Huff	Dickerson	Orchard	Brotherton	Others	Total
Prior to 1900	1,103,594	[4] 1,784,426	[4] 58,500	43,000	[4] 3,915,433	[4] 500,000	[4] 90,000	1,000,000	325,042	54,800	3,443,982	11,312,899
1900	20,468	[4] 102,000										
1	34,895	121,763		[5] 7,000		20,317				200		
2	20,456	102,649				20,000						
3	58,793	[4] 100,000			[6] 1,084,567							
4	46,704	88,398										
5	21,297	98,589										[7] 3,199,281
6	33,087	100,632						[8] 16,000				
7	50,050	75,892										
8	55,930	84,683			[10] 48,059	80,596	[4, 9] 60,000		5,067			
9	98,197	92,604			46,690	73,518			18,705			
1910	59,979	112,810			57,763	52,737			26,186			
11	35,174	104,560			49,929	30,430						220,093
12	42,111	77,198			27,870	22,523						169,702
13	36,484	46,939										83,423
14	82,909	25,000										107,909
15	138,713	65,642										204,355
16	215,184	55,362										270,546
17	142,800	53,150										195,950
18	132,292	5,245	5,860									143,397
19	143,076		22,407									165,483
1920	147,212		55,539									202,751
21	16,741	266	2,522	10,200								29,729
22	41,616	9,667	22,437	4,938								78,658
23	126,295	61,462		17,000								204,757
24		64,928										64,928
25	134,562	68,444										203,006
26	141,004	68,217										209,221
27	133,625	86,995										220,620
28	151,651	81,655		16,848								250,154
29	147,274	63,993		29,606								240,873
1930	118,140	73,836	13,596	2,726								208,298
31	96,148	39,313	60,635									196,096
32	30,845											30,845
33												0
34			94,418									94,418
35			81,020									81,020
36		14,166	162,095									176,261
37	106,714	79,789	264,304									450,807
38	112,558	35,002	42,649									190,209
39	113,618	3,184	274,945									391,747
1940	133,137	87,822	328,147									549,106
41	133,472	122,311	336,405									592,188
42	139,521	188,744	292,973									621,238
43	111,542	151,020	272,543									535,105
44	131,242	106,060	231,552									468,854
45	128,213	124,237	192,773									445,223
46	140,289	127,940	161,878									430,107
47	127,225	149,363	188,486									465,074
48	118,077	153,201	184,028									455,306
49	109,167	135,166	206,444									450,777
1950	178,434	164,334	216,276									559,044
Total												26,175,336

[1] Production published with permission of Warren Foundry and Pipe Corp.
[2] Production published with permission of Colorado Fuel and Iron Corp.
[3] Production published with permission of Alan Wood Steel Co.
[4] Estimate based upon data given by Bayley (1910).
[5] Production for 1900–1902.
[6] Production for 1901–05.
[7] Production for 1900–10.
[8] Production for 1905–07.
[9] Production for 1905–10.
[10] Production 1908–12 from Wharton mine except in 1909 when 3,057 tons came from Wood and DeCamp mines.

ducing mines, for several reasons, however, could not compete with the larger mines in the Lake Superior districts, and since the late 1880's they have contributed a relatively small proportion of the country's iron ore. The New Jersey mines, though, have been consistent producers of high-grade lump ore that is in constant demand in steelmaking; and of other ores that are in demand for special purposes, such as powdered magnetite for rifling in modern weapons; and these mines still constitute a flourishing industry.

A comprehensive history of mining in New Jersey was compiled by Bayley (1910, p. 1–18), and additional historical information has been recorded by Roche and Stoddard (1915) and Roche (1937). The following, therefore, is principally a summary of the written history, together with additional data of interest for the period since Bayley's important publication. Because the Dover district has been by far the most important source of iron ore in the State, the history of iron ore mining for the entire state is discussed. Detailed historical information on individual mines in the district is given in this report in the section on mines and prospects.

Before the middle of the 19th century the iron ore was treated by local forges and furnaces which converted the ore into bar iron. All the ore, of course, was reduced by charcoal. These furnaces, which were small, handled the local ores. Few, if any, records were kept during this period, but it is known that the production was small. Probably only enough ore was mined, and subsequently smelted, to supply the local needs, which generally were slight. During the Revolutionary War mines from the Dover district, together with the mines from the Ringwood district and others, supplied the local forges with iron ore to make shot and cannon for the Continental Army. In 1821 the production of iron ore was small, for only 2,500 tons of iron were manufactured in New Jersey, and 10 years later the production still was only about 4,700 tons annually (Bayley, 1910, p. 8).

With the advent of the anthracite furnaces, iron production increased greatly, and concomitantly there was a marked increase in production of the ore. In 1855 the annual production of iron ore in the State had increased to 100,000 tons, according to an estimate by Kitchell (Bayley, 1910, p. 8); and by 1867 the production had reached 275,000 tons. A large proportion of this ore came from 57 mines in the Dover district (Cook, 1868, p. 540–542). There continued to be a general increase in output until the financial depression of 1873, when there was a marked reduction for several years. During this period of depression the operators were forced to adopt more effective and economical methods of mining in order to survive, and despite the relatively low price of ore and the beginning of competition from the hematite-producing mines in the Lake Superior district, they were able to steadily increase their output, and by 1882 they shipped a peak of more than 932,000 gross tons of iron ore. Following this peak year there was a general decrease not only in output but also in the number of producing mines. Undoubtedly the major cause of this decrease was the rapid advance made in the uses of steel, rather than iron for which the magnetite ores are particularly well suited. At this time also, many of the older and larger mines in the Dover district, which had contributed so much of the iron ore, were closed because they had reached a depth too great for profitable extraction; and many of the smaller mines were too far from railroad sidings to be able to ship ore at the lower market prices.

Again in 1886 there was an increase in production to 500,500 tons (Bayley, 1910, p. 13), principally because of a rise in the price of ore. All this yield came from 33 mines, a notable decrease in number over preceding years. Production remained at this general level until 1892, when it again diminished. By 1897 the total annual output from the State was only 237,000 tons, and most of this ore came from a few large, well-established mines. The decrease in the number of active mines was not caused by exhaustion of minable ore, but was the result of a more competitive market, whereby only the larger mines, and those favorably situated in relation to transportation, could operate profitably.

After a low in 1897 (Bayley, 1910, p. 17, fig. 1) there was a gradual increase in the State's production of iron ore for a few years. The depression of 1903, however, caused all the independent mines to close, and after that date only the larger mines which were run in direct connection with blast furnaces were open. In 1905, 500,000 tons of iron ore were produced in the State from 16 mines (Kümmel, 1905, p. 317), 10 of which were in the Dover district—Hurd, Richard, Huff, Baker, Mount Hope, Dickerson, and the Hibernia mines: Andover, De Camp, Upper Wood, and Wharton. The production from the Baker, Huff, and Hurd mines, however, was small and the figures are not known (table 1). During the years from 1905 to 1910 the Mount Hope, Richard, Hibernia, Hurd, Huff, Dickerson, and Orchard mines were substantial ore shippers. In 1910, however, the Orchard mine was closed because of excessive costs of pumping, and in 1912 the Hurd and Hibernia mines were closed. From 1913 to 1917 only two mines in the district were in operation, the Mount Hope and Richard, but in 1918 the Scrub Oaks mine was reopened. The total production of iron ore from the Dover district during the decade 1910–19 was 1,885,000 tons, substantially less than the 2,875,000 tons produced from 1900–1909. During the next decade (1920–29) the output from the Dover district was 1,700,000 tons. This ore came principally from the Mount Hope and Richard mines; the Scrub Oaks mine yielded a little ore during 1921 and 1922, but it was closed for the next 7 years; and the Beach Glen mine yielded only a small quantity during 1920, 1921, 1922, 1928 and 1929. During the period from 1921 to 1930 the total production of iron ore in New Jersey was 2,263,000 tons (Roche, 1937, p. 74).

All the mines in the Dover district were closed at one time or another during the depression of the early 1930's, and accordingly the production for the period 1930–39 was relatively small, totaling 1,750,000 tons. With the exception of 1930, when the Beach Glen mine yielded 2,726 tons of iron ore, all the ore during this period came from 3 mines—the Mount Hope, Richard, and Scrub Oaks. In 1940 there was a sharp increase in the ore shipped from the Dover district to 550,000 tons, and since that year the production has averaged about 500,000 tons annually. This ore has come from 3 mines—the Mount Hope, Richard, and Scrub Oaks. The production of iron ore from the Dover district for the 10-year period, 1940–49, was 5,572,000 tons (table 1), considerably greater than that of any previous decade.

In 1950 there was only one productive mine, the Washington mine, in New Jersey outside of the Dover district.

The production of individual mines that have yielded ore is given in table 13. The figures for the years before 1870 are based upon estimates recorded in various New Jersey State Geological Survey publications and estimates by the writer. The annual production figures since 1870 are known more accurately as the yield for each mine has been recorded, in most part in the State publications. Production figures for the mines now in operation were obtained from the mine operators.

As can be seen in table 13, five mines in the Dover district have each yielded more than 1 million tons of shipping ore. They are in order of their output: Mount Hope, Richard, Hibernia, Scrub Oaks, and Dickerson mines. Of these, the Hibernia and Dickerson mines now are abandoned.

EXTRACTION OF ORE

Mining practices throughout the Dover district have been similar, as the ore deposits are generally suited to a common method of extraction. Before 1912 the ore bodies were mined by open-pit and by underhand stoping methods, and this method of mining is described by Roche and Crockett (1933a, p. 162–163) and by Sweet (1932, p. 9). Commonly, inclined shafts were sunk on the footwall of a deposit, in ore, and at intervals of about 400 feet along the outcrop. Hand drilling and hand tramming were used, and the broken ore was hoisted in buckets by horse whims and small steam hoists. Considerable tonnages were mined from open-cuts by this method because of the relatively long outcrops and the generally low rake of the deposits. Where the topography was favorable, drift and crosscut adits were driven to develop the ore at lower depths, the drifts being advanced until the lower or upper edge of the deposit was encountered. Elsewhere it was necessary to sink winzes on the dip of the ore, and from these to drift to the lower and upper edges of the ore bodies. Underground mining by underhand stoping methods, though, was dangerous and expensive. It was necessary to leave substantial pillars and the percentage of ore extractions was low, being about 30 to 40 percent, according to Roche and Crockett (1933a, p. 163); nevertheless, large tonnages of ore were removed from many of the old mines by this method.

In 1912 shrinkage stoping without timbering or filling was started at Mount Hope mine, and soon afterwards this method of mining was adopted at the other mines in the district. Shrinkage stoping is generally well adapted to the ore bodies in the district because of their steep dip and generally strong walls. Slight variations in the method have been developed at each of the mines, though, because of differences in the ore bodies. A detailed description of the mining practice at Scrub Oaks mine is given by Roche and Crockett (1933a) and at Mount Hope mine by Sweet (1932). A brief description of the mining method at the Richard mine is given on page 101 of this report.

In 1949 sublevel stoping was initiated at the Mount Hope mine to mine the Richard ore body on the 1700 level. This method of extraction was adopted to reduce dilution and to provide additional information on the structure of the ore prior to stoping.

BENEFICIATION OF ORE

All the ore that was shipped from the district prior to 1893 was hand cobbed or hand picked, and that shipped between 1893 and 1916 was in part hand cobbed and in part concentrated on dry magnetic separators (Roche and Crockett, 1933b). The ore shipped from 1916 to 1927 was all beneficiated—that is, concentrated by means of magnetic separators. Since 1927 all the shipping ore has been magnetic concentrate, sized especially for sintering; or lump ore (Roche, 1937, p. 75).

The hand-cobbed ore, as shipped, probably averaged about 50 percent iron; the shipments of part hand-cobbed ore and part coarse dry magnetic concentrate probably averaged about 54 percent iron (Roche, 1937, p. 75). The present shipments of magnetic concentrate average more than 60 percent iron.

The first magnetic separation mill in the district was built at the Hibernia mine in 1893 (Roche and Crockett, 1933b, p. 241). In 1903 two additional magnetic concentrators were built at Wharton, New Jersey, at the Hurd and Orchard mines.

The milling practices at the three producing mines have been fully described—Scrub Oaks mine (Roche and Crockett, 1933b, 1933c), Richard mine (Roche, 1923), and Mount Hope mine (Davenport, 1945)—and will not be repeated here. The ore from each of the mines is concentrated by means of magnetic separation. At Mount Hope and Richard mines two shipping products are prepared: lump ore and fine concentrate. The lump ore averages about 60 percent iron and is concentrated by dry magnetic means, whereas the fine concentrate is produced by wet magnetic concentration. At Scrub Oaks mine only fine concentrate is produced. Because it contains several percent of nonmagnetic iron, the ore requires a dual treatment. It is first passed over wet magnetic separators and then passed through gravity separation machines to recover the nonmagnetic portion (Roche and Crockett, 1933c, p. 274).

GEOLOGY

As shown on plate 1, the bedrock of the Dover district consists predominantly of pre-Cambrian rocks. These rocks are intruded at places by small diabase dikes of Triassic(?) age; and are bordered on the northwest by steeply dipping sedimentary rocks of early to middle Paleozoic age. Surficial deposits of the Quaternary form a discontinuous, generally thin, cover over the bedrock.

As the pre-Cambrian rocks predominate and contain the magnetite deposits, and because little is known of the petrology and structure of these rocks, they are described in some detail on the following pages, whereas the younger rocks are described only briefly.

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks consist of a wide variety of metasedimentary rocks, migmatites, and intrusive igneous rocks. The oldest rocks—metamorphosed sediments—were derived from calcareous and alumino-siliceous materials; their thickness and age sequence are imperfectly known. The metamorphosed calcareous rocks include marble, pyroxene gneiss, pyroxene and hornblende skarn, and amphibolite and related rocks; and the metamorphosed alumino-siliceous rocks include oligoclase-quartz-biotite gneiss and biotite-quartz-feldspar gneiss. The metasedimentary rocks were intruded successively by quartz diorite and related facies, albite-oligoclase granite and albite-quartz pegmatite, and hornblende granite and related facies; and at places they were injected in a lit-par-lit manner by granite and pegmatite or were thoroughly soaked by granitic fluids to form permeation gneisses.

The pre-Cambrian rocks, because of their metamorphic character and structure, are believed to be early Proterozoic (Wilmarth, 1938, p. 1737), but a more exact age cannot be given as absolute age determinations are not available.

TERMINOLOGY USED IN PREVIOUS REPORTS

The terminology found in earlier publications describing the rocks of the Highlands differs considerably from that used in this report, and accordingly a review of the previously used rock names is given in this section. Also reasons are given for the adoption of a different terminology.

The pre-Cambrian rocks of the New Jersey Highlands previously have been divided into three formations—the Byram gneiss, the Losee gneiss, and the Pochuck gneiss—by Spencer (Spencer and others, 1908) and Bayley (Darton and others, 1908; Bayley and others, 1914). Where large bodies of white crystalline limestone occur, as in the Franklin Furnace quadrangle (Spencer and others, 1908) and in the Delaware Water Gap and Easton quadrangles (Bayley, 1941), the limestone has been mapped as a separate formation, the Franklin limestone.

The Byram gneiss, as used by Spencer and Bayley, includes several varieties of granitoid gneiss that are characterized by the presence of abundant potash feldspar, either microcline or microperthite, or both, and quartz as the essential constituents. Two principal facies were recognized: a dark facies that typically contains hornblende as the principal varietal mineral and a light facies that characteristically contains some biotite. The Losee gneiss includes a group of granitoid rocks that are distinguished lithologically from varieties of Byram gneiss in containing plagioclase, generally oligoclase, instead of microperthite or microcline. It differs from Pochuck gneiss in containing considerable quartz and only minor amounts of dark minerals. The Pochuck gneiss of Spencer includes all gneisses in the Highlands that contain hornblende, pyroxene, or mica as principal mineral constituents, and has been subdivided by the U. S. Geological Survey (Wilmarth, 1938, p. 1686) into the Pochuck gabbro gneiss and the Pickering gneiss. The name Pochuck gabbro gneiss is now restricted to the black gneiss of intrusive igneous origin, whereas the older dark gneisses of sedimentary origin that formerly were included under the name Pochuck gneiss are now included in Pickering gneiss.

The gneisses mapped by Spencer and Bayley grade into each other through intermediate rocks, and accordingly the formations in the Raritan, Passaic, and Franklin Furnace quadrangles were mapped on the basis of the dominant type. Consequently the areal delineation of individual types was arbitrary; the gneisses of intermediate character were included with the type to which they were believed to be most closely allied.

In the Franklin Furnace, Raritan, and Passaic quadrangles the Pochuck gneiss is older than both the Byram and Losee gneisses, and was intruded by them. The age relations of the Byram and Losee gneisses in these areas, however, were not determined (Spencer and others, 1908; Darton and others, 1908; Bayley, and others, 1914).

Each of the formations, as defined and mapped by Spencer and Bayley, includes rocks of widely different petrographic character and origin, and the use of these formational names results in much confusion and uncertainty. To clarify the interpretation of the petrology and structure of the Dover district the writer mapped the recognizable rock units using mineralogic adjectives instead of previously accepted formation names to describe the various rock types. In general, the Byram gneiss of Spencer includes the hornblende granite and related facies of this report; the Losee gneiss includes the albite-oligoclase granite and albite-quartz pegmatite, oligoclase-quartz-biotite gneiss, biotite-quartz-feldspar gneiss, and quartz diorite and related facies of the present writer; and the Pochuck gneiss includes the amphibolite and related rocks, pyroxene gneiss, and skarns.

METASEDIMENTARY ROCKS

The metasedimentary rocks are widely distributed and constitute approximately 25 percent of the bedrock. They have been isoclinally folded, intruded by igneous sheets and phacoliths, and faulted; consequently, they crop out both as distinct layers and lenses of different widths and lengths and as generally concordant inclusions within the intrusive rocks. The metasediments are high-grade metamorphic rocks that have been thoroughly recrystallized and reconstituted, probably during both regional and contact metamorphism, and most primary textures and structures have been obliterated. The mineral assemblages developed by the metamorphism show analogies to the amphibolite, granulite, and pyroxene hornfels metamorphic facies, but conform exactly to none of these (Eskola, 1939, p. 344; Turner, 1948, p. 61–107).

Because of the complex structure, the fragmentary record of the metasediments, and the preponderance of igneous rocks, it is not possible to establish a reliable age sequence for the metasedimentary rocks of the district.

An age sequence for the metasedimentary rocks can be established, however, for individual large-scale folds. (See pl. 1.) In the axial region of the Splitrock Pond syncline the following age sequence, from oldest to youngest, is indicated by the distribution of the metasedimentary rocks: Amphibolite; amphibolite; biotite-quartz-feldspar gneiss and skarn; amphibolite; biotite-quartz-feldspar gneiss; and pyroxene skarn, pyroxene gneiss, and amphibolite. The occurrence in the sequence of more than one layer of a certain rock type probably is not due to duplication by folding or faulting, but instead is the result of a repetition of beds of similar lithologic character in the original unmetamorphosed sequence. Thus, the sequence of sedimentary rocks in this region contained four separate beds of impure calcareous sediments that yielded amphibolite, two distinct beds of alumino-siliceous sediments that yielded biotite-quartz-feldspar gneiss, and two separate beds of carbonate sediments that yielded skarn. Similarly, a local age sequence can be established for the metasedimentary rocks on the limbs of the Hibernia anticline, another large fold, but these sequences differ somewhat from that in the Splitrock Pond syncline. Here too there appears to be a repetition of certain metasedimentary units—amphibolite, biotite-quartz-feldspar gneiss, and oligoclase-quartz-biotite-gneiss—but the repetition cannot be definitely attributed to original beds of similar lithologic character; instead, it may in part result from folding that has not been recognized.

Although a reliable age sequence for the metasedimentary rocks cannot be established, certain facts are known concerning the original sediments. It is evident that the original sediments were composed of variable, but generally thin, interlayers of alumino-siliceous and calcareous beds. As described above, there was repetition of certain lithologic units in this sequence, and some units may have been repeated several times—as, for example, impure calcareous sediments that were metamorphosed to amphibolite. Others may not have been repeated in the section—as, for example, the quartz-bearing sediments that yielded oligoclase-quartz-biotite gneiss—but there is no certainty of this.

Because of the many uncertainties in their age sequence, the metasedimentary rocks are discussed on the following pages under two headings: metamorphosed calcareous rocks and metamorphosed alumino-siliceous rocks. Insofar as possible the writer has attempted to place the rocks within these groups in the probable sequence of formation, but it should be kept in mind that the order of development of the metamorphic rocks does not always follow the sedimentary age sequence.

METAMORPHOSED CALCAREOUS ROCKS

The rocks of a calcareous origin include marble, pyroxene gneiss, skarn, amphibolite and related rocks, and serpentine; the most abundant and widespread is amphibolite. These rocks probably have been derived from sediments containing variable proportions of lime, magnesia, alumina, iron, and silica. The proportion of these oxides in the original sediments has been changed greatly by leaching and by additions of these and other oxides from magmatic and ultra metamorphic sources.

NOMENCLATURE

The nomenclature for the metamorphosed calcareous rock units mapped in the Dover district in general conforms to that used by Buddington in the Adirondacks, but inasmuch as the final report on the geology of the St. Lawrence magnetite district, by Buddington and Leonard, is not completely prepared, a brief discussion of the map units of the Dover region is given here.

The rocks mapped as pyroxene gneiss consist predominantly of oligoclase or albite and diopside or augitic diopside. Sphene and quartz are at places abundant accessory minerals, and scapolite locally constitutes all or part of the felsic minerals. At most places the gneiss has a conspicuous compositional layering produced by alternating layers of felsic and mafic minerals.

The amphibolites are dark, generally uniform gneisses, locally layered, that consist of about equal proportions of plagioclase feldspar, commonly andesine, and mafic minerals—hornblende, augite, and hypersthene. Quartz is sparse to absent. All the amphibolites in the Dover district contain some pyroxene—clinopyroxene or orthopyroxene—and accordingly they are distinguished as amphibolite and pyroxene amphibolite; the pyroxene amphibolite designates those rocks in which the total pyroxene is in excess of hornblende. The pyroxene amphibolites are distinguished from pyroxene gneisses by differences in mineral composition and structure. The mafic mineral in pyroxene gneiss is diopside or augitic diopside, a medium-green pyroxene, and the feldspar is more sodic than in amphibolite; hypersthene is absent. Structurally, pyroxene gneiss commonly is characterized by a conspicuous compositional layering, a feature generally absent in the amphibolites.

Skarn is an old Swedish mining term for aggregates of calcium, magnesium, and iron silicates that characteristically are associated with certain deposits of iron ore and sulfides. Originally it was applied by Fennoscandian geologists to the pre-Cambrian rocks, but subsequently it has been extended to cover analogous products of contact metamorphism in younger rocks (Holmes, 1920, p. 211). The term generally is restricted to the dark-colored mineral aggregates, but some writers apply it also to pale or colorless masses of diopside, tremolite, and anthophyllite.

Skarn generally occurs at or near the contacts between carbonate rocks and igneous rocks, commonly granite, and this association has led most geologists to interpret the skarn as a product of metasomatism of the carbonate rocks. The skarn assemblage is characteristic of the pyrometasomatic deposits (Lindgren, 1922, p. 293; Knopf, 1933, p. 537–540). Tactite, a term used by some geologists synonymously with skarn, was originally applied by Hess (1919, p. 377) to rocks of the inner zone of the contact-metamorphic aureole, and it should be considered, therefore, as one variety of skarn.

The skarn minerals consist predominantly of the pyroxene, garnet, and amphibole groups; but they also include the mica, olivine, epidote, humite, and scapolite groups. Fluorite is a characteristic accessory mineral in many places, and nearly always carbonate occurs within or in close association with skarn. The metallic minerals that characteristically occur in the skarn assemblage include the iron oxides—magnetite and in places hematite—and the common sulfides—chalcopyrite, pyrite, pyrrhotite, sphalerite, and in places galena.

Skarns believed to have resulted from processes other than metasomatism have been described by some Fennoscandian geologists. These skarns, generally known as "reaction skarns," belong to several types (Eskola, 1914, p. 233; Magnusson, 1928; Korjinsky, 1945, p. 32–33). In a common type, consisting of interlayered skarn and siliceous rocks, the skarn, generally composed of diopside, is interpreted to be the result of reaction between the calcareous and siliceous rocks without the addition of material of magmatic source (Eskola, 1914, p. 233). Other writers have departed widely from the accepted usage. For example, Holmes and Reynolds (1947) have used the term "skarn" to include metasomatic rocks rich in magnesia, iron, and alumina and comparatively poor in calcium that show no genetic relation to carbonate rocks.

Buddington and Leonard (oral communication) have suggested that the unqualified term "skarn" be restricted to the silicate aggregates that have a demonstrable or inferred genetic relation with limestone or dolomite, and this usage of the term is followed by the writer.

Following the terminology established in the Adirondack Mountains by Buddington and Leonard (oral communication) the unqualified term "skarn" is restricted to those massive rocks consisting of at least 90 percent Ca-Fe-Mg silicate minerals. Where such minerals form less than that amount, but more than 50–60 percent of the rock, a qualifying term is used, such as "feldspathic pyroxene skarn" or "scapolitic pyroxene skarn."

Pyroxene gneiss is distinguished from feldspathic pyroxene skarn and pyroxene skarn principally on the basis of the proportions of mafic minerals, but also it tends to be layered in contrast to most of the skarns, which tend to be homogeneous. Pyroxene gneiss contains less than 50 percent dark minerals, whereas feldspathic skarn contains more than 50 percent dark minerals and skarn contains more than 90 percent dark minerals.

Associated with the iron deposits in both skarn and gneiss host rocks are partings, thin films, and selvages of mica, which are similar to one type of sköl, or shell, that has been described from some Fennoscandian deposits, (Eskola, 1914, p. 226, 259). The sköls in the Dover district consist predominantly of either a dark mica, probably biotite, or a pale-green mica. (See p. 61.)

MARBLE

DISTRIBUTION

Marble of several different types is exposed along the west side of Timber Brook valley, $1\frac{1}{4}$ miles north of Splitrock Pond, and is found on the dump at Splitrock Pond mine, but it was not observed elsewhere in the district. Its presence at other places is suggested by a linear belt of depressions and by rubble of characteristic lime silicates. Because of its restricted occurrence, marble is mapped with skarn and related rocks on plate 1.

The marble in Timber Brook valley is in contact with quartz diorite on the west and with diopside skarn on the east. A thin sheet of albite-oligoclase granite crops out adjacent to the pyroxene skarn. The following section was measured across the marble and pyroxene skarn, from east to west:

	Width (feet)
Diopside skarn	25
Schistose chondrodite marble, in part serpentinized	5
Chondrodite marble	25
Marble, essentially free from silicate minerals	20

MEGASCOPIC CHARACTER

The marble exposed in Timber Brook valley ranges from a medium- to a coarse-grained calcitic marble, essentially free from silicate minerals, to a partly silicated calcitic marble that contains variable quantities of chondrodite and serpentine. There is a gradual transition from marble containing chondrodite to marble essentially free from chondrodite, and the contact between these rocks, therefore, is gradational.

The marble that is essentially free from silicate minerals is a white to gray, medium- to coarse-grained crystalline rock. Weathered surfaces are rough and commonly cellular. A conspicuous ribbing believed to reflect the original bedding is visible in some exposures where weathering has accentuated small differences in composition or texture. The ribbing is conformable to the foliation in the surrounding gneisses.

The partly silicated marble differs from the silicate-free marble mainly in containing scattered isolated grains of yellowish brown chondrodite—a member of the humite group—and sparse serpentine. The chondrodite constitutes as much as 25 percent of the rock near the contact with diopside skarn and it gradually decreases in amount away from the contact. Adjacent to the pyroxene skarn the marble has a conspicuous schistose structure and a distinct green color due to abundant serpentine.

PETROGRAPHY AND CHEMICAL COMPOSITION

The marble is, for the most part, an equigranular rock composed of calcite and sparse to abundant chondrodite. The chondrodite occurs as colorless, faintly pleochroic, subhedral grains as much as a millimeter in diameter that are irregularly dispersed through the calcite. Most grains show some alteration to antigorite along the grain borders and cracks. Fine dustlike particles of magnetite locally are associated with the antigorite. In marble with a conspicuous schistose structure the calcite is granulated and the chondrodite is nearly completely altered to antigorite.

The marble in the Dover district has not been analyzed. Throughout the New Jersey Highlands, however, the marble of the Franklin limestone of Spencer, believed to correlate with that in the mapped area, has been analyzed, and the analyses indicate a composition ranging from nearly pure calcium carbonate to that of a typical dolomite.

According to Bayley (1941, p. 10) the Franklin limestone, where not greatly metamorphosed, is for the most part a nearly pure calcite. Kümmel (1906, p. 175–190) showed that the proportion of magnesium carbonate in the marble varies from bed to bed; usually it is less than 5 percent and very few specimens contain more than 10 percent. Some beds, however, contain as much as 40 percent of magnesium carbonate. The marble in the Edison quarry, near Oxford, N. J., showed the following range in composition (Bayley, 1941, p. 11): 1–8 percent SiO_2; 0.5–3 percent Fe_2O_3 and Al_2O_3; 2–20 percent $MgCO_3$; 85–90 percent $CaCO_3$.

PYROXENE GNEISS

DISTRIBUTION AND CHARACTER

Pyroxene gneiss of varying composition forms layers and lenses that are intercalated with other metasedimentary rocks. The gneiss is common in the region west of Kitchell (pl. 1), where it is intercalated with plagioclase-quartz gneiss, pyroxene skarn, and feldspathic skarn; and near the mouth of the stream valley on the west side of Splitrock Pond, in the axial area of the Splitrock Pond syncline, it is interlayered with, and grades into, pyroxene skarn and feldspathic pyroxene skarn. At this locality these rocks are injected by albite-quartz pegmatite that has partially shredded and digested them. A pyroxene gneiss layer that has a conspicuous compositional layering, and which contains scattered cavities a fraction of an inch wide formed by the leaching of calcite, crops out on the north side of U. S. Highway 46, opposite the race track in Dover. The contact with amphibolite is sharp. Typically, the pyroxene gneiss is green to grayish green and ranges from a uniform to a prominently layered rock.

PETROGRAPHY

Plagioclase of a composition An_5 to An_{15} characteristically constitutes somewhat more than 50 percent of pyroxene gneiss (table 2). In places scapolite, of a composition ranging from $Ma_{35}Me_{65}$ to $Ma_{56}Me_{44}$ takes the place of plagioclase. Diopside or augitic diopside, the principal mafic mineral, constitutes 35 to 40 percent of the rock. It is pale to medium green and is slightly pleochroic. In a specimen from the pyroxene gneiss layer at Richard mine the nY of diopside is $1.685 \pm .001$, as determined by oil immersion. According to data given by Hess (1949, table VI, p. 641) this diopside contains slightly more than 9 percent Fe atoms in total Ca+Mg+Fe atoms. Green hornblende, apparently an alteration product of diopside, is a local varietal mineral. Biotite occurs in some places as an alteration

TABLE 2.—*Approximate modes (volume percent) of pyroxene gneiss*

	N11-10	S98	S915-1
Plagioclase	57	------	53.5
Scapolite ($Ma_{35}Me_{65}$)	------	52	------
Diopside	36	41	36
Sphene	2.0	6.5	------
Hornblende	------	------	2.0
Biotite	------	------	1.0
Magnetite	.5	------	.5
Apatite	1.0	.5	------
Quartz	.5	------	4.0
Orthoclase	2.0	------	------
Microcline	------	------	3.0
Epidote	1.0	------	------
Total	100.0	100.0	100.0
Average grain diameter,[1] in millimeters	------	------	0.32

[1] Average grain intercept measured by mechanical stage; not true grain diameter. Actual diameter is somewhat larger.

N11-10. Pyroxene-feldspar gneiss, taken from the hanging wall of the Mount Pleasant ore body, northeast end 1100-ft level, Richard mine. Plagioclase is An_{14}.
S98. Pyroxene-scapolite gneiss from valley on west side of Splitrock Pond, Boonton quadrangle.
S915-1. Pyroxene-feldspar gneiss exposed on west side of road 1/10 mile northwest of Kitchell, Newfoundland quadrangle. Quartz occurs as tiny rounded grains in plagioclase and pyroxene. Biotite is secondary. Plagioclase is An_{10}.

product of hornblende or diopside. Quartz, as tiny rounded "inclusions" in both plagioclase and diopside, and sphene are common accessory minerals. Locally sphene is abundant and constitutes a varietal mineral. The minor accessory minerals, opaque iron oxides, apatite, orthoclase, microcline, and epidote, are sparsely disseminated through the rock. The texture is wholly crystalloblastic, the diopside and plagioclase occurring as polygonal grains that form a mosaic pattern.

AMPHIBOLITE AND RELATED ROCKS

The amphibolite and related rocks include amphibolite and pyroxene amphibolite and their alteration products. In the section that follows, amphibolite and pyroxene amphibolite are discussed together, as they are closely similar rocks that cannot be distinguished megascopically. A group of interlayered mafic gneisses and schists of uncertain derivation encountered in core drilling at the Hibernia Pond anomaly also is included.

AMPHIBOLITE AND PYROXENE AMPHIBOLITE

Distribution and occurrence

Amphibolite and pyroxene amphibolite are widely distributed throughout the Dover district; they occur as inclusions in igneous rocks and as discrete layers associated with metasedimentary gneisses. Inclusions are present in all types of granitic rocks; they are common in the albite-oligoclase granite and the microantiperthite granite, and locally are abundant. At places the amphibolite forms ghostlike schlieren in these rocks. The amphibolitic inclusions in hornblende granite and alaskite generally have sharp contacts. Streaks, layers, and schlieren of pyroxene amphibolite locally are abundant in some of the quartz diorite masses. Discrete bodies of amphibolite commonly are closely associated with biotite-quartz-feldspar gneiss, oligoclase-quartz-biotite gneiss, pyroxene gneiss, and pyroxene and hornblende skarn.

Mappable units of amphibolitic rocks are not common, but a few are shown on plate 1. The largest mass, predominantly pyroxene amphibolite, crops out on the hills on either side of Cedar Lake, north of Denville (pl. 1). Another large body, a long narrow tabular mass, extends from the crest of the hill 3/4 mile west of Meriden northward a distance of 3 miles, and it pinches out on the northwest limb of the Cobb anticline. It is truncated at its southern end by granite pegmatite.

Petrography

Amphibolite and pyroxene amphibolite are distinguished by their predominant mafic mineral. Amphibolite includes those rocks that contain hornblende in excess of total pyroxene, and pyroxene amphibolite indicates those in which pyroxene predominates over hornblende.

The amphibolites are brownish-gray to dark-gray, medium-grained, equigranular to inequigranular rocks that have a wholly crystalloblastic texture. They have been so thoroughly reconstituted that the primary fabric has been completely destroyed. The rocks commonly have a fair to good foliation produced by subparallel tabular feldspars and hornblende or by alternating layers of the felsic (plagioclase) and mafic (hornblende and pyroxene) constituents, but at places they are essentially massive. The layered amphibolite, a banded gneiss, is not common; hence the writer has not attempted to separate it as a mappable unit.

Amphibolite and pyroxene amphibolite are composed principally of plagioclase (An_{30}–An_{45}), with variable proportions of hornblende, clinopyroxene, and orthopyroxene. Biotite, apatite, and iron ore are common accessory minerals. Approximate modes determined by Rosiwal analyses of thin sections are given in table 3.

The percentages of the essential minerals vary between moderate limits. Plagioclase constitutes between 40 and 65 percent of the rock, and averages near 50 percent. It is commonly clear and well-twinned according to the laws of albite and pericline twinning. Carlsbad twinning is rare but it can be seen in some thin sections.

Hornblende is present in all amphibolites, ranging from about 1 to 35 percent, but it never constitutes the only mafic mineral. It is a medium-green variety with a brownish hue. It commonly forms discrete polygonal grains that are intergrown with the plagioclase and pyroxene, but in some rocks it forms partial rims on, or poikilitically includes, the pyroxene.

Pyroxene, either clinopyroxene or orthopyroxene, or both, is present in all the amphibolites, but the proportion of each mineral varies within wide limits (table 3). In most amphibolites examined under the microscope the pyroxenes constitute between 20 and 30 percent of the rock, but they may account for a much smaller proportion. Both varieties of pyroxene occur as discrete polygonal grains; where they are intergrown they seem to have developed simultaneously. The orthopyroxene—hypersthene—is distinctly pleochroic, ranging from pink to pale green; the clinopyroxene is light green and never sensibly pleochroic.

The common accessory minerals—opaque iron oxides, biotite, and apatite—together generally constitute about 5 percent of the rock. The iron ore is the most abundant and at places is a varietal mineral. The biotite is a pale-reddish-brown variety that generally is closely associated with hornblende. Its relation to the hornblende suggests that it always is an alteration product of hornblende. Locally orthoclase, chlorite, epidote, calcite, sericite, and an unknown red amorphous mineral occur in minor quantities.

A local variety of amphibolite that contains 10 percent of orthoclase and a percent of epidote (N13–17 table 3) is exposed at several places in the Richard mine, near the bottomrock of the Major shoot of the Mount Pleasant (North) ore body. This rock differs megascopically from the other amphibolites in containing sparse to abundant elliptical green "spots" or "knots" that are composed of aggregates of andesine. The orthoclase contains from less than 5 to about 25 percent of albite in perthitic intergrowth, and it is intergrown with the andesine, apparently being contemporaneous with it. The epidote occurs in thin veinlets and as spotty replacements of plagioclase feldspar.

Sphene, in association with biotite, locally is abundant in some amphibolites. Amphibolite containing visible quantities of sphene occurs here and there as lenses in biotite-quartz-feldspar gneiss, always in close association with granite pegmatite, and locally along the footwall of the New (or Baker) shoot of the Mount Pleasant ore body in the Richard mine. A few percent of biotite, which appears to embay, vein, and replace hornblende, always occurs in association with the sphene. The biotite in some specimens contains myrmekitic intergrowths with quartz. At the Richard mine the sphene characteristically forms rims around isolated grains of magnetite; elsewhere it commonly is closely associated with biotite. (See pl. 17*c*.)

TABLE 3.—*Approximate modes (volume percent) of amphibolite and pyroxene amphibolite*

	DF98-1	DA13-1	DM4	DG47	N13-17	DA91-2	DA96	DG1-1
Plagioclase	45	47	60	39	48	61	64	51
Hornblende	31	33	28	29	25	1.5	8	9
Clinopyroxene	20	2	2		10	18	11	28
Orthopyroxene		16		32		17	12	
Biotite		2		Tr.	Tr.			.5
Opaque iron oxides	3		4		5	2	4	10
Apatite			1		1	.5	1	.5
Orthoclase	.5				10			
Chlorite			1					.5
Epidote			2		1			.5
Red amorphous mineral	.5							
Calcite			1					
Sericite			1					
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average grain diameter,[1] in millimeters	0.51	0.43	0.5	0.40	0.33	0.40	0.38	0.40

[1] Average grain intercept measured by mechanical stage; not true grain diameter. Actual diameter is somewhat larger.

DF98-1. Amphibolite from west slope of low hill a mile south of Marcella, Boonton quadrangle. The rock has a conspicuous compositional layering. The plagioclase is An_{26}.

DA13-1. Amphibolite interlayered with garnetiferous feldspar-quartz-biotite gneiss, from hill half a mile northwest of Beach Glen, Boonton quadrangle. Plagioclase has the composition An_{37}.

DM4. Amphibolite from barren layer within Teabo ore body, stope 7, 1700-level, Mount Hope mine, Dover quadrangle. Plagioclase (An_{30}) is sericitized. Epidote replaces both hornblende and plagioclase.

DG47. Pyroxene amphibolite, half a mile north-northeast of shaft 12, Hibernia mine, Boonton quadrangle. Plagioclase has the composition An_{37}.

N13-17. Amphibolite from 1300-ft. level, Richard mine. Black, medium-grained rock with prominent "spots" composed of green oligoclase. Occurs at bottom of Kearney ore shoot, Mount Pleasant ore body. The plagioclase is in part microantiperthite; the orthoclase contains some plagioclase in perthitic intergrowth.

DA91-2. Pyroxene amphibolite from southeast slope of hill north of upper end of White Meadow Lake, Dover quadrangle. Plagioclase is An_{37}.

DA96. Pyroxene amphibolite from east side small valley a quarter of a mile northwest of White Meadow Lake, Dover quadrangle. The plagioclase is An_{48}.

DG1-1. Pyroxene amphibolite, 300 feet west of house on southeast slope of hill 1 mile south of Marcella, Boonton quadrangle.

INTERLAYERED GNEISSES CONTAINING BIOTITE, HORNBLENDE, PYROXENE, AND FELDSPAR

Occurrence

The host rock for the ore at the Hibernia Pond prospect is a heterogeneous well-foliated to schistose, layered rock sequence that contains variable proportions of biotite, hornblende, pyroxene, and feldspar. The proportions of the various constituent minerals vary considerably across the foliation and accordingly several facies, gradational into one another, can be recognized. The principal facies are pyroxene-quartz-plagioclase gneiss, hornblende-quartz-plagioclase gneiss, biotitic hornblende-plagioclase gneiss, and pyroxenic mica-plagioclase gneiss. The magnetite for the most part is in pyroxenic mica-plagioclase gneiss with accessory quartz. Although the gneisses are poorly exposed, they have been cored by several diamond-drill holes, which indicate that they form a layer as much as 100 feet thick. The cores show that the rock sequence lies between walls of albite-oligoclase granite or, locally, amphibolite migmatite.

Petrography

The gneiss sequence is composed of gray, green, or brown, medium-grained, well-foliated to schistose, inequigranular, heterogeneous rocks of variable mineralogic character. It consists of alternating layers of variable thickness that contain different proportions of the essential minerals. At places albite-oligoclase granite and syenitic facies of the granite occur as layers within the gneiss. The tabular minerals—biotite, hornblende, and plagioclase—are oriented essentially parallel to the compositional layering of the rock. In thin sections it can be seen that the ore-bearing rock within the sequence has been cataclastically deformed;

biotite laths are curved, warped, and locally broken; plagioclase is fractured and strained and the twinning is for the most part destroyed; and quartz, where present, is strained and strongly sutured.

The essential minerals, biotite, hornblende, pyroxene, and feldspar, together constitute more than 90 percent of the rocks, except where magnetite is abundant, but they vary greatly in their abundance. Feldspar is the most abundant constituent, and it averages near 50 percent. The feldspar is for the most part microantiperthite but in places it is normal oligoclase. The hornblende is a pale-green variety with the following pleochroism: X=yellowish green, Y=olive green; Z=pale green. The pyroxene is in part clinopyroxene that shows a faint pleochroism from yellowish green to pale green, and in part orthopyroxene, which also is pleochroic. The biotite is colorless to pale brown. The accessory minerals, magnetite, apatite, and quartz, constitute about 5 percent of the rock, except where magnetite is abundant. At places chlorite forms veinlets along fractures in the feldspar.

AMPHIBOLITE MIGMATITE

Amphibolite characterized by alternating dark and light layers, highly irregular in width and length, is abundant locally in the Dover district. It occurs in irregular patches in some layers, particularly near the contacts with granitic and pegmatitic rocks, and it constitutes almost the whole of other layers. Because of its sporadic occurrence and its gradation into typical dark homogeneous amphibolite, this rock, interpreted to be amphibolite migmatite, is mapped with amphibolite and related rocks on plate 1. Amphibolite migmatite differs from layered amphibolite, described previously, in being more irregular, and in containing felsic layers that have the composition and texture of granite, generally alaskite, or granite pegmatite. The felsic layers in layered amphibolite are composed of plagioclase of the same composition (andesine) as the plagioclase in the homogeneous amphibolite and generally lack quartz.

Amphibolite migmatite is a variable rock. At places it is a rather regularly layered rock consisting of alternating dark (mafic) and light (felsic) layers, but in most places it is quite heterogeneous and consists of highly irregular layers, lenses, and knots of felsic material in the mafic host. The layers generally are sharply defined and clearly discernible. The mafic layers for the most part have the same mineral compositions as the typical amphibolite. In close-spaced layered migmatites, however, the mafic layers in places contain sparse to abundant biotite and some quartz and microperthite. The felsic layers for the most part have the same mineral assemblage as does alaskite; that is, they consist predominantly of microperthite, plagioclase, and quartz. The microperthite and quartz appear to embay and replace the plagioclase and the hornblende of the host.

SKARN

Skarn of different compositions is abundant in parts of the Dover district, and certain types are related to magnetite ore bodies.

The skarns in the Dover district can be classified into the following general types: (1) pyroxene skarn, (2) hornblende skarn, and (3) hornblende-phlogopite-spinel skarn. The pyroxene skarn is essentially monomineralllic, but in places it contains small quantities of hornblende. The pyroxene in the different masses ranges in composition from diopside to ferrosalite, and it is the more iron-rich varieties that contain magnetite ore bodies. The hornblende skarn is more variable; commonly it contains a few to several percent pyroxene in addition to hornblende, and thin layers, lenses, and selvages of biotite sköls. All the hornblende skarn bodies that are known in the district contain magnetite ore bodies. The hornblende-phlogopite-spinel skarn is local in occurrence and barren. The skarns are mapped on plate 1 with skarn and related rocks.

PYROXENE SKARN

Distribution and occurrence

Pyroxene skarn, the predominant skarn of the district, occurs in a number of places in association with marble, pyroxene gneiss, amphibolite, biotite-quartz-feldspar gneiss, and plagioclase-quartz gneiss. Some pyroxene skarn bodies in the Green Pond and Splitrock Pond-Charlottesburg ore belts contain magnetite ore bodies. In Timber Brook valley diopside skarn occurs at the contact between marble and albite-oligoclase granite, and in the stream valley on the west side of Splitrock Pond it is intercalated with pyroxene gneiss and amphibolite. Several bodies of pyroxene skarn were mapped in the region northwest of Kitchell. The most important of these constitute the host for the deposits in the Green Pond ore belt. Others are found in close association with a biotite-quartz-feldspar gneiss layer in the region west of Kitchell and are well exposed along the Wharton & Northern Railroad tracks, 0.4 mile northeast of Green Lake station, Newfoundland quadrangle. Within the rocks mapped as undifferentiated metasedimentary rocks, pyroxene skarn locally forms lenticles or pods in plagioclase-quartz gneiss. The distribution of the skarn lenticles within the gneiss is erratic, but they seem to be more abundant in some gneiss layers than others. At Splitrock Pond mine (pl. 1), fragments of pyroxene skarn that contain magnetite are found on the dump in association with marble, serpentinized marble, serpentine, and mica sköls.

Pyroxene skarn occurs here and there as widely spaced bodies along the margins of and within the layer of biotite-quartz-feldspar gneiss that is on the southeast limb of the Hibernia anticline (pl. 1). In places the skarn contains inch-thin layers of scapolite.

Petrography

Pyroxene skarn is a light- to dark-green, medium- to coarse-grained, generally equigranular, homogeneous massive rock, whose texture typically is crystalloblastic. In places where scapolite is present the skarn has a fair compositional layering produced by alternating dark and light layers.

The color change in the skarn probably reflects a progressive change in the composition of the pyroxene from diopside through salite to ferrosalite. The nature of the change is imperfectly known, however, and additional petrographical and chemical work is needed. Index determinations by oil immersion indicate that the light-colored skarns contain pyroxene whose composition is diopside and that the dark-colored skarns contain pyroxene whose composition is salite or ferrosalite. It is significant that the light-colored skarns are barren and that the iron-ore bodies are confined to the dark-colored skarns. Accordingly, in the sections that follow, the barren skarn and the ore-bearing skarn are discussed separately.

The pyroxene skarn that does not contain magnetite ore—barren pyroxene skarn—is characteristically light green and is composed of 95 percent or more of diopside or salite and 5 percent or less of quartz, calcite, and scapolite. Magnetite is not present. The pyroxene is pale green, faintly pleochroic, and occurs as stubby subhedral crystals that generally lack any preferred optical orientation. Generally it contains about 9 percent Fe atoms in total Ca+Mg+Fe atoms, and is diopside, according to the data of Hess (1949, table VI, p. 641). A specimen taken from the stream valley on the west side of Splitrock Pond, however, was determined by oil immersion to have an index $_nY$=1.695±0.001; this pyroxene contains 16 percent Fe atoms in total Ca+Mg+Fe atoms, and is salite.

The pyroxene skarn that is the host rock for certain magnetite deposits—ore-bearing pyroxene skarn—is characteristically dark green and, except locally, is composed of 90 percent or more salite or ferrosalite and about 10 percent of other mineral constituents, principally magnetite, hornblende, phlogopite, quartz, plagioclase, and apatite. The content of quartz and plagioclase is low and rather consistent, but the other varietal and accessory minerals vary considerably in their abundance. Magnetite, in places, constitutes as much as 90 percent of the rock, and it locally is accompanied by serpentine.

The pyroxene in ore-bearing pyroxene skarn is moderately pleochroic, ranging from pale green through green to pale pink; and, so far as known, it contains 18 percent or more Fe atoms in total Ca+Mg+Fe atoms. Locally, it is embayed by and rimmed by hornblende. Phlogopite is commonly present as thin plates and foliae that occur along and near veinlets and blebs of magnetite. Plagioclase and quartz form sparse interstitial grains. Apatite is an ubiquitous accessory mineral, apparently occurring in direct proportion to the amount of magnetite. Serpentine was observed in two ore deposits—the north ore body at Winters mine and the Splitrock Pond ore body—to vein and embay the pyroxene. An unknown mineral with one good cleavage is closely associated with the magnetite in a specimen from the main opencut at the Green Pond mines (fig. 44), but was not observed elsewhere. This mineral has the following partial optical properties: pleochroic, and in part color zoned, with X=wine yellow, Y=very dark red brown, and Z=dark red brown; $Y>Z>>X$; (−) 2V=about 50°; $r>v$, extreme, for one axis; $_nX>1.72$; birefringence=about 0.03.

HORNBLENDE SKARN

Occurrence

Hornblende skarn forms the host rock for several magnetite deposits in the Dover district; also it occurs as lenticular layers and lenses, generally less than 2 feet wide, along one or both walls of some ore deposits in oligoclase-quartz-biotite gneiss. Hornblende skarn was not observed outside of the Wharton and Hibernia-Hibernia Pond ore belts. The hornblende skarn generally occurs as widely spaced discrete bodies. It contains sparse thin lenses and layers, generally less than a foot thick, of oligoclase-quartz-biotite gneiss and amphibolite; and layers and selvages of biotite sköls of comparable thickness. At many places it is cut by granite pegmatite, which forms conformable lit-par-lit layers or crosscutting bodies.

The wall rocks of most hornblende skarn bodies are alaskite, but at places amphibolite (Taylor deposit, Mount Hope mine) or pyroxene gneiss (Mount Pleasant deposit, Richard mine) constitute one wall of the deposit.

Petrography

The hornblende skarn is a dark-green to black, equigranular to inequigranular, coarse-grained, heterogeneous rock that characteristically has a fair to good gneissic structure. A fair to good foliation is produced locally by alternating layers of different mineral composition, and a fair lineation is given by the subparallel alinement of the hornblende. The texture of the skarn is crystalloblastic, except where it has been cataclastically deformed or has been injected by granite pegmatite. The skarn typically is composed of 90 percent or more hornblende and about 10 percent of pyroxene, biotite, apatite, and calcite. At places, as in the Carlton skarn body, Mount Hope mine, however, pyroxene is far more abundant, and locally exceeds hornblende. Magnetite locally occurs in place of most or nearly all the skarn minerals, and where it is abundant the host minerals constitute residual embayed grains in the ore.

The hornblende is pale green to bluish green, and it forms polygonal to subhedral grains, commonly 1 to 3 mm in diameter. Where it is associated with pyroxene, the hornblende generally embays and appears to replace the pyroxene.

Pyroxene, the next most abundant mineral, occurs in the hornblende skarn as a light-green pleochroic variety and a more common dark-green pleochroic variety. A dark-green pyroxene in a specimen from the Mount Pleasant ore body at Richard mine was determined by oil immersion to have an index, $_nY=1.699 \pm .002$. According to data given by Hess (1949, p. 641) this pyroxene is salite that contains 20 percent Fe atoms in total Ca+Mg+Fe atoms.

Biotite as thin plates is sparsely distributed through the skarn, but more commonly is concentrated in layers or selvages, generally less than a foot thick, that are known as biotite sköls. The pleochroic formula of the biotite is: $X=Y=$colorless, $Z=$golden yellow. A few percent of quartz and oligoclase generally occur with the biotite in the sköls.

The common accessory minerals are apatite and calcite. The apatite forms small subhedral crystals distributed through the skarn, but it is most abundant near magnetite; the calcite occurs as blebs in hornblende or pyroxene or as tiny veinlets that cut both the magnetite and the host minerals. A yellow mineral, tentatively identified as helvite, was recognized locally in one ore body.

HORNBLENDE-PHLOGOPITE-SPINEL SKARN

A small body of hornblende-phlogopite-spinel skarn, probably less than 25 feet wide, that is intercalated with pyroxene skarn, crops out in one place at the east edge of the layer of garnetiferous biotite-quartz-feldspar gneiss, three-fourths of a mile east of the lower end of Splitrock Pond (pl. 1). The skarn has been injected by a coarse-grained granite pegmatite that contains crystals of hornblende as much as 6 inches long.

The hornblende-phlogopite-spinel skarn is a black, fine-grained, massive, equigranular rock. Pale green hornblende constitutes about 85 percent and phlogopite about 10 percent of the rock. The phlogopite most commonly occurs as thin interstitial plates. Bright green spinel (pleonaste), which contains abundant inclusions of a black, opaque mineral, probably an iron ore, forms about 5 percent of the rock. The index of the spinel was determined by oil immersion to be $N=1.755 \pm .002$.

SERPENTINE

DISTRIBUTION

Serpentine is found on the dump at Splitrock Pond mine, where it is associated with magnetite, marble, and diopside skarn; and in the north ore body at Winter mine where it occurs with pyroxene skarn and magnetite. Because of its restricted occurrence it was not mapped separately on plate 1.

PETROGRAPHY

The serpentine at Splitrock Pond mine is a dark-green massive rock that is composed of antigorite and variable amounts of pale green to colorless phlogopite. It contains varying amounts of magnetite, which has two distinct modes of origin. One generation of magnetite is intergrown with the antigorite as small trains of dustlike particles; the other, a coarsely crystalline variety, forms irregular veinlets and blebs that embay and corrode the serpentine and to a lesser extent the associated diopside and phlogopite.

The serpentine in the North ore body at Winters mine is a dark-bluish-green dense massive rock that consists predominantly of antigorite and magnetite with a few small remnants of clinopyroxene and sparse phlogopite and apatite. The pyroxene forms ragged crystals embayed by antigorite. The phlogopite occurs as small aggregates that are alined for the most part along streaks of magnetite. The magnetite is similar to that at the Splitrock Pond mine; it occurs as dustlike particles that form an intricate network of trains and as blebs and veinlets in the serpentine.

METAMORPHOSED ALUMINO-SILICEOUS ROCKS

Two types of quartz-bearing metasedimentary rocks—biotite-quartz-feldspar gneiss and oligoclase-quartz-biotite gneiss—are present in the mapped area, and together they constitute more than 50 percent of the metasediments. Both the oligoclase-quartz-biotite gneiss and the biotite-quartz-feldspar gneiss are interpreted as having formed by the metamorphism of alumino-siliceous sediments, but some facies of the latter were further altered by permeating fluids of igneous origin and by the intrusion of granite pegmatite. As these rocks contain both feldspar and quartz in abundance, they are referred to at places on the following pages as feldspathic-quartzose rocks.

Because both rock units contain feldspar, quartz, and biotite as essential minerals, some discussion of the terminology is desirable. Oligoclase-quartz-biotite gneiss is named from its essential minerals, which are given in order of abundance. The unit mapped as biotite-quartz-feldspar gneiss contains the same essential constituents, with certain exceptions generally in the same order of abundance; but because the rocks of the two mapping units are believed to have been derived from slightly different original materials, and hence are not facies of the same rocks, the map unit biotite-quartz-feldspar gneiss was named from the most conspicuous mineral components. With few exceptions, biotite is conspicuous in all outcrops; at places garnet, sillimanite, and graphite are prominent, and accordingly these minerals are used, where appropriate, as qualifying adjectives.

Although the essential minerals of both rock units are the same, the units can be distinguished by the following criteria:

1. Oligoclase-quartz-biotite gneiss is relatively homogeneous in mineral composition and in structure; biotite-quartz-feldspar gneiss is highly variable in mineralogic and lithologic character.
2. Weathered surfaces of oligoclase-quartz-biotite gneiss are gray to white, whereas exposures of biotite-quartz-feldspar gneiss are typically reddish, except locally.
3. Garnet, graphite, and sillimanite are absent in oligoclase-quartz-biotite gneiss but locally are abundant in biotite-quartz-feldspar gneiss.
4. The feldspar in oligoclase-quartz-biotite gneiss is principally oligoclase or microantiperthite; microperthite is sparse. The feldspar in the biotite-quartz-feldspar gneiss includes microperthite, and it may be the principal feldspar; microantiperthite is absent.
5. The quartz-feldspar ratio in oligoclase-quartz-biotite gneiss generally ranges between 1:2 to 1:3, whereas it is highly variable in biotite-quartz-feldspar gneiss and at places quartz exceeds total feldspar.

BIOTITE-QUARTZ-FELDSPAR GNEISS

The biotite-quartz-feldspar gneiss unit as mapped by the writer includes several varieties of rock in addition to the predominant facies, which is a medium- to coarse-grained gneiss composed essentially of varying proportions of biotite, quartz, and plagioclase feldspar. The types of minor or local importance include (1) garnetiferous biotite-quartz-feldspar gneiss; (2) sillimanitic, garnetiferous biotite-quartz-feldspar gneiss; and (3) graphitic biotite-quartz-feldspar gneiss. Also, these rocks contain lenticular bodies, too small to be mapped, of amphibolite, pyroxene skarn, pyroxene gneiss, and other metasedimentary rocks. The biotite-quartz-feldspar gneiss of the writer includes the graphitic quartz-mica schist and garnetiferous graphite schist as mapped by Bayley (Darton and others, 1908; Bayley and others, 1914) in the Raritan and Passaic quadrangles.

Many of the different layers of biotite-quartz-feldspar gneiss contain somewhat different suites of varietal and accessory minerals, principally garnet, graphite, and sillimanite, and accordingly these layers can be distinguished on the basis of their mineral composition and lithologic character.

Biotite-quartz-feldspar gneiss commonly is well exposed, but it is generally more highly weathered than other gneisses in the district. It can be identified by its distinctive reddish outcrops that contrast with the drab appearance of the other rocks in the district. Upon weathering, the gneiss produces a rusty-colored soil because pyrite is a common accessory mineral.

OCCURRENCE AND DISTRIBUTION

A remarkably elongate and folded layer of biotite-quartz-feldspar gneiss trends through the central part of the district (pl. 1). South of the Wisconsin terminal moraine it is exposed only on the hill south of the Delaware, Lackawanna & Western Railroad tracks. North of the moraine it can be traced almost continuously northeastward from White Meadow Lake for 5 miles to its end on the northwest limb of Cobb anticline. It may correlate with another thin layer that crops out 500 feet west of Cobb mine and continues around the southeast end of Splitrock Pond syncline. This layer pinches out in the axial area of Telemark anticline. The biotite-quartz-feldspar gneiss body is extremely heterogeneous. Near the Cobb mine it is a foliated rock composed predominantly of biotite, quartz, and plagioclase, but elsewhere it is more variable in mineralogic composition, texture, and structure. The variability of the gneiss is caused by alternating layers of different mineralogic composition and texture and by differences in the proportions of the various constituents. Sillimanite and graphite are conspicuous in certain layers but are absent or sparse in others; a red variety of garnet, probably almandite, is a prominent constituent of many of the layers, but its abundance appears to vary directly with the quantity of granite pegmatite, which differs considerably in amount from outcrop to outcrop. In the trough of the Splitrock Pond syncline, the gneiss is intimately associated with, and grades imperceptibly into, biotite granite. To the northeast a second lens composed of garnetiferous biotite-quartz-feldspar gneiss with abundant granite pegmatite pinches out into hornblende granite on either end. It is bounded on the south by hornblende granite and amphibolite migmatite and on the north by hornblende granite.

In the western part of the district a facies of the biotite-quartz-feldspar gneiss, exposed on the north shore of Washington Pond in Wharton, contains abundant garnet. It is correlated with the garnetiferous gneiss body, more than 500 feet thick (fig. 35), that was intersected in drill holes that explored the Scrub Oaks ore body.

A lenticular layer of biotite-quartz-feldspar gneiss, injected and disrupted by coarse granite pegmatite and enclosed by hornblende granite, crops out on the east slope of the hills immediately west of Hibernia Pond. A local 15-foot layer within the gneiss contains as much as 5 percent graphite. The graphite is more abundant adjacent to pegmatite, where it forms elongate plates and aggregates rather uniformly scattered throughout the rock; in places it occurs within pegmatite. Individual graphite flakes are thin and are oriented roughly parallel to the foliation; they range from about 0.2 millimeter to more than a millimeter in diameter.

Biotite-quartz-feldspar gneiss that is characterized by abundant graphite and a pink-to-purplish garnet forms a layer about 200 feet wide and 6 miles long in the southeastern edge of the district (pl. 1). The layer is exposed intermittently south of the Wisconsin terminal moraine; north of the moraine, in the vicinity of Cooks Lake, two layers of this gneiss, separated by an anticlinal mass of alaskite, are present. The mineral composition of the gneiss layers on either side of the terminal moraine is quite similar, and the layers may be correlatives.

On the east slope of Copperas Mountain biotite-quartz-feldspar gneiss is intercalated with other metasedimentary rocks. The gneiss is well exposed at numerous places, particularly along the Wharton & Northern Railroad tracks. This gneiss is generally finer grained and more homogeneous than the other bodies in the Dover district. Much of the rock is devoid of intimately associated granitic material, and garnet is a minor component. A number of small pyroxene skarn pods occur in the rock at scattered localities.

South of Green Pond, in the valley between Copperas Mountain and Green Pond Mountain, a layer of biotite-quartz-feldspar gneiss about 1,000 feet wide is exposed on some of the hills. In mineral composition and structure it is similar to the gneiss that crops out on the east slope of Copperas Mountain. The gneiss layer is bordered by alaskite, but the contact is not exposed.

CHARACTER

The biotite-quartz-feldspar gneiss differs from place to place in composition, texture, and structure. It ranges from a dark-gray, generally medium- to fine-grained, conspicuously layered rock to a white, coarse-grained, nearly massive granitic-appearing rock. The compositional layering reflects differences in the composition of the original beds and, locally, the lit-par-lit injection of granite magma. The rocks are intricately folded and the individual thin layers can seldom be traced more than a few feet. A fair to excellent lineation is produced by the subparallel alinement of the long axes of quartz, feldspar, and biotite, and locally by other minerals, such as sillimanite.

Small lenticular bodies of amphibolite, pyroxene skarn, pyroxene gneiss, and other metasedimentary rocks, generally only a few tens of feet thick, locally are intercalated with the gneiss. Most of these masses are too small and too intimately associated with the gneiss to be mapped separately, but some of the larger pyroxene skarn bodies are shown on plate 1.

Contacts between the gneiss and the surrounding granite are rarely sharp. The gneiss grades into granite by a gradual decrease in biotite and plagioclase content and a corresponding increase in microperthite, and locally hornblende.

PETROGRAPHY

The rocks mapped as biotite-quartz-feldspar gneiss include the following principal facies: (1) biotite-quartz-plagioclase gneiss, (2) garnetiferous biotite-quartz-feldspar gneiss, (3) sillimanitic, garnetiferous biotite-quartz-feldspar gneiss, and (4) graphitic biotite-quartz-feldspar gneiss. Other varieties of the gneiss were noted at places, but inasmuch as these are believed to be local in extent, they are not discussed. Approximate modes determined by Rosiwal analyses of thin sections, believed to be typical of the variations in the gneiss, are given in table 4.

TABLE 4.—*Approximate modes (volume percent) of representative facies of biotite-quartz-feldspar gneiss*

	S152	DG34	DG31	DA69	D282
Plagioclase	41	39	75	17.5	28.5
Microperthite	3	14.5		25	6.0
Quartz	46	14	Tr.	25	47
Biotite	9	23	19	1.5	6.0
Garnet		9.5	5	27	6.5
Sillimanite				2.0	
Rutile		Tr.	.5	1.0	.5
Pyrite	.5		Tr.	1.0	Tr.
Zircon	Tr.		Tr.	Tr.	
Muscovite	Tr.	Tr.	Tr.	Tr.	3.0
Chlorite	.5				
Epidote			Tr.	Tr.	.5
Hematite	Tr.				
Apatite		Tr.	Tr.		.5
Graphite		Tr.			1.5
Total	100.0	100.0	100.0	100.0	100.0
Average grain diameter,[1] in millimeters	0.31	0.43	0.60	0.42	0.40

[1] Average grain intercept measured by mechanical stage; not true grain diameter. Actual diameter is somewhat larger.

S152. Biotite-quartz-feldspar gneiss, a third of a mile east of Splitrock Pond, Boonton quadrangle. Several grains of myrmekite are included with the plagioclase (An_{28}). Texture is crystalloblastic.

DG34. Garnetiferous biotite-quartz-feldspar gneiss. Exposure along road, a quarter of a mile east of the south end of Splitrock Pond, Boonton quadrangle. The plagioclase varies from An_{23} to An_{31}.

DG31. Garnetiferous biotite-feldspar gneiss, crest of hill, half a mile south of Splitrock Pond, Boonton quadrangle. The plagioclase is An_{49}.

DA69. Sillimanitic, garnetiferous biotite-quartz-feldspar gneiss, half a mile east of White Meadow Lake, Dover quadrangle. Texture is crystalloblastic. Sillimanite bundles are intergrown with garnet. Rutile occurs as blades up to 0.6 mm long. The plagioclase varies from An_{34} to An_{42}.

D282. Graphitic biotite-quartz-feldspar gneiss, half a mile northeast of Cooks Lake, Boonton quadrangle. Graphite is intergrown with biotite. The plagioclase is andesine (An_{35}).

The most typical facies of the biotite-quartz-feldspar gneiss is a gray, medium- to fine-grained moderately uniform, nearly equigranular rock with a crystalloblastic texture that consists principally of oligoclase, quartz, and biotite. (See table 4, S152.) Quartz generally is more abundant than plagioclase. The biotite is a strongly pleochroic variety with straw-yellow to dark-reddish-brown pleochroism. The sparse zircon grains included in the biotite are surrounded by well-developed pleochroic halos. Pyrite is a common accessory mineral that occurs as small irregularly disseminated grains.

The less abundant, but locally prominent, facies have widely different mineralogic compositions and are more coarsely grained and generally more massive than the typical facies of the gneiss.

Garnetiferous biotite-quartz-feldspar gneiss is the most abundant facies in the layer that trends through the central part of the district and in the layer exposed on the north shore of Washington Pond in Wharton. This rock is a medium- to coarse-grained, heterogeneous inequigranular gneiss with a crystalloblastic texture, except where it contains abundant injected material. The essential minerals vary within wide limits, even within the same outcrop. Both plagioclase and microperthite usually are present, but the plagioclase generally is most abundant. Quartz ranges from a maximum of about 45 percent to a trace. Red-brown garnet, probably almandite, constitutes an average of about 10 percent of the rock, but locally it is considerably more abundant. The garnet occurs as poikilitic porphyroblasts, commonly one-eighth inch to an inch, but locally as much as 3 inches, in diameter, that are concentrated in poorly defined layers, in "halos" around pegmatite masses, and within pegmatite. Many garnet crystals are enclosed by a thin sheath of biotite, generally less than half an inch thick. At places the garnets are almond or spindle shaped, but within pegmatites they occur as somewhat larger subrounded aggregates. The common accessory minerals are rutile, pyrite, zircon, muscovite, graphite, and apatite; epidote is uncommon.

A facies of the gneiss that is similar to the garnetiferous biotite-quartz-feldspar gneiss, but which contains small but conspicuous quantities of sillimanite, was observed at a few places in the layer that trends through the central part of the district. The sillimanite, which occurs as needles and bundles as much as 3 inches long that produce a conspicuous lineation, appears to be restricted to thin layers.

Another facies, graphitic biotite-quartz-feldspar gneiss, constitutes nearly all the layer along the southeast part of the district, and local lenses in other bodies. The graphitic biotite-quartz-feldspar gneiss is a gray, but locally pink to purple, coarse- to fine-grained, nequigranular, heterogeneous rock with a crystalloblastic texture and a fair to good foliation. Quartz is the most abundant constituent and generally it comprises more than 40 percent of the rock. Plagioclase and microperthite are variable in amount. In some specimens plagioclase is most abundant; in others, microperthite predominates. Biotite, at places partly altered to chlorite, averages between 5 and 10 percent of the rock. The garnet is a pale-pink to purple variety, distinctly different from the garnet in the nongraphitic garnetiferous facies, and it occurs as small disseminated grains, generally half an inch or less in diameter. Graphite, an ubiquitous mineral in this facies, forms conspicuous crinkled plates as much as a millimeter in diameter, that are distributed throughout the rock but which tend to be somewhat more abundant in certain layers. It commonly is intergrown with biotite. The common accessory minerals are muscovite, apatite, rutile, and pyrite; epidote is uncommon.

OLIGOCLASE-QUARTZ-BIOTITE GNEISS

OCCURRENCE AND DISTRIBUTION

Two large bodies and several small bodies of oligoclase-quartz-biotite gneiss were mapped in the Dover district (pl. 1). The small bodies are important because they contain many of the ore deposits. A large mass, about 6 miles long and nearly a mile wide, is exposed sporadically on the low hills at the upper end and along either side of Beaver Brook valley, east of the Beach Glen mine (no. 62, pl. 1). The north end of the body plunges beneath hornblende granite in an anticlinal fold; the south end is covered by terminal moraine, and hence the relation to the quartz diorite exposed south of the moraine is unknown (pl. 1). The gneiss is generally uniform in texture and composition, but locally, it contains thin conformable sheets of albite-oligoclase granite. Another large mass lies between Kitchell and Charlottesburg; it is truncated at its north end by the Green Pond (Silurian) conglomerate, which caps Copperas Mountain, and at its south end by quartz diorite. The gneiss contains thin interleaves of pegmatite, generally only a few inches wide, and small lenticular layers of amphibolite, but amphibolite seldom constitutes more than 10 percent of the rock.

The oligoclase-quartz-biotite gneiss layer that is the host rock for several magnetite deposits in the Wharton ore belt, is poorly exposed but can be seen on Hickory Hill, at the Mount Hope mine (pl. 2), and in some of the prospect pits farther north. Another narrow elongate mass of gneiss that contains several small mines and prospects extends from White Meadow Lake to the Cobb mine. Several of the deposits in the region south of Scrub Oaks mine may also occur in the gneiss; but exposures are limited to the walls of opencuts in these mines, and it is difficult to determine whether the host rock is oligoclase-quartz-biotite gneiss or a granite.

CHARACTER

Oligoclase-quartz-biotite gneiss is a greenish-gray, medium-grained, equigranular rock, that generally weathers brown, but locally to gray or even white. Usually biotite is conspicuous, and where it is abundant the gneiss has a prominent foliation. A strong lineation is commonly produced by the subparallel alinement of elongate biotite plates.

Certain parts of the gneiss contain 5 percent or more of disseminated magnetite and correspondingly less biotite, and another facies contains only traces of either mafic mineral. Because of these mineralogic differences, a moderate- to large-scale layering is produced that is evident when exposures are studied in detail.

The only metasedimentary rock commonly intercalated with oligoclase-quartz-biotite gneiss is amphibolite. It forms thin to moderately wide layers and lenses that for the most part have little continuity, and it seldom constitutes more than 10 percent of the gneiss bodies. The gneiss locally contains small masses of pegmatite, which are particularly abundant near ore bodies.

The contacts of the gneiss against amphibolite and other metasedimentary rocks are sharp; the contacts against alaskite, however, are transitional for the gneiss is partly altered at the contact to microantiperthite granite.

PETROGRAPHY AND CHEMICAL COMPOSITION

Sodic plagioclase, quartz, and biotite constitute the essential minerals in oligoclase-quartz-biotite gneiss, except in some facies where magnetite occurs instead of biotite. Plagioclase feldspar is the most abundant mineral, constituting from 50 to 75 percent of the rock; generally it is oligoclase but it varies in composition from An_4 to An_{19}. The plagioclase occurs as anhedral grains and is well-twinned except where the gneiss has been cataclastically deformed; in a few places it shows chessboard twinning. Microantiperthite is locally abundant, and in some parts of the gneiss it is the predominant feldspar. Quartz commonly constitutes 20 to 30 percent of the gneiss, except locally where it is more abundant. Two generations of quartz are present—an apparently early unstrained quartz forming anhedral grains in oligoclase and a late commonly strained quartz that occurs interstitially to plagioclase, or more rarely as large amoeboid grains. Biotite constitutes as much as 15 percent of the rock but averages between 5 and 10 percent. In some facies of the gneiss that contain magnetite, biotite is absent or sparse. (See table 5, DM10-18.) The biotite is a reddish-brown variety, and it is altered at places to chlorite mottled by fine-grained magnetite dust. At a few places hornblende is a varietal mineral, and rarely hypersthene or augite constitutes 2 to 3 percent of the rock. The hornblende is a pale-green variety; the hypersthene is pleochroic and the augite is light green and faintly pleochroic. The accessory minerals are opaque iron oxides, apatite, zircon, epidote, chlorite, and sericite; all except the iron ores, which locally are abundant, are sparse.

The modes, determined by Rosiwal analysis of thin sections of representative specimens, are given in table 5.

The oligoclase-quartz-biotite gneiss has a granoblastic texture, except in the ore zones where it has been cataclastically deformed.

The chemical analysis and norm of a typical specimen (table 5, 28C-1) of oligoclase-quartz-biotite gneiss are given in table 8.

TABLE 5.—*Approximate modes (volume percent) of oligoclase-quartz-biotite gneiss*

	S16-1	K82	S888	DM10-18	28C-1	S208-48
Plagioclase with microantiperthite intergrowth	65	58	65	71.5	73	50.5
Microperthite		.8	3.0			
Quartz	20	29	23.5	26	18.5	36
Biotite	7.5	12	8		6.5	2
Hornblende	5					
Magnetite	2	.1	Tr.	2.5	Tr.	9.5
Apatite	.5	.1	Tr.			1.5
Sericite					2	
Chlorite		Tr.	.5	Tr.	Tr.	
Zircon		Tr.	Tr.	Tr.	Tr.	Tr.
Epidote						.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
Average grain diameter,[1] in millimeters	0.45	0.40	0.41	0.44	0.33	0.29

[1] Average grain intercept measured by mechanical stage; not true grain diameter. Actual diameter is somewhat larger.

S16-1. Oligoclase-quartz-biotite-hornblende gneiss, exposure on north side of stream 500 feet northwest of Meriden, Boonton quadrangle. Plagioclase has the composition An_{11}. Quartz is strained.

K82. Oligoclase-quartz-biotite gneiss, east slope of Copperas Mountain, four-fifths of a mile northeast of Kitchell, Newfoundland quadrangle. Plagioclase is An_{11}. The biotite is partly altered to chlorite.

S888. Oligoclase-quartz-biotite gneiss, along road on south side of Timber Brook, half a mile northeast of Kitchell, Newfoundland quadrangle. Texture is granoblastic. Microperthite occurs as small interstitial grains.

DM10-18. Oligoclase-quartz gneiss, 1,000-foot level, Mount Hope mine, Dover quadrangle. The plagioclase is mostly An_4.

28C-1. Oligoclase-quartz-biotite gneiss, half a mile northeast of New Leonard shaft, Mount Hope mine, Dover quadrangle. The plagioclase is An_{11}. (For chemical analysis see table 8.)

S208-48. Oligoclase-quartz magnetite gneiss, footwall of Northwest ore body, Huff mine, Dover quadrangle. The plagioclase varies from An_8 to An_{19}.

UNDIVIDED METASEDIMENTARY ROCKS

West of Kitchell fine- to medium-grained rocks are exposed that were not distinguished on the geologic map (pl. 1) because the layers are too thin to be mappable as individual units. These rocks, mapped as undivided metasedimentary rocks, consist largely of interlayered plagioclase-quartz gneiss, pyroxene gneiss, pyroxene skarn, and amphibolite. With the exception of the plagioclase-quartz gneiss all the rock types have been described previously.

The plagioclase-quartz gneiss forms thin layers generally 10 feet or less thick. In most places it is intercalated with amphibolite but locally it occurs as discrete layers. In places the gneiss contains small lenses and lenticles of diopside skarn, commonly 1 to 3 inches in diameter; in other places a few percent of diopside is present as a varietal mineral.

The plagioclase-quartz gneiss is a white to gray generally fine-grained rock that tends to be massive. It has a crystalloblastic texture; individual grains are polygonal and form a mosaic pattern. The plagioclase has the composition of sodic oligoclase and commonly constitutes more than 50 percent of the rock; at places, it constitutes as much as 70 percent. Quartz, which forms anhedral grains, is next in abundance and occurs for the most part as rounded inclusions within the oligoclase. Other quartz grains are intergrown with the oligoclase. Clinopyroxene, biotite, and magnetite are sparse accessory minerals.

ORIGIN OF THE METASEDIMENTARY ROCKS

Because all the rocks in the mapped area have been thoroughly recrystallized and reconstituted and because they have been subjected both to dynamothermal metamorphism and metasomatism, many aspects of their origin are not known. The assemblage consisting of marble, pyroxene gneiss, amphibolite, and skarn, characteristic of many pre-Cambrian terranes, is interpreted as altered carbonate sediments; the feldspathic-quartzose gneisses probably are altered alumino-siliceous sediments. The mineralogic assemblage depended upon the bulk composition of the original rocks and the quantity and kind of material added or subtracted by solutions of magmatic and ultrametamorphic sources.

METAMORPHOSED CALCAREOUS ROCKS

The marble developed from calcitic or dolomitic limestone by recrystallization and introduction of material, principally silica, fluorine, and possibly magnesia. The silicate-free marble is a product of recrystallization of the host rock, without the addition of substance; the chondrodite marble is interpreted to be the product of recrystallization and addition of substance from thermal solutions derived probably from a cooling granitic magma. The sequence of marble and skarn exposed in Timber Brook valley is typical of that found in the contact-metamorphic aureole of granitic rocks and is generally interpreted to be the result of metasomatic alteration of carbonate rocks. The most intense metamorphism took place adjacent to the granite, where the limestone was converted to diopside skarn. Farther from the contact, where thermal solutions were cooler and probably more dilute, scattered chondrodite grains were formed in the limestone, and these gradually diminish in abundance away from the granite. The limestone farthest from the granite is not altered. The conclusion for a metasomatic origin of the chondrodite marble seems warranted because of the spatial relation of the marble to the granite, and its mineral composition. Chondrodite, a magnesium fluosilicate, generally is considered to be of thermal origin, and the fluorine necessary for its formation must have been introduced. The role of silica and magnesia, however, is more difficult to assess, and it is possible that the original rocks contained sufficient quantities of these elements to yield chondrodite, without any addition of substance.

Pyroxene gneiss, although not abundant, is more widely distributed than marble; and it is interlayered with both skarn and plagioclase-quartz gneiss. The field relations and sparse residual grains of quartz and other accessory minerals in the rock suggest that the pyroxene gneiss was formed by the metamorphism of impure calcareous sediments, probably sandy and argillaceous calcareous rocks. The occurrence of pyroxene gneiss in layers as much as a mile long considerably removed from known granitic rocks suggests that the gneiss was formed by dynamothermal metamorphism without the addition of substance from a magma. Heat, together with the original moisture content of the rocks, possibly could account for its origin, but the presence of soda in the rock in excess of that in known primary sediments cannot be accounted for. The quartz in the gneiss represents the SiO_2 present in excess of that needed to form the silicate minerals.

It could be argued that the pyroxene gneiss associated with bodies of skarn formed by the metasomatism of relatively pure carbonate rocks, for it is known that identical pyroxene gneisses can be developed by either dynamothermal metamorphism of impure calcareous sediments or by metasomatism of carbonate rocks (Adams, 1909), and it cannot be disproved in the Dover district. Because of the sharp breaks or abrupt transitions between skarn and pyroxene gneiss, however, it seems more probable that these gneisses formed in a manner analogous to those intercalated with the plagioclase-quartz gneisses. Also, pyroxene gneiss forms layers that extend beyond the limits of the associated skarn beds, and thus are not coextensive with the skarn.

The pyroxene gneiss represents a less intense phase of metamorphism than the amphibolites. The plagioclase in the pyroxene gneiss is oligoclase or albite, rather than andesine; scapolite is present in parts of the gneiss but is absent in the amphibolite; and scattered carbonate occurs in the gneiss but not in the amphibolite.

The amphibolites, because of their intimate association with rocks clearly of metasedimentary origin, most likely are also derived from sediments; but this origin cannot be proved, for the primary fabrics of the rock have been obliterated by metamorphism. As Adams (1909, p. 3–4) has shown in the Laurentian area of Canada, amphibolites can be derived by the (1) metamorphism of basic igneous rocks, (2) metamorphism of impure calcareous and magnesian sedimentary rocks, and (3) metasomatic replacement of limestone by granitic solutions. The field evidence in the Dover district supports an origin by metamorphism of impure calcareous or magnesian sedimentary rocks for most of the amphibolites, but some may well represent altered mafic igneous rocks. The rocks in part show analogies to the mafic components of the charnockite series. (See Quensel, 1952.) Engel and Engel (1950, p. 1457) recently have shown that the accessory elements in hornblendic amphibolites provide clues to their source, but a study of these elements was not made by the writer.

The occurrence in the Dover district of both hornblendic and pyroxenic amphibolites is believed to be principally the result of differences in bulk composition, dependent upon "wet" or "dry" conditions; for there is no evidence of appreciable differences in the metamorphic intensity. Both types of pyroxene are intergrown and appear to have developed simultaneously; most of the hornblende forms discrete grains and apparently is in equilibrium with the pyroxene, but some of it forms partial rims around, or poikilitically includes, pyroxene.

Although the pyroxene amphibolites of this region show many analogies to the granulite facies of Eskola (1939), it is now known that they also are characteristic of certain terranes belonging to the amphibolite facies. As stated by Ramberg (1952, p. 156):

> It is evidenced by field and laboratory tests that rhombic pyroxene is stable in the highest half of the amphibolite facies just below the granulite—or the pyroxene hornfels facies.

Poldervaart and von Backström (1949) found in the Kakamas area, South Africa, metabasaltic rocks of both the granulite facies and the amphibolite facies within the almandine and sillimanite zones of the associated pelites.

An explanation for the occurrence of both pyroxene and hornblende in the amphibolites is given by the work of Yoder (1952). In his investigation of the system $MgO—Al_2O_3—SiO_2—H_2O$ he found (p. 569) that the mineralogy of a metamorphic rock is influenced greatly by the presence of an "excess" or "deficiency" of water vapor. For an excellent discussion of the problem the reader is referred to Poldervaart (1953).

The unusual accessory mineral, orthoclase, which occurs in one amphibolite layer in the Richard mine, forms individual grains that apparently are contemporaneous with the plagioclase in the amphibolite, suggesting that it was derived from original calcareous sediments that contained moderate K_2O. The epidote in this rock is principally in veins and is of secondary origin. Sphene occurs in amphibolites that are veined by granite pegmatite or that are adjacent to magnetite deposits. It is always accompanied by biotite, an alteration product of hornblende. Accordingly, the sphene probably is an alteration product formed by the introduction of Ti and perhaps other elements by pegmatitic or hydrothermal fluids. The biotite associated with the sphene-bearing rocks in part forms myrmekitic intergrowths with quartz.

The interlayered biotite-hornblende-pyroxene-feldspar gneisses, host rocks for the Hibernia Pond deposit, are believed to be altered amphibolites; metamorphism of an originally heterogeneous bedded sedimentary sequence, however, cannot be omitted as a possible origin for these rocks, and further studies are needed. If derived from amphibolites, the rocks could have been formed by magmatic fluids, in part hydrothermal in character, that permeated and thoroughly modified the original solid rock. The principal change in the rock produced by the fluids was the formation of biotite after hornblende and microantiperthite from plagioclase. Probably the alteration was produced by fluids that shortly preceded the iron-forming stage.

The amphibolite migmatites are characterized by alternating mafic layers, generally of the composition of normal amphibolite, and felsic layers of the composition of alaskite. The granitic (felsic) layers are generally sharply defined and clearly discernible; schlieren and ghostlike or phantom structures in the granitic layers are uncommon. The migmatites probably formed largely from the mechanical injection of magma of the composition of alaskite along the foliation planes of the amphibolite; probably they should be called arteritic migmatites (Sederholm, 1926). The occurrence of the granitic material in well-defined layers and streaks indicates that it was injected lit-par-lit along well-developed foliation surfaces that were formed prior to the recorded injection, probably in a manner similar to that described by Fenner (1914) and Harker (1932). Amphibolite migmatites of similar character and origin have been described by Prucha (1949, unpublished Ph. D. dissertation, Princeton Univ.) and Buddington (1939, p. 176) from the Adirondack Mountains.

The field relations, mineralogic and chemical composition, and structure of the skarn rocks suggest that they developed by metasomatism of carbonate rocks. The chemical change resulted mainly from an addition of silica and iron; calcium and carbon dioxide, especially, were removed. It is possible, however, that the hornblende skarn formed in part from amphibolites. The character of the original carbonate rock could have been either limestone or dolomite, or both. Judging from the general absence of layering in the pyroxene skarns, it seems probable that the host was fairly uniform in composition and perhaps was limestone. A clue to the character of the original carbonate rocks in the Dover district is given by the large belt of marble belonging to the Franklin limestone of Spencer (1908) that occurs in the valley near Franklin, N. J. These rocks, except locally, have not been affected by igneous activity, and they consist predominantly of relatively pure marble; siliceous layers are sparse, and where present they generally are thin. If it is assumed that the original carbonate rocks in the Dover district were of comparable composition, they did not contain sufficient quantities of iron and silica to yield pyroxene skarn by reconstitution alone. Some silica and considerable iron must have been added by metasomatism.

The pyroxene skarns contain pyroxene ranging from diopside, through salite, to ferrosalite in composition. The diopside skarn occurs principally as interlayers and pods in alumino-siliceous rocks and in the contact aureole of the albite-oligoclase granite; the more iron rich skarns are associated with the metamorphic rocks that probably are derived from impure calcareous sediments and consitute the host for several ore deposits. The occurrence of the more iron rich pyroxenes (salite and ferrosalite) in the ore environments suggests that the iron is derived from the same source as that which produced the magnetite deposits.

That hornblende-phlogopite-spinel skarn was formed in a manner similar to that of pyroxene skarn is evident from its occurrence with and gradational relationship to pyroxene skarn.

The hornblende skarn is inferred to represent the last stage in the alteration of the carbonate rocks of the Dover district; it is possible, however, that some of these rocks are altered amphibolite modified by ore-forming fluids. The presence of corroded, embayed, and rimmed fragments of pyroxene in hornblende skarn suggests that the hornblende formed by replacement of pyroxene skarn under the action of solutions rich in iron and aluminum and other components; so far as known the pyroxene in this environment always has the composition of salite or ferrosalite. This alteration took place only where the skarn is adjacent to alaskite. The restriction of hornblende skarn to ore-bearing zones suggests that the alteration was produced by the solutions that deposited the magnetite. These solutions—a hydrous fluid containing fluorine and/or chlorine, and rich in iron and probably aluminum—metasomatically changed the pyroxene to hornblende; then later, for some reason, the same kind of solutions provided the magnetite, which replaced the hornblende skarn host.

Others also have found that in regions containing both pyroxene and hornblende skarn, the hornblende skarn developed by the alteration of preexisting pyroxene skarn, but their views on the origin of the hornblende skarn are not necessarily the same as the writer's. In the Orijärvi region in southwestern Finland, Eskola (1914, p. 229) concluded that the "hornblende rock is, in all probability, a metasomatic skarn and has originated through complete replacement of the original substance". In the Marysville mining district, Montana, Barrell (1907, p. 140–141) noted that diopside may be changed into a hornblende, crystallizing on a coarser scale, if much Fe or Mg is introduced in the presence of the necessary amount of Si. In the Ljusnarsberg pyroxene-hornblende skarn iron ores in Västmanland, Magnusson (1940, p. 73–75; 184) found the hornblende to be a metamorphic product of pyroxene, formed for the most part where granitic veins penetrate the skarn. Certain amphibolites in the Laurentian area of Canada (Adams, 1909, p. 10–17) and in the Urgebirge (Barth, 1928, p. 122–125) also show many analogies to the hornblende skarn of the Dover district. In both of these regions it has been demonstrated that hornblende in amphibolite formed by the replacement of pyroxene.

The serpentine at the Splitrock Pond and Winter mines is an alteration product of chondrodite marble and diopside skarn, and various stages in the alteration process can be observed. Serpentine is found in intimate association with chondrodite in chondrodite marble and with pyroxene, probably salite, in pyroxene skarn, and locally unreplaced "islands" of these minerals can be seen in serpentine. In the last stages of alteration all vestiges of the original silicate minerals are destroyed, and the resultant rock consists almost wholly of antigorite, with some associated fine-grained magnetite derived by serpentinization. The alteration is thought to have been produced by hydrothermal solutions that slightly preceded the ore-forming fluids. The coarse magnetite that embays and replaces the serpentine has been introduced by later iron-bearing fluids.

Serpentine rocks of similar lithologic character have been described from the Redback, Morehead, and Patterson mines in the Sterling Lake district, New York (Hotz, 1953, p. 211). Colony (1923, p. 88) suggested that this serpentine was formed from alteration of ultramafic igneous rocks, but Hotz has clearly shown that it was a product of serpentinization of pyroxene skarn and chondrodite marble. Also, Bayley (1941, p. 23) has described serpentine in association with marble and dark silicate minerals from the Queen and Little mines in the Pequest area, New Jersey.

The serpentine in the sheared chondrodite marble in

Timber Brook valley, away from the granite contact and any known ore deposits, probably was derived from shearing, accompanied by hydration. There is no evidence that this serpentine was formed by hydrothermal solutions derived from the alaskite magma.

METAMORPHOSED ALUMINO-SILICEOUS ROCKS

The feldspathic-quartzose gneisses formed primarily by the dynamothermal metamorphism of original alumino-siliceous sediments, but the biotite-quartz-feldspar gneiss at places was further modified by magmatic fluids.

The origin of the biotite-quartz-feldspar gneiss has received the attention of several geologists. Nason (1890, p. 46) first described graphitic gneisses from the New Jersey Highlands. He recognized two types, but he did not attempt an explanation of their origin. Wolff (1894, p. 369) mapped one layer of the gneiss in the area of Hibernia in detail, and he concluded that the gneiss was derived "from a previous bedded series by metamorphism and recrystallization which took place contemporaneously with the folding." Bayley did the first detailed petrographic work on the gneiss and in mapping the Raritan and Passaic quadrangles he divided the gneiss into graphitic quartz-mica schist and garnetiferous graphite schist. In discussing the origin of the graphitic quartz-mica schist, he stated (Bayley and others, 1914, p. 7):

> Because of its common association with the limestone, its occurrence in small lenticular masses, and its composition, it is inferred that the schist is a metamorphosed sedimentary rock older than the gneisses by which it is surrounded.

He regarded part of the garnetiferous graphite schist, however, as sheared pegmatite dikes; the remainder as metamorphosed sedimentary rocks. Later Bayley (1941, p. 12–19) described similar graphitic gneisses in the Delaware Water Gap and Easton quadrangles in association with quartzites, conglomerates, slates, and banded gneisses. He found these rocks to be intimately intercalated with limestone, which he correlates with the Franklin limestone, and he mapped them as Pickering gneiss. Bayley believes that the limestone and the members of the Pickering gneiss are of essentially contemporaneous origin and that they represent merely different lithologic facies of the same series of sediments. He interpreted the graphitic schists as having formed from siliceous muds (Bayley, 1941, p. 16).

The present writer believes that biotite-quartz-plagioclase gneiss, the most typical facies of the biotite-quartz-feldspar gneiss, formed by reconstitution of the primary sediments, probably without the addition of substance from an igneous or ultrametamorphic source. The chemical composition of the gneiss, to judge from its modal composition, is similar in most respects to that of graywacke (Pettijohn, 1949, p. 250) and graywacke probably was the original source. The biotite-quartz-plagioclase gneiss, however, contains more soda than the average graywacke. Engel and Engel (1950, p. 1457) have suggested that gneisses of similar mineralogic and chemical composition in the northwest Adirondacks were derived from a siliceous, sodic shale (tuff?).

The less abundant and more heterogeneous facies owe some of their present lithologic character to dynamothermal metamorphism of the primary sediments and some to the addition of substance from an igneous source. It is not possible in all cases, however, to state categorically the origin of all the mineral constituents. The biotite, quartz, plagioclase, pyrite, and graphite in these rocks probably are primary because of their widespread distribution and their lack of any spatial relationship to igneous rocks. Individual layers, however, contain different amounts of these constituents. The graphite probably represents original carbonaceous beds; the pyrite represents original iron and organic material in the sediments. However, as Turner and Verhoogen (1951) point out, both minerals can form by purely inorganic processes. The sillimanite also probably is primary; it represents high alumina shales (?). It occurs in thin layers that conform to the foliations of the gneiss and it shows no obvious relationship to exposed bodies of igneous rocks. The other accessory minerals—rutile, zircon, muscovite, iron ore, and apatite—probably are primary.

Stewart (Bayley and Stewart, 1908) described a thin layer of graphite schist occurring at Tuxedo Park in Orange County, N. Y., and concluded (p. 538) that—

> the schist may be the product of metamorphism of a sediment rich in organic matter. This view is supported by the close relationship existing between it and the limestone and by the presence of graphite disseminated through the latter rock.

Hotz (1953, p. 173) described garnetiferous quartz-biotite gneiss from the Sterling Lake and Ringwood districts, New York–New Jersey that is similar to the biotite-quartz-feldspar gneiss in the Dover district. He stated that this gneiss represents metamorphosed alumino-siliceous sedimentary rocks, such as sandy shales. He attributed the development of garnet and sillimanite in the gneiss, however, to metasomatic processes accompanying injected granitic material.

Closely similar, if not identical, rocks occupy an area of several hundred square miles in the Adirondack Mountains (Smyth and Buddington, 1926; Martin, 1916; Engel and Engel, 1950, p. 1457).

The writer considers the biotite-quartz-feldspar gneiss possibly to be metamorphosed graywacke, which was in part permeated and injected by granitic and pegmatitic material. The lenticular diopside skarn bodies found scattered through the gneiss represent original beds of carbonate rock, and the interlayered amphibolitic rocks probably were impure calcareous sediments. The extreme heterogeneity of the gneiss is partly the result of metamorphism of an original bedded series of sedimentary rocks of different compositions and partly the result of the addition of magmatic material during the orogeny that deformed and recrystallized the sedimentary rocks. Consequently, the present lithologic layering reflects the original composition of the sedimentary beds as well as the lit-par-lit injection of magma.

Most of the microperthite and garnet probably resulted from the addition of magmatic material. These minerals are present in those rocks that contain considerable pegmatite and alaskite and which are more coarse grained than the typical facies. The microperthite, a feldspar generally thought to form at high (igneous) temperatures (Spencer, 1938, Bowen and Tuttle, 1950, p. 497), is a highly variable component of the gneiss. It is sparse to absent in the biotite-quartz-plagioclase facies of the gneiss (table 4, S152), and locally in other facies, and is present in consider-, able quantity in those rocks that are closely related to igneous rocks—either granite pegmatite or alaskite. Also, the microperthite is similar in appearance to the microperthite in alaskite or hornblende granite and granite pegmatite. Its spatial distribution and character suggests that it was introduced into these rocks by feldspathic fluids that were derived from the magma that consolidated to form hornblende granite and alaskite. The fluids intimately permeated through the host rocks; they did not migrate only along the foliation or bedding planes.

The garnet (almandite) occurs most commonly adjacent to and within granite pegmatite, in close association with biotite, and accordingly it probably formed by the reaction of pegmatitic solutions with biotite. Some of the garnet, however, as for example, the disseminated garnet in the graphitic biotite-quartz-feldspar gneiss, possibly is the normal product of recrystallization of clayey and calcareous (?) rocks.

Granite pegmatite and, less commonly, alaskite at places were injected into the gneiss to form arteritic migmatites. For the most part these bodies were emplaced in a lit-par-lit manner, but in small part the pegmatite cuts across the gneiss. Inclusions within the large crosscutting pegmatites typically have a random orientation.

Because the gneiss was modified principally by fluids that permeated through it, the gneiss is similar to the permeation gneiss described by Read (1931, p. 120), who wrote:

> The term permeation gneiss is employed . . . to denote those injection rocks arising from the soaking and permeation of country rock by juices from the injecting magma. They are distinguished from injection gneisses in that, in the latter, the igneous portion forms discrete layers or patches, whilst in the permeation-gneisses when normally developed no such separation of components is possible.

Bayley (1914) did not map oligoclase-quartz-biotite gneiss as a separate formation, but instead he included it in the Losee, a light-colored gneiss containing sodic plagioclase, that he considered to be dominantly of igneous origin. Because of its marked layering and lineation and its metamorphic texture the writer interprets oligoclase-quartz-biotite gneiss to be of metamorphic origin. The original sediment probably was a graywacke. In contrast to the biotite-quartz-feldspar gneiss, however, the original source material must have been quite homogeneous. Also like the biotite-quartz-feldspar gneiss, it contains more Na_2O than normal clastic sediments. Although one prominent facies contains accessory magnetite, whereas the principal facies contains accessory biotite, it is probable that the two facies have essentially the same bulk composition.

An original igneous origin for oligoclase-quartz-biotite gneiss cannot be disproved. Chemically and mineralogically the rock is similar to the biotite trondhjemites in the Fennoscandian countries (Hietanen, 1947). At places in the Dover district (pl. 1) oligoclase-quartz-biotite gneiss is spatially associated with the quartz diorite and related facies; the reason for this association is not known.

IGNEOUS ROCKS

The pre-Cambrian igneous rocks in the Dover district consist of quartz diorite and related facies, albite-oligoclase granite, albite-quartz pegmatite, and hornblende granite and related facies.

Throughout this section the terms gneissoid and gneissic are used according to the definitions of Grout (1932, p. 58). Granites that are undeformed and have a primary planar and linear structure are designated gneissoid granites; igneous rocks that are deformed—that have a secondary gneissic structure—are referred to as gneissic.

QUARTZ DIORITE AND RELATED FACIES

The series of rocks, for the most part of the composition of quartz diorite, that occur within the Dover district, are similar mineralogically and structurally to the noritic members of the charnockite series of igneous rocks. (See Turner, 1948, p. 101.)

DISTRIBUTION AND CHARACTER

Quartz diorite and related facies constitutes several percent of the igneous rocks in the mapped area and forms large masses. Some of the masses are relatively uniform, but others are quite variable because of variations in lithologic character, in part resulting from the injection of younger granitic material.

In the northeast part of the district quartz diorite forms two large masses: the Splitrock Pond mass and the Kinnelon mass. The Kinnelon mass is composed mainly of rocks of the composition of hypersthene-quartz diorite, but at places hypersthene diorite predominates. At least one layer, exposed on the east slope of the hill west of Kinnelon, contains abundant garnet. Pegmatitic facies of the quartz diorite are conspicuously absent. Along the borders of the mass, the dioritic rocks are intruded locally in a lit-par-lit manner by hornblende granite and alaskite. The Splitrock Pond mass, so far as known, ranges in composition from quartz diorite to diorite and every gradation can be seen between the two facies. The rocks in the core of the Splitrock Pond syncline are relatively homogeneous, but the rocks on the northwest limb of Telemark anticline are migmatites formed by the lit-par-lit injection of granite pegmatite. The dioritic rocks in the mass are bordered for the most part by hornblende granite and alaskite, which locally intrude them.

A sheetlike body of dioritic rocks is exposed north and west of Mount Freedom (Mendham quadrangle) and extends northward to approximately the latitude of the Beach Glen mine. The best exposures of the mass are on the hill east of Millbrook (Mendham quadrangle). This body is bordered principally by hornblende granite, and it surrounds a long belt of graphitic biotite-quartz-feldspar gneiss. The body is heterogeneous; hypersthene diorite and quartz diorite predominate, but local migmatitic belts, marked by interleaved alaskite and granite pegmatite, are not uncommon.

A lenticular mass of diorite occurs along the crest of the Hibernia anticline; the rocks are best exposed on the hills near Jackson Brook, west of Dover.

The rocks within all the masses are characterized by a conspicuous compositional layering produced by alternating light and dark bands; typically the dark layers are much thinner than the light layers, and they tend to be lenticular and streaky. Boundaries between the light and dark layers usually are transitional. At many places the material constituting the light layers cuts across the dark layers. The dark layers are composed of the same minerals as the light layers but contain higher proportions of the mafic minerals; commonly they have the composition of pyroxene amphibolite.

The weathered surfaces characteristically are brown, streaked with black, and typically tend to be smooth and rounded. The fresh rock is greenish gray, dark gray, or brownish gray and usually has a greasy appearance. These distinctive greenish and brownish shades are caused principally by the coloring of the feldspars, not the mafic minerals; accordingly the rocks are darker than would be expected from their mineral composition. Because of this characteristic color, the compositional layering, and the presence of abundant plagioclase with broad polysynthetic twin bands that are easily visible to the naked eye, the rocks are readily distinguished in the field.

PETROGRAPHY

The diorites are generally equigranular and consist essentially of plagioclase, hypersthene, quartz, augite (?), and hornblende. Garnet locally is a prominent constituent, but it is absent in most layers. Pegmatitic facies are almost entirely absent. Modal analyses of representative specimens from several masses are given in table 6.

Plagioclase, mainly andesine, but locally oligoclase, is the dominant mineral, constituting 50 to 80 percent of the rock. Most of the plagioclase contains a small to moderate amount of orthoclase in antiperthitic intergrowth. Moderately pleochroic hypersthene is always present and constitutes an average of about 20 percent of the rocks, but it is more abundant in the dark layers. On weathered surfaces the hypersthene is partly altered, either to antigorite, which develops along cracks and grain boundaries, or to a fine aggregate of chlorite, carbonate, and magnetite. The clinopyroxene is a pale green augite (?). The hornblende is a green variety that forms subhedral crystals or, at places, rims that partially surround the pyroxene.

TABLE 6.—*Approximate modes (volume percent) of quartz diorite and diorite*

	S132	D150	DA55	S108	S795-2	S359	S119
Plagioclase	70	77.5	51	60	71.5	67	80
Quartz	9.5	4.5	26	25.5	19.0	19	0
Hypersthene	11	10.5	18	9.5	6.0	11	13
Augite (?)	4.5						5.5
Hornblende	4.5		4	.5		Tr.	
Biotite		3.5	Tr.	Tr.		Tr.	
Orthoclase	Tr.					.5	
Iron ore	.5	3.5		4.0	3.0	2	1
Apatite		.5		.5	.5	.5	.5
Chlorite	Tr.						
Zircon			Tr.		Tr.		
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average grain diameter,[1] in millimeters	0.40	0.51	0.47	0.40	0.53	0.60	0.61

[1] Average grain intercept measured by mechanical stage; not true grain diameter. Actual diameter is somewhat larger.

S132. Quartz diorite, from prominent outcrop on west slope of hill half a mile northwest of upper end of Splitrock Pond, Boonton quadrangle. Plagioclase has the composition An_{35}. Hypersthene shows weak pleochroism.

D150. Hypersthene diorite, from southeast slope of small conical hill a third of a mile south of Mill Brook settlement, Mendham quadrangle. The plagioclase is An_{19}

DA55. Hypersthene-quartz diorite, from crest of rounded hill north of upper end of Splitrock Pond, Dover quadrangle. Plagioclase (An_{43}) is in part antiperthitic. Biotite replaces hypersthene.

S108. Hypersthene-quartz diorite, from hill a mile southeast of Marcella, Boonton quadrangle. Plagioclase has composition An_{31}.

S795-2. Hypersthene-quartz diorite, from hill four-fifths of a mile north-northwest of Kinnelon, Newfoundland quadrangle. Plagioclase (An_{43}) contains about 5 percent potash feldspar in microantiperthite intergrowth.

S359. Hypersthene-quartz diorite, from hill a quarter of a mile south of Coleman's Hollow, Mendham quadrangle. Plagioclase has the composition An_{31}.

S119. Pyroxene diorite, from Splitrock Pond mass, on west shore of Splitrock Pond, Boonton quadrangle. Plagioclase has the composition An_{27}.

Biotite that ranges from straw yellow to reddish-brown forms is usually present as small scattered plates that commonly embay pyroxene.

Quartz is variable, but usually is inconspicuous; and in many specimens it cannot be recognized megascopically. In some exposures, however, it forms more than 30 percent of the rock. In thin sections two generations of quartz are evident: an apparently early quartz that occurs as small subrounded grains poikilitically included in plagioclase, and a late generation that embays the feldspar. Where most abundant, the late quartz forms irregular elongate amoeboid lenses that in places completely surround plagioclase. At places seams of quartz less than an inch thick cut the rock, commonly at an angle to the layering.

The accessory minerals are iron ores and apatite, and very rarely zircon. Iron ore is present in nearly every specimen, and locally it is as much as 5 percent by volume.

The rocks typically have a xenomorphic granular texture, indicating that the constituents crystallized more or less simultaneously.

ALBITE-OLIGOCLASE GRANITE

The individual masses of albite-oligoclase granite differ somewhat in composition and there are local variations in composition within each mass, but for the most part the granites are pink medium-grained leucocratic rocks that can be distinguished megascopically from alaskite only by the presence of abundant, readily recognized plagioclase. At places clinopyroxene is a conspicuous accessory mineral. In composition, the granite varies from an albite granite to an oligoclase granite, but because the plagioclase generally has the composition of albite-oligoclase, it is referred to as albite-oligoclase granite.

Because some bodies of the granite contain more than 20 percent by volume of metasedimentary rock, principally amphibolite, these bodies are distinguished on plate 1 from the more abundant masses with smaller quantities of inclusions.

DISTRIBUTION AND CHARACTER

Bodies of albite-oligoclase granite are widely distributed through the mapped area, but mostly are small (pl. 1). The largest body, interpreted to be a phacolith (see p. 52), forms part of the limbs and plunging nose of the Hibernia anticline. Locally, near Telemark village, the body is syenitic, but elsewhere it is a granite of variable lithologic character. Inclusions of amphibolitic rocks are common and locally abundant. A sheetlike mass at the Scrub Oaks mine forms the host for the important Scrub Oaks ore body; this sheet is bordered on both sides by green microantiperthite granite. (See figs. 34 and 35.) Another small body at the Richards mine contains the low-grade Hilltop magnetite deposit. A body, unusually variable in composition, is exposed sporadically in Timber Brook valley, north of Splitrock Pond (pl. 1). The variability in composition can be seen near the Wood mine; here the granite contains discontinuous zones, a few feet thick, rich in biotite, hornblende, or pyroxene, and at places abundant rutile. Diopside skarn occurs along the west contact at one place. A body of albite-oligoclase granite, interleaved with abundant amphibolite layers, is well exposed at the Beach Glen mine. At places the granite contains irregular clusters of hornblende and pyroxene, spatially related to the inclusions, and abundant albite-quartz pegmatite.

The inclusions are mostly conformable to the structure of the granite. The contacts of the inclusions at most places are sharp, but at other places they are gradational; and there is considerable variation in the character of the contacts in different bodies. Not uncommonly the included rocks are shredded and disintegrated; and adjacent to these masses the granite typically is enriched in mafic minerals.

PETROGRAPHY AND CHEMICAL COMPOSITION

Albite-oligoclase granite consists essentially of plagioclase of the composition An_8 to An_{15} and quartz with lesser quantities of microantiperthite and microcline. A few percent of clinopyroxene and hornblende, and rarely biotite, are found locally as varietal minerals, but these minerals are sparse to absent in typical facies of the granite. Muscovite, magnetite, rutile, and zircon are common accessory minerals. The approximate modes of representative specimens of alaskitic facies, the principal facies of the rock, are given in table 7.

The granite is commonly a pink to buff, medium-grained, equigranular, leucocratic rock that is tan, or even white, on weathered surfaces. At the Scrub Oaks

TABLE 7.—*Approximate modes (volume percent) of albite-oligoclase granite*

	S424	DE53
Plagioclase	72	78
Quartz	27	18
Microcline	.5	2
Muscovite	.2	1.0
Magnetite	.2	Tr.
Hematite		1.0
Zircon	.1	
Total	100.0	100.0
Average grain diameter,[1] in millimeters	0.4	0.85

[1] Average grain intercept measured by mechanical stage; not true grain diameter. Actual diameter is somewhat larger.

S424 Albite-oligoclase granite, from west side of Charlottesburg road, a mile north of upper end of Splitrock Pond, Boonton quadrangle. Plagioclase has the composition An_8.

DE53 Albite-oligoclase granite, taken a third of a mile northeast of Lake Telemark, Boonton quadrangle. (For chemical analysis see table 8.) Plagioclase has the composition An_{14}.

mine it is locally distinctly red owing to tiny inclusions of hematite in the plagioclase that tend to be oriented parallel to the (010) direction.

The plagioclase characteristically forms subhedral laths that are clear and well-twinned. In the contact zones the plagioclase frequently shows checkerboard twinning. Microantiperthite may constitute a part of the feldspar, and microcline is almost always present in amounts of as much as 3 percent, occurring as interstitial anhedral grains that embay the plagioclase. Quartz occurs as tiny grains included within plagioclase and as interstitial grains. In recrystallized parts of the granite the quartz typically forms elongate aggregates whose length is several times the average diameter. It may contain abundant tiny red inclusions, presumably hematite.

Muscovite is a common and diagnostic accessory in much of the granite, as at the Scrub Oaks mine, although it nowhere constitutes more than 2 percent of the rock. Zircon and opaque iron oxides are ubiquitous, being present as sparsely disseminated subhedral to euhedral grains. Rutile is locally a prominent accessory. Sphene, apparently derived from the assimilation of wall rock, is found in association with those facies of the granite that contain several percent of pyroxene as a varietal mineral.

TABLE 8.—*Chemical analyses and norms of oligoclase-quartz-biotite gneiss and albite-oligoclase granite*

	28C-1	DE53	Y
Chemical analyses			
SiO_2	67.96	68.81	77.53
Al_2O_3	16.13	17.65	13.60
Fe_2O_3	.36	.85	.23
FeO	2.04	.36	.16
MgO	2.00	.20	Tr.
CaO	1.53	.71	.73
Na_2O	6.54	7.77	6.65
K_2O	1.78	1.83	1.20
H_2O+	.52	.66	.18
H_2O-	.08	.14	.15
TiO_2	.87	.69	.16
P_2O_5	.02	.07	.03
MnO	.01	Tr.	Tr.
CO_2	----	----	Tr.
Total	99.84	99.74	100.62
Norms			
Quartz	15.87	15.72	32.84
Orthoclase	10.56	10.56	7.23
Albite	55.23	64.98	56.07
Anorthite	7.51	3.06	3.43
Corundum	.63	1.94	.07
Ilmenite	1.67	.76	.30
Hypersthene	6.85	.50	----
Magnetite	.46	----	----
Hematite	----	.80	.24
Rutile	----	.32	----
Apatite	.03	.17	.06
Normative plagioclase	$Ab_{88}An_{12}$	$Ab_{95}An_5$	$Ab_{94}An_6$

28C-1. Oligoclase-quartz-biotite gneiss, half a mile northeast of New Leonard shaft, Mount Hope mine, Dover quadrangle. Analyst: E. Chadbourn.

DE53. Albite-oligoclase granite, a third of a mile northeast of Lake Telemark, Boonton quadrangle. Analyst: E. Chadbourn.

Y. White Losee diorite gneiss [albite granite], little knob about a mile northeast of Berkshire valley, Lake Hopatcong quadrangle. Analyst: W. T. Schaller. Reference: Bayley, 1910, p. 121.

Most of the granite is gneissoid but there is some variation within individual masses and from one mass to another. The gneissoid granite is characterized by an interlocking texture; locally, particularly where the granite is the host rock for ore, it has a cataclastic texture; and here and there the quartz is recrystallized into long fingerlike masses that have unequal extinction.

The chemical composition and norm of a specimen of albite-oligoclase granite is given in table 8; the mode is given in table 7. For comparison a specimen from the Lake Hopatcong quadrangle is included. It is noted that the specimen from the Lake Hopatcong quadrangle has a higher SiO_2 content and a correspondingly lower content of Al_2O_3, FeO, MgO, and alkalies.

ALBITE-QUARTZ PEGMATITE

CHARACTER AND DISTRIBUTION

Pegmatite composed essentially of albite and quartz commonly is associated intimately with the albite-oligoclase granite. At many places the pegmatite appears to be simply a coarse-grained facies of the albite-oligoclase granite. Albite-quartz pegmatite occurs with albite-oligoclase granite at the Hibernia, Scrub Oaks, and Beach Glen mines. At the Scrub Oaks mine it forms irregular masses of variable composition, ranging from a syenite to a quartz-rich granite pegmatite. Little is known of pegmatites at the other mines, for the workings are entirely inaccessible and the available specimens are from dumps. Some pegmatites are found locally as small lenses and sheets interleaved with country rocks distant from known ore deposits.

PETROGRAPHY

The albite-quartz pegmatite is a generally red coarse-grained rock that is simple in mineralogic character. In addition to albite and quartz, hornblende, or more rarely pyroxene, locally constitutes as much as 10 percent of the rock. The albite is red and in the specimens studied it has the composition An_6. The quartz, which varies in amount even within a single small exposure from almost nil to 50 percent or more, forms irregular grains that interlock with the albite. The mafic minerals, hornblende and pyroxene, occur as large subhedral to euhedral crystals. Their distribution is erratic and they are most abundant adjacent to amphibolitic rocks; they are almost completely absent in pegmatites within uncontaminated albite-oligoclase granite. Epidote, commonly a sparse accessory, locally constitutes about 5 percent of the rock. Magnetite, which appears to be secondary, is found in pegmatites at the Scrub Oaks mine as a mineral so variable in quantity that locally it is of such abundance as to constitute low-grade ore.

The texture of the pegmatites is characteristically marked by interlocking quartz and feldspar crystals. Locally, mortar structure indicates some cataclastic deformation of this rock unit.

HORNBLENDE GRANITE AND RELATED FACIES

Hornblende granite and related facies, the youngest of the pre-Cambrian igneous rocks, occupy an estimated 30 percent of the mapped area.

Six facies of the granite—hornblende granite, hornblende granite gneiss, alaskite, microantiperthite granite, biotite granite, and granite pegmatite—are sufficiently distinct to warrant separate discussion, and 4 of these are distinguished on plate 1; microantiperthite granite and pegmatite were not mapped as separate units. In addition the bodies of hornblende granite and alaskite that contain more than 20 percent of metasedimentary inclusions are distinguished separately.

HORNBLENDE GRANITE

DISTRIBUTION AND OCCURRENCE

Hornblende granite, the most abundant granite facies in the Dover district, forms numerous large bodies interpreted as sheets and phacoliths (see p. 52), and is widely distributed. A large body of hornblende granite encloses the Wharton ore belt, and adjacent to the ore belt a wide alaskite facies is developed. This body of granite is well exposed north of the terminal moraine but is mostly covered south of it; its south end is overlapped by sedimentary rocks of Paleozoic age. Northward this body of granite can be traced around the nose of Telemark anticline and the keel of Splitrock Pond syncline. A thin, elongate sheet of hornblende granite, containing local bodies of alaskite, crops out along the eastern part of the district, from Mount Freedom northward to beyond Lake Kinnelon. Intercalated with the granite, and locally splitting it, are masses of amphibolitic rocks and quartz diorite. In contrast to the other granite masses in the district, this body is locally composed of hornblende-pyroxene granodiorite (S521, table 9). In the area north of Lake Kinnelon conformable lenticular sheets of homogeneous hornblende granite are associated with quartz diorite, and one of these sheets definitely intrudes the quartz diorite.

CHARACTER

The hornblende granite is a buff, but locally pinkish to whitish, medium- to coarse-grained, generally equigranular rock that weathers to brown, tan, or white. Beneath the weathered surface, the rock may be reddish to a depth of half an inch or less. Outcrops are generally smooth and rounded, though where the rock is coarse-grained, a rough surface may be produced by weathering. Many exposures appear massive because of the homogeneity of the granite. The granite is generally more uniform in mineralogic composition and texture than the other igneous rocks in the area. Many exposures are free from inclusions of older rocks, but others are streaked with them. Where inclusions are present, they are essentially conformable. Irregular masses and streaks of pegmatite commonly cut the granite.

PETROGRAPHY

The hornblende granite in the individual bodies is remarkably uniform in composition and texture. Typically, it is a uniform, equigranular, medium- to coarse-grained, gneissoid rock (pl. 16*B*); but adjacent to inclusions and along its borders it locally is gneissic. Except in areas of intense postcrystallization deformation, the microperthite, quartz, hornblende, and other mineral grains interlock to produce a typical igneous fabric. Microperthite, the predominant feldspar, ranges in amount from 35 to 65 percent. Plagioclase (oligoclase) is always present, and its abundance in general is in inverse proportion to the quantity of microperthite present. Quartz averages about 25 percent. Hornblende, probably ferrohastingsite, is the only common ferromagnesian mineral and constitutes from 5 to as much as 11 percent of the rock. In a few places, the hornblende has altered to biotite. Pyroxene, both augite and hypersthene, occurs in the sheet that crops out north of Cedar Lake (Boonton quadrangle); and locally these are the only mafic minerals present. Magnetite, apatite, and zircon are sparsely disseminated accessory minerals. Epidote and, more rarely, garnet and sphene are present in some varieties of the granite. Modes of representative specimens from different masses of the hornblende granite are given in table 9.

The potash feldspar in the microperthite is largely microcline; some possibly is orthoclase. As can be seen in plate 16*B*, a photomicrograph of a typical specimen, the plagioclase is in rods and strings (Alling, 1938, p. 142–147); the rods have a length-breadth ratio of about 2:1. There is some variation in the proportion of plagioclase in the intergrowths; in general, the quantity of plagioclase in the intergrowths varies inversely with the quantity of plagioclase in the rock, thus the bulk composition of the rock remains essentially the same, despite the differences in mineralogic composition. As Alling has noted, the rod-shaped plagioclase blebs are absent at the extreme margins of a potash feldspar grain, leaving that area free for strings and stringlets. Halos around quartz inclusions in the microperthite grains generally contain no plagioclase blebs. Replacement types of perthite, as defined by Alling, are entirely absent.

TABLE 9.—*Approximate modes (volume percent) of hornblende granite and granodiorite*

	S121-48	DB2	S341	D223	S356	DF92	S521
Microperthite	46	46.5	47	51	43	41	27.5
Quartz	28.5	26	25	23	25	25.5	18
Plagioclase, including myrmekite	18	22	18	19.5	28	21.5	37
Hornblende	7	5.5	10	6	2	11	5.5
Pyroxene							2.5
Magnetite	.5		Tr.	.5	.5		4
Apatite	Tr.		Tr.		Tr.	.2	.5
Zircon	Tr.		Tr.	Tr.		.1	Tr.
Biotite	Tr.						1
Epidote					1.5		4
Sphene						.7	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average grain diameter,[1] in millimeters	0.35	0.57	0.40	0.43	0.41	0.38	0.40

[1] Average grain intercept measured by mechanical stage; not true grain diameter. Actual diameter is somewhat larger.

S121-48. Hornblende granite, from hill half a mile east of Marcella, near the axis of Telemark phacolith, Boonton quadrangle.
DB2. Hornblende granite, from small outcrop on Denmark road, opposite north end of Lake Denmark, Dover quadrangle.
S341. Hornblende granite, from hill half a mile west of Mount Freedom, Mendham quadrangle. Microperthite is predominantly microcline. Some myrmekite is included with plagioclase.
D223. Hornblende granite, from small knob west of Lake Denmark. Dover quadrangle. Microperthite is predominantly microcline.
S356. Hornblende granite, from hill half a mile southwest of Ironia, Mendham quadrangle.
DF92. Hornblende granite, from hill a third of a mile south of Marcella, Boonton quadrangle. Hornblende is partly altered to chlorite and magnetite.
S521. Granodiorite, from hornblende granite sheet on crest of hill on west side of Cedar Lake, Boonton quadrangle. The pyroxene includes both augite and hypersthene. Biotite is secondary after hornblende.

The plagioclase has the composition of oligoclase (An_{12-19}). It alters more readily than the potash feldspars, and in weathered specimens it is commonly somewhat altered to clay; less commonly it is sericitized. Microantiperthitic intergrowths of potash feldspar in plagioclase are absent. Myrmekite is common, especially near metasedimentary inclusions, where it is more abundant adjacent to microperthite grains.

Quartz has two modes of occurrence. (See pl. 16*B*.) Small generally rounded grains with uniform extinction are present as inclusions within the feldspars; larger grains, frequently amoeboid in shape and usually showing slight undulatory extinction, are intergrown with the feldspar. The difference in occurrence suggests two distinct generations: an early and a late quartz.

The hornblende is a very dark green to black variety, nearly opaque in thin section, that has the following optical properties: The optic angle is estimated at 45°–50°, and the absorption formula is $Y \gtreqless Z > X$. X=yellowish green, Y and Z=dark green. The dispersion of the optic axes is strong with $r<v$. Its color and optical properties indicate that the hornblende is either femaghastingsite or ferrohastingsite, probably the latter. The alteration products of the hornblende are variable. A few specimens show incipient alteration to biotite. More commonly, though, hornblende alters to chlorite (var. penninite) and magnetite, with the opaque mineral occurring as irregular rods and worm-like masses within the chlorite. Some hematite is locally formed as an alteration product.

The accessory minerals—opaque iron oxides, apatite, zircon, epidote, and sphene—constitute a small percent of the rock. Magnetite is commonly subhedral, but is in part euhedral. Apatite and zircon are frequently euhedral; in a few places the zircon is zoned. Garnet is present in a few exposures as sparsely disseminated grains, probably resulting from reaction between granitic solutions and small metasedimentary inclusions.

CHEMICAL ANALYSES

The chemical analysis and norm of a typical specimen of hornblende granite from the Dover district are given in table 10. For comparison an analysis of normal Storm King granite of Berkey (1907) from Bear Mountain, N. Y. (Lowe, 1950, p. 146), and of hornblende granite from the Lowville quadrangle, New York (Buddington, 1939, p. 138), are included.

The close chemical and mineralogic similarities of these granites from three widely spaced localities in the eastern United States are readily apparent. The

TABLE 10.—*Chemical analyses and norms of hornblende granite and alaskite*

	S156-48	133	Storm King granite (of Berkey)	1	137-L
Chemical analyses					
SiO_2	74.89	70.72	73.35	77.07	76.41
Al_2O_3	12.33	13.11	13.07	12.61	12.41
Fe_2O_3	.69	1.85	.74	.71	1.01
FeO	1.50	1.97	2.29	.73	.50
MgO	.16	.50	.08	Tr.	.46
CaO	.91	1.36	1.11	.87	.78
Na_2O	2.95	3.35	2.98	3.43	3.34
K_2O	5.38	5.60	5.62	4.06	4.33
H_2O+	.35	.37	.23	.62	.34
H_2O-	.10	.06		.23	.13
TiO_2	.21	.41	.20	.12	.03
P_2O_5	.04	.23	.06	Tr. ?	
MnO	.03		.03	.09	.06
CO_2				Tr.	
Total	99.54	99.53	99.76	100.54	99.80
Norms					
Quartz	34.18	26.46	30.70	39.12	37.95
Orthoclase	31.69	33.36	33.25	24.46	25.58
Albite	25.15	28.30	25.15	28.82	28.30
Anorthite	4.17	4.17	5.14	4.45	3.89
Corundum	.31		.18	.92	.82
Diopside		.93			
Hypersthene	2.30	2.25	3.51	.79	1.23
Magnetite	.93	2.65	1.07	.93	1.39
Ilmenite	.46	.77	.38	.15	
Apatite	.10	.58	.13		
Water	.45		.23	.85	

S156-48. Hornblende granite, from small rounded knob on hill three-fourths of a mile east of upper end of Splitrock Pond, Boonton quadrangle. Contains a trace of magnetite. Analyst: E. Chadbourn.
133. Hornblende granite, taken 1⅕ miles north-northeast of Bushs Corners, Lowville quadrangle, New York (Adirondack Mountains). Analyst: R. B. Ellestad. Reference: Buddington, 1939, p. 138.
Storm King granite (of Berkey). Hornblende granite, from Perkins Memorial Drive, Bear Mountain, N. Y. Analyst: L. C. Peck. Reference: Lowe, 1950, p. 146.
1. Light-colored Byram gneiss (alaskite), from quarry a mile west of Hibernia. Analyst: W. T. Schaller. Reference: Bayley and others, 1914, p. 9.
137-L. Hornblende alaskitic granite, from Mount Morris, Long Lake quadrangle, New York. (Adirondack Mountains). Analyst: E. W. Morley. Mode given in table 11. Reference: Buddington, 1939, p. 138.

Storm King granite, in particular, is in every respect analogous chemically, as well as mineralogically, to the hornblende granite of the Dover district, and is believed to correlate with it. The low value for MgO and the correspondingly low ratio of MgO to FeO reflects the negligible MgO content of the ferrohastingsite.

HORNBLENDE GRANITE GNEISS

OCCURRENCE AND CHARACTER

The hornblende granite gneiss, noted at three localities in the Dover district, is a deformed facies of hornblende granite that contains microcline and albite-oligoclase instead of microperthite.

One body of this gneiss crops out along the steep outer slope of the hill at the southwest end of Splitrock Pond, and excellent exposures can be seen along the east side of Hibernia road. The hornblende granite gneiss occurs as an elongate crescent-shaped mass, less than 300 feet wide and about a mile long, that parallels the structural trend of the adjacent rocks (pl. 1). Numerous thin layers of biotite-quartz-plagioclase gneiss are included within the hornblende granite gneiss. The granite gneiss appears to grade outward into the enclosing hornblende and biotite granites.

Another mass of similar character is exposed on the west slopes and crest of the north-trending hill east of the upper end of Splitrock Pond. This mass consists of two separate sheets, separated by a layer of biotite-quartz-plagioclase gneiss, that wrap around the nose of the sharply overturned Cobb anticline (pl. 1). Small isolated deformed granite lenses also occur in hornblende granite near the nose of the same anticline, about 1,000 feet south of the small pond west of Stickle's Pond. A very strong lineation, marked by quartz pencils and rods, characterizes these rocks.

The hornblende granite gneiss is a gray, buff, or greenish-gray rock that has a pronounced gneissic structure. It is cut by numerous thin seams of pink granite pegmatite, pegmatitic granite, epidote, and carbonate, and consequently has a remarkable banded appearance. The pegmatitic granite bodies are generally thin, a fraction of an inch to about 2 inches wide, closely spaced, and lenticular. For the most part the granite pegmatites are concordant with the foliation, but locally they crosscut the preexisting structure. The compositional banding produces a very pronounced ribbing on weathered surfaces. Locally, tiny vugs, formed by the leaching of carbonate from the rock, give weathered surfaces a somewhat spongy appearance. In some exposures the hornblende granite gneiss appears to have been sheared, and subsequently healed by pegmatite.

PETROGRAPHY

The hornblende granite gneiss is a highly variable, inequigranular gray or greenish-gray to buff rock with a pronounced gneissic structure. It has a granoblastic to a flaser texture. The rock is always migmatitic. The mineralogic and textural characteristics are so different from those of the normal gneissoid hornblende granite that the two rocks can be readily distinguished in the field.

The hornblende granite gneiss consists chiefly of quartz, microcline, and albite or oligoclase, with varietal hornblende. Epidote and sphene are diagnostic secondary minerals.

The feldspars—microcline and sodic plagioclase—are present as discrete grains. Microperthite is entirely absent. Microcline usually occurs as polygonal grains from about 0.2 mm to 0.5 mm in diameter. Locally porphyroblasts about 1 mm in diameter are surrounded by a comminuted groundmass consisting principally of sutured quartz and scattered epidote aggregates. The microcline in part has a well-developed grid structure, but locally that structure has been wholly to partly obliterated by cataclastic deformation, and extinction of the twin bands under crossed nicols is shadowy rather than sharp. The plagioclase has the composition of albite or oligoclase and is, for the most part, highly altered, either to sericite, kaolinite, or both. Locally it is replaced by epidote. Twinning is generally visible, but the twin bands are wide, quite unlike the closely spaced twinning in undeformed hornblende granite. A few scattered grains of myrmekite are present. The plagioclase is veined or embayed by microcline in a few places, to form a small amount of vein antiperthite.

Quartz in the granulated groundmass is in sutured grains and in leafy aggregates whose length is several times their width. Some specimens with a pronounced lineation contain quartz leaves and pencils as much as 4 cm long. Each leaf commonly has a uniform extinction under crossed nicols. In most specimens the quartz leaves and pencils show strain shadows.

The hornblende, as much as 7 percent of the rock, is a bluish-green variety. It is strongly pleochroic and has a strong dispersion of the optic axes; the dispersion formula is $r>v$. Epidote occurs as coarse aggregates and anastomosing veinlets that comprise a few percent, locally as much as 40 percent, of the rock. A little chlorite and calcite generally are intergrown with epidote. Epidote locally has pervasively invaded the rock along foliation planes and along the joint surfaces that trend nearly at right angles to the foliation. Sphene is an ubiquitous constituent of the rock that can be seen in most hand specimens; in many it occurs in part as reaction rims around small magnetite grains. Muscovite and sericite are late minerals that replace plagioclase. Apatite, magnetite, and a few sparsely disseminated grains of zircon occur as common minor accessory minerals.

ALASKITE

OCCURRENCE AND DISTRIBUTION

Alaskite is more restricted in occurrence than hornblende granite, but it is nevertheless abundant. It occurs at and near the contacts of hornblende granite with country rock and along the anticlinal crests of large folds (pl. 1).

An elongate belt of alaskite, at places more than half a mile wide, encloses the oligoclase-quartz-biotite gneiss that contains the important magnetite deposits in the Wharton ore belt. Alaskite, near the roof and nose of Hibernia anticline, attains a width at the surface of nearly half a mile. Numerous layers and wisps of amphibolite and related metasedimentary rocks are intercalated with the alaskite. Southwest of this anticlinal mass, in the town of Dover, a sheet of alaskitic granite crops out, but the presence of some hornblende and pyroxene in the rock suggests that the mass may have a closer affinity to hornblende granite. Northeast of Cooks Lake a coarse-grained facies of alaskite forms the core of an anticline whose limbs are biotite-quartz-feldspar gneiss. Another small variable body of alaskite, intercalated with quartz diorite and amphibolitic rocks, crops out north of Lake Kinnelon.

CHARACTER

Alaskite is a white, tan, or buff, medium- to coarse-grained gneissoid rock. Weathered surfaces tend to be smooth and appear massive. The foliation is poor to excellent and is most prominent where inclusions of amphibolite are abundant. Adjacent to inclusions and contacts, quartz rods and pencils produce a marked lineation.

The contacts of alaskite with amphibolite for the most part appear sharp megascopically. Thin sections of contact zones, however, show that the hornblende adjacent to the contact is reconstituted to augite and that a few percent of pyroxene and plagioclase occurs in the alaskite. These mineralogic changes presumably were produced by the assimilation of amphibolitic material.

Alaskite is generally conformable to the gneissic structure of the country rock, but in a few places it cuts across the structure of the country rock on a small scale. Inclusions of the wall rock conform both to the structure of country rock and to the foliation and lineation of the alaskite. These inclusions tend to be lenticular, but in places they are extremely angular.

PETROGRAPHY AND CHEMICAL COMPOSITION

Alaskite differs mineralogically from hornblende granite mainly in the nearly complete absence of hornblende. The texture of the two granites is in all respects similar; the feldspars, quartz, and other minerals interlock to produce a typical igneous fabric. Modal analyses of typical specimens of alaskite are listed in table 11.

TABLE 11.—*Approximate modes (volume percent) of alaskite and biotite granite*

	DE37	24C	DA88	137-L	DG40
Microperthite	46	30	46.5	61.74	40
Quartz	29	31	33	34.57	30
Plagioclase	24	31	20	2.01	24
Hornblende	1			1.13	1.5
Magnetite		5		.34	
Biotite		.5	Tr.		4.0
Garnet					.5
Apatite		.5	Tr.		Tr.
Chlorite		1.5	.5		Tr.
Zircon		.5		.18	
Sphene				.03	
Total	100.0	100.0	100.0	100.00	100.0
Average grain diameter,[1] in millimeters	0.45	0.40	0.53		0.31

[1] Average grain intercept measured by mechanical stage; not true grain diameter. Actual diameter is somewhat larger.

DE37. Alaskite, from hill half a mile north of Hibernia, Boonton quadrangle.
24C. Magnetite alaskite, from Mount Hope mine, Dover quadrangle. Plagioclase has the composition An_{20}.
DA88. Alaskite, from south end of ridge half a mile northwest of upper end of White Meadow Lake, Dover quadrangle.
137-L. Hornblende alaskitic granite, from Mount Morris, Long Lake quadrangle, New York. Hornblende is chloritized. Chemical analysis and norm given in table 10. Reference: Buddington, 1939, p. 138.
DG40. Biotite granite, taken a third of a mile southwest of lower end of Splitrock Pond, Boonton quadrangle. Most of the hornblende is altered.

Microperthite is the most abundant mineral, constituting 30 to 50 percent of the rock. In places, however, microantiperthite is the chief feldspar. Quartz is somewhat more abundant than in hornblende granite; the average is about 30 percent. Plagioclase of the composition An_{15} to An_{20} constitutes 20 to 30 percent of the rock and in part shows chessboard twinning.

Hornblende, pyroxene (augite), and biotite are variable minor components whose presence is believed to have resulted from contamination by metasedimentary rocks. The hornblende differs considerably from the ferrohastingsite in the hornblende granite; it is light green, and similar to the hornblende in the amphibolites.

The minor accessory minerals—opaque iron oxides, allanite, apatite, and zircon—are found as sparsely disseminated subhedral and euhedral grains. In some areas magnetite constitutes several percent of the rock. Allanite was observed in coarse-grained phases of alaskite, particularly adjacent to magnetite deposits. Chlorite is present as an alteration product of hornblende.

The chemical composition of a specimen from the alaskite mass that forms the core of Hibernia anticline is given in table 10. Bayley (1914, p. 9) does not give a modal analysis for the rock, but specimen DE 37, collected by the writer from the same mass (table 11), is probably similar mineralogically, and it consists predominantly of microperthite, quartz, and sodic plagioclase. Mafic components total only about 1 percent of the rock. An analysis of hornblende alaskitic granite from Mount Morris, N. Y., in the Adirondack Mountains (137–L, table 10), is given for comparison. For chemical analyses of other alaskites from New Jersey the reader is referred to Parker (1948).

A comparison of the chemical analyses of alaskite with hornblende granite shows that SiO_2 and FeO are somewhat lower than in the granite.

MICROANTIPERTHITE GRANITE

OCCURRENCE AND DISTRIBUTION

Microantiperthite granite, so far as known, principally forms narrow, roughly linear masses in the contact zones between alaskite or hornblende granite and rocks containing abundant sodic plagioclase—either albite-oligoclase granite or oligoclase-quartz-biotite gneiss. It also occurs as local isolated masses in bodies of alaskite. Because of its limited extent and intimate association with, and megascopic similarity to, alaskite, microantiperthite granite was mapped with alaskite (pl. 1). The microantiperthite granite, however, is distinguished on plate 10 and figures 34 and 35 at the Scrub Oaks mine.

Microantiperthite granite constitutes an integral part of the alaskite sheet that encloses the magnetite deposits in the Wharton ore belt. At the Cogill mine, a small deposit near the northeast end of the Wharton ore belt (3, pl. 1), microantiperthite granite forms an envelope around the ore body. At the Mount Hope and Richard mines it occurs near the contacts of alaskite with oligoclase-quartz-biotite gneiss. Farther to the southwest, in the vicinity of the Irondale group of deposits, microantiperthite granite is exposed at the surface in a few places and forms the host rock for some of the ore deposits. The field relations of the microantiperthite granite to ore deposits and to alaskite in this area are not well known, except locally, because of the sparse exposures and the difficulties in megascopic recognition of the rock. At the Randall Hill mine, where exposures are fairly good, the microantiperthite granite appears to grade into alaskite. The gradation is marked by a change in the dominant feldspar from microperthite in alaskite to microantiperthite in microantiperthite granite. At the Scrub Oaks mine microantiperthite granite forms an envelope around albite-oligoclase granite, the principal host rock for the Scrub Oaks deposit (pl. 10 and figs. 34, 35).

Outside of the Wharton ore belt microantiperthite granite was observed at the contact between hornblende granite and albite-oligoclase granite, near the crest of Hibernia anticline; and locally as the host rock of some of the ore deposits in the Dalrymple ore belt (pl. 1).

CHARACTER

The microantiperthite granite is similar in appearance to alaskite, and the two rocks generally cannot be distinguished megascopically. The microantiperthite granite is a buff, tan, or green medium-grained rock that weathers whitish. Certain facies are devoid of mafic components; others contain visible hornblende or augite. Commonly the mafic minerals are partly or entirely chloritized.

The contacts between this granite and the albite-oligoclase granite and alaskite appear gradational; the principal change is the variation in the principal type of feldspar. Inclusions of amphibolitic rocks in the microantiperthite granite are uncommon; where present they are generally not sharply delineated, as they are in alaskite, but are wisps and schlieren that appear to have been modified to a considerable extent by the granite magma.

PETROGRAPHY

The ratios of the essential minerals in microantiperthite granite—microantiperthite, plagioclase, and quartz—vary considerably. Hornblende and augite are local varietal mafic minerals.

There are several distinctive types of microantiperthite in the granite. One common type, characterized by uniformly oriented rods or strings (Alling, 1938, p. 144), resembles at first glance the microperthite of the alaskite. The blebs or films, however, tend to be thinner and longer in microantiperthite and frequently constitute as much as 40 percent, or locally more, of an individual grain. A similar type of microantiperthite has irregular curved oriented blebs that interlock and bifurcate. In this type the potash feldspar blebs generally form about 25 percent of the grain.

Other, more varied types of microantiperthite are present in the granite, particularly near its contacts. These types are similar to the plume and patch perthites described by Alling (1938). Plume microantiperthite was observed in specimens from the dump at the Canfield mine (42, pl. 1). In this type, veins of potash feldspar appear to embay the plagioclase host. A more common type—patch microantiperthite—is abundant near the contacts of the microantiperthite granite. This type is characterized by irregular patches of microcline that embay and corrode the plagioclase host. In places, islands of the plagioclase that are in optical continuity remain in the microcline, indicating that these are remnants of a former large single grain. In contrast to the microantiperthites with uniformly oriented rods or strings, the patch microantiperthite contains highly variable quantities of potash feldspar. Potash feldspar constitutes more than 50 percent of the total feldspar in some parts of the granite, but it constitutes as little as 5 percent in other parts. A type of patch microantiperthite that is characterized by veins and irregular patches of microperthite that embay and corrode the plagioclase host was observed near the Randall Hill mine (36, pl. 1). This type occurs near the contact of the microantiperthite granite with alaskite.

The plagioclase in the granite is albite-oligoclase. A few grains clearly exhibit albite twinning, but a very large percentage of the plagioclase is poorly twinned or cloudy. Chessboard twinning is common and invariably is associated with the patch, plume, and film types of microantiperthite, and cloudy plagioclases.

The quartz in microantiperthite granite occurs in a variety of forms, depending largely upon the texture of the rock. In gneissoid facies of the granite it forms generally equidimensional anhedral grains. In gneissic facies it occurs as elongate spindles and tapering lenses 3 to 5 mm long. Individual lenses may extinguish as a unit and exhibit little or no evidence of strain. Other lenses, however, show strain shadows and local crushing.

Pyroxene (augite) is the most common varietal mafic component. It is a medium-green, pleochroic variety that alters readily to chlorite and a reddish-brown amorphous substance. In rare cases it alters to uralite. The amphibole is pale green to bluish green. The dispersion of optic axes is distinct, with $r>v$. The optic angle is always large and is estimated to be near 80°. The accessory constituents—opaque iron oxides, apatite, zircon, and more rarely sphene—occur in minute, sparsely disseminated, euhedral to subhedral grains. Where microantiperthite granite is host for ore, magnetite is abundant and was introduced by ore-forming solutions.

The texture of the granite is variable, ranging from granoblastic to interlocking. In ore zones, where microantiperthite grains form the host rock for magnetite, the granite is always crackled and in places exhibits mortar structure produced by cataclastic deformation.

BIOTITE GRANITE

OCCURRENCE AND CHARACTER

Biotite granite is closely related to the hornblende granite but is restricted in its occurrence to areas containing biotite-quartz-plagioclase gneiss.

The only biotite granite mass of any importance in the Dover district is southwest of the lower end of Splitrock Pond, in the axial area of Splitrock Pond syncline (pl. 1). The mass is lenticular and consists predominantly of biotite granite with numerous thin layers and schlieren of biotite-quartz-feldspar gneiss and amphibolite, and an occasional layer of hornblende granite. The biotite granite is bordered on the north by migmatized amphibolite and hornblende granite gneiss, on the south by hornblende granite and amphibolite. The biotite granite lenses out at both ends into hornblende granite.

The granite has a prominent foliation formed by parallel biotite flakes and by flat leaves of quartz and feldspar. The granite is cut by thin, closely spaced seams of pegmatitic granite, and granite pegmatite, from a fraction of an inch to about 2 inches wide, that for the most part parallel the foliation; locally the seams are discordant. In some places the foliation planes and pegmatitic seams are crumpled and sharply bent into tiny drag folds. The limbs of the folds are locally transected by small shear faults with slight displacement.

A local facies of biotite granite containing microcline rather than microperthite was observed at two places: on the south slope of the hill south of Splitrock Pond and adjacent to the biotite-quartz-feldspar gneiss mass in the hanging wall of the Scrub Oaks mine. Each occurrence was associated with layers of the biotite-quartz-feldspar gneiss. The rock has a granoblastic texture.

PETROGRAPHY

The biotite granite is a buff, fine- to medium-grained rock that consists of interlocking grains of microperthite, quartz, and oligoclase, with variable quantities of biotite. In places hornblende constitutes a percent or more of the rock. The proportions of the essential minerals vary between wide limits, but the mode of DG 40 (table 11) probably represents a typical biotite granite. A few small red garnets are present. Apatite, zircon, and magnetite are sparsely disseminated accessory minerals.

Microperthite forms subhedral grains as much as 2 mm long. The intergrown albite occurs as strings and rods, as defined by Alling (1938), distributed uniformly throughout the grains. Both types of blebs occur in some grains. The plagioclase is generally accompanied by a few sparse grains of myrmekite. Microcline is absent except in one facies. Two generations of quartz occur: an apparently early quartz that forms subrounded inclusions in feldspar and a late quartz that occurs as interstitial grains.

The biotite is strongly pleochroic from reddish brown to yellow. It is fine grained and uniformly distributed throughout the rock, but occurs as coarse plates sparsely distributed throughout the pegmatitic facies of the rock. In all respects the biotite is similar to that present in biotite-quartz-feldspar gneiss. Green hornblende occurs in only a few places, and then it is partly to completely altered to biotite, or to chlorite and a dark reddish-brown amorphous mineral.

GRANITE PEGMATITE

DISTRIBUTION AND OCCURRENCE

Granite pegmatites that probably are genetically related to the hornblende granite are abundant and are found both in the granites and in the country rocks. Masses of pegmatite, from small bodies to masses 100 feet wide, occur in nearly every exposure of alaskite and hornblende granite. Statistically, pegmatite is more common adjacent to mafic inclusions and in the crests of minor anticlinal foldlike structures. For the most part, pegmatite is in irregular bodies, but it also occurs in comformable lenses and as tabular crosscutting dikes parallel to transverse joints. Pegmatite is found as intimate lit-par-lit layers in amphibolitic rocks and as highly irregular, crosscutting masses in biotite-quartz-feldspar gneiss. In this gneiss there is abundant evidence that the pegmatitic solutions permeated into and reacted with the country rock. Garnet selvages are common along the margins of these altered gneiss bodies, and the adjacent pegmatite contains abundant garnet and large subhedral hornblende xenocrysts.

Pegmatite is common in the vicinity of most of the ore bodies, either in the walls or as unreplaced masses within the ore; it is more abundant in the hornblende skarn deposits than in the deposits in oligoclase-quartz-biotite gneiss.

A feldspathic quartz vein, associated with pegmatite, on the 1,300 level near the bottom rock of the Major ore shoot (Mount Pleasant ore body), contains numerous euhedral crystals of zircon nearly an inch long, alined parallel to the mineral lineation in the country rock.

CHARACTER AND PETROGRAPHY

The granite pegmatite is a pink to buff coarse-grained rock that consists essentially of feldspar—principally microcline-perthite—and quartz. Plagioclase is a minor constituent. The pegmatites are homogeneous; no "complex" pegmatites are known in the district. Local concentrations of mafic minerals—hornblende or pyroxene—and garnet (almandite?) are locally abundant in pegmatites within biotite-quartz-feldspar gneiss. Minor accessory minerals—opaque iron oxides, allanite, and zircon—are found sparsely disseminated through the pegmatite. Allanite is easily distinguished by its pitchy appearance, radioactive halo, and prominent radial cracks.

The pegmatite is typically massive and nonfoliated. Inclusions have a random orientation. The pegmatite consists of interlocking grains of feldspar; evidences of granulation with or without recrystallization are lacking except in a few places where mortar structures are observed. The quartz may be strained and in part broken by cataclastic deformation.

AGE SEQUENCE OF THE IGNEOUS ROCKS

The igneous rocks definitely are younger than the metasedimentary rocks, for the metasedimentary rocks occur as inclusions in all the intrusive bodies and at places are intruded lit-par-lit or crosscut by them. The age relations among the igneous rocks, because they are generally conformable bodies, cannot be determined by crosscutting relationships and other megascopic features that are commonly used to date intrusive rocks; instead they are determined by lithologic, textural, and structural relations. The inferred sequence of intrusion, from oldest to youngest, is: quartz diorite and related facies, albite-oligoclase granite, and hornblende granite and related facies.

The quartz diorite and related facies are intruded lit-par-lit near the contacts of several bodies by alaskite and hornblende granite, but all contacts with the albite-oligoclase granite are conformable.

The contacts of albite-oligoclase granite against both quartz diorite and related facies and hornblende granite and related facies, are conformable. The albite-oligoclase granite, though, probably is younger than the quartz diorite, for the quartz diorite has been strongly deformed throughout the district and it is characterized by a texture that indicates that it has been thoroughly recrystallized. The albite-oligoclase granite, on the other hand, has been deformed only locally. The individual bodies have not been folded, and only in places have they been granulated and recrystallized. The common occurrence of micro-antiperthite granite in the contact zones between albite-oligoclase granite and hornblende granite and alaskite is a critical problem that must be resolved before the age relationships among the granites are known.

ORIGIN OF THE IGNEOUS ROCKS

The field data are interpreted by the writer to indicate that the igneous rocks consolidated from three separate magmas: namely, a magma of dioritic composition, a magma of the composition of soda granite, and a magma of the approximate composition of hornblende granite.

QUARTZ DIORITE AND RELATED FACIES

The quartz diorite and its related facies contain both monoclinic and orthorhombic pyroxenes, are even-grained granular rocks, and have a conspicuous compositional layering; and accordingly they are similar in many respects to rocks that have been included in the "charnockite series" (Holland, 1900; Quensel, 1952). The origin of rocks of this type has long been debated (see Quensel, 1952, p. 274–315), and there is no agreement among those who have studied them. In the Dover district the diorites are believed to be of igneous origin; possibly, as Goldschmidt (1922, p. 9) has suggested, they formed by primary crystallization from a relatively dry magma. Yet there is no evidence that they could not be the product of plutonic metamorphism (Tyrell, 1948, p. 313), perhaps with local mobilization, culminating in the development of a magma which was able to move upward. A feature of these rocks that can be interpreted as favoring an igneous origin is the occurrence of local crosscutting felsic layers.

ALBITE-OLIGOCLASE GRANITE AND ALBITE-QUARTZ PEGMATITE

The albite-oligoclase granite in the Dover district has much in common with soda granites in pre-Cambrian rocks elsewhere, and its origin is indeed a perplexing problem. To explain the derivation of rocks of this composition it seems to the writer that two principal hypotheses must be considered: (1) that the soda granite was formed by magmatic differentiation or (2) that it was derived by anatexis or differential fluxing. Goldschmidt (1922) has suggested that soda granite may be derived through absorption of water in a granitic magma, which causes crystallization of biotite; the sinking of the biotite crystals leaves the residual magma poor in potash. Geijer (1936, p. 155) and Sundius (1925, p. 35) favor differentiation in the fluid state of the magma to explain soda granites. Bowen (1928, p. 7–19), however, has presented arguments, based on experimental evidence, against limited miscibility in natural magmas.

The alternative hypothesis of an origin through anatexis has been proposed by Buddington to account for the small albite or oligoclase granite bodies in the Adirondack Mountains (Buddington, 1939, p. 170; 1948, p. 39). He recognizes that granitization may also contribute to the formation of soda granite (Buddington, 1948, p. 38).

In the Dover district the albite-oligoclase granite forms small bodies, widely dispersed, and it is definitely subordinate in volume to the hornblende granite and alaskite, probably not exceeding 10 percent of the total volume of the other granites. Associated with the albite-oligoclase granite is albite-quartz pegmatite. The smaller bodies of the granite are nearly always found intimately associated with amphibolitic rock and contain varietal pyroxene or hornblende.

Because of these features, the writer favors an origin for albite-oligoclase granite similar to that postulated by Buddington. Prior to the emplacement of the hornblende granite into the level now exposed by erosion, a magma of a composition near that of the albite-oligoclase granite was generated at depth by anatexis or differential fluxing of oligoclase-quartz-biotite gneiss and perhaps other rocks of similar composition. This magma rose to the present observed level during the period of orogeny that deformed the metasedimentary rocks, making its way largely by displacement, but locally it assimilated fragments of the country rock by incorporation. The extremely irregular distribution and variation in the quantities of hornblende, augite, and biotite probably is in itself an argument against their primary origin, for the albite-oligoclase granite is leucocratic, except locally adjacent to amphibolitic xenoliths or country rock. Granitization may well be responsible for a small proportion of the granite, particularly those small bodies found locally in intimate association with amphibolite, but the sodic fluids that produced these rocks must have emanated from nearby magma of similar composition, and not from depth.

Because of the intimate association with, gradation into, and similar mineralogic character of the albite-quartz pegmatite and the albite-oligoclase granite, the pegmatite is considered to be a late differentiate of the magma that consolidated to form the albite-oligoclase granite. In part the pegmatite appears to be a coarse-grained facies of the granite; hence it must have formed in a more aqueous environment. The hornblende and pyroxene crystals in the pegmatite, because of their abundance adjacent to amphibolitic inclusions, are thought to have been derived by assimilation and incorporation of the mafic rocks.

HORNBLENDE GRANITE AND RELATED FACIES

The writer interprets the hornblende granite and related facies to have formed predominantly by the differentiation of a magma of granitic composition, although some facies were formed in part by assimilation of metasedimentary wall rocks or granitization of wall rocks. During the waning stages of the Proterozoic orogeny a magma of granitic composition was emplaced into the previously consolidated rocks. For the most part the magma consolidated to form hornblende granite. A more mobile felsic differentiate of the magma, containing a high proportion of volatiles, developed locally in the crests of anticlinal structures and at the contacts with wall rocks, and consolidated as alaskite. At places where the alaskitic magma was in contact with solid (?) rocks containing abundant Na_2O—oligoclase-quartz-biotite gneiss and albite-oligoclase granite—microantiperthite granite was formed. At other places where the alaskitic magma was emplaced adjacent to, and within, solid bodies of biotite-quartz-feldspar gneiss, it reacted with and assimilated the gneiss to form biotite granite.

After the consolidation of most of the granite magma, metasomatic (?) solutions rose along the contact zones of the microantiperthite granite and altered the plagioclase of the granite and the adjacent wall rocks, forming patch and plume microantiperthites. The last differentiate of the granite to consolidate was granite pegmatite. It was emplaced at the end, and possibly in part after the cessation of the deforming stresses. Iron-bearing fluids derived from the alaskitic magma yielded the magnetite deposits in the district.

As stated above, the writer prefers to postulate a magmatic origin for most of these granitic rocks, but it is not possible to state categorically that the granites either were consolidated from a melt or were formed in place by granitization. As Buddington (1948) has recently pointed out, there are no criteria that are uniformly accepted as decisive tests to discriminate granites of igneous origin from those formed by granitization. Evidence is presented below, however, that seems to the writer to be more compatible with an igneous origin for the greater part of these granitic rocks. Evidences of metasomatic replacement in these rocks as outlined by Grout (1941, p. 1541–1553) are almost entirely absent. The principal criteria used by the writer for determining an igneous origin are listed below:

1. Internal homogeneity of granites and rather small differences between granite masses (see Chayes, 1950; 1952).
2. The presence of abundant microperthite, which generally is considered to be a high-temperature mineral (E. Spencer, 1938).
3. A texture whereby the quartz, feldspar, and other minerals interlock in the same manner as in the coarser grained volcanic rocks that have crystallized from lavas and in artificial melts rather than in the manner of minerals formed in rocks known to be of metamorphic or metasomatic origin.
4. The presence of unaltered inclusions of different rock types that have sharp boundaries with the enclosing rock.
5. Crosscutting relationships whereby the granite locally transgresses the gneissic structure of the enclosing rock.
6. Phacolithic form of granite masses (see Buddington, 1929).

HORNBLENDE GRANITE AND ALASKITE

Both the hornblende granite and the alaskite are interpreted as having formed by the differentiation of a magma of granitic composition. That the two types of granites were derived from the same source is indicated by the close-spatial association (see pl. 1) of the granites and their gradation into each other. The alaskite, because it occurs at the contacts and in the crests of anticlinal masses of granite and contains abundant pegmatite and included carbonate rocks that have been converted to skarn, probably is consolidated from a magma that contained a higher proportion of volatiles and was more mobile than the hornblende granite magma. The residual fluids of the alaskite magma yielded the magnetite deposits.

Both the hornblende granite and alaskite are remarkably uniform in composition throughout the district (see tables 9 and 11); the local and regional variations can be accounted for by differences in the degree of magmatic differentiation in slightly different structural environments. The contacts with inclusions of amphibolitic rocks are sharp; there is no clear evidence that the magma replaced their wall rocks during invasion. The granites transgress the foliation of the country rocks locally; but, because they are syntectonic, such phenomena are rare.

Both the hornblende granite and the alaskite contain microperthite as the dominant feldspar and, where undeformed, have a texture in which the essential mineral components are intergrown in the same manner as the minerals of the coarser grained volcanic rocks. The foliation and lineation are interpreted to be primary for the most part, but in a few places a secondary gneissic structure was superimposed upon the earlier primary one after complete consolidation of these rocks. Inclusions, which are commonly tabular and angular, are generally, but not always, oriented parallel to the internal primary structure of the hornblende granite or alaskite and to the contacts. The inclusions tend to be more abundant near the borders of the granitic bodies.

MICROANTIPERTHITE GRANITE

The microantiperthite granite is extremely heterogeneous in character and probably formed for the most part by crystallization from magma of alaskitic composition. The origin of these rocks is complex, however, and further studies on them are needed.

The microantiperthite that is characterized by generally regular intergrowths of potash feldspar and sodic feldspar (rod, string, and film types), which is typical of most of the microantiperthite granite, is thought to have been formed by a process similar to that which produced the more common microperthite. Possibly during cooling of the magma equilibrium in the melt was upset by reaction between the soda-rich country rock and the magma, causing potash feldspar to be exsolved from plagioclase, rather than the more common reverse process. This mode of formation is similar to that suggested by Anderson (1929, p. 200–205) to explain microantiperthites in pegmatites. He postulated that microantiperthite may result from simultaneous rhythmical crystallization of potash feldspar and plagioclase, accompanied by occasional resorption of one phase and the crystallization of the other phase in its place.

The plume and patch types of microantiperthite are, on the other hand, thought to be of probable replacement origin, because the potash feldspar appears to constitute a highly variable proportion of the total feldspar. It does not seem probable that deuteric rearrangement in a closed system could account for such highly variable rocks. More probably, the potash feldspar was introduced by hydrothermal(?) fluids from the cooling alaskite magma, which migrated upward along the contacts of the granite and replaced the completely or nearly completely crystallized plagioclase of the granite and locally also the plagioclase in the wall rocks.

The writer's interpretation of the origin of the various types of microantiperthititic intergrowths is in general accord with the views of Alling (1938, p. 164) on microperthites. He states:

> There is a definite relationship between the bleb shape, size, and origin. The small blebs, stringlets, strings and rods are the result of exsolution, accomplished through diffusion in the solid. The larger irregular blebs which are much less uniform in orientation are mainly due to replacement processes.

Kohler (1948, p. 55–59) also noted microantiperthite in the contact gneisses in granite masses in Southern Bohemia, and he concluded that the potash feldspar infiltrated into sodic plagioclase during periods of quiescence. He, however, does not believe that any types of antiperthite can form by unmixing.

Subsequent to the writer's studies A. F. Buddington studied the microantiperthite granites penetrated by drill cores at the Hibernia mine, and the results of his work are given later in this report.

BIOTITE GRANITE

The occurrence of biotite granite and its petrographic character strongly suggest that it formed primarily by assimilation and modification of biotite-quartz-feldspar gneiss. Biotite granite occurs only in intimate association with, and grades into, biotite-quartz-feldspar gneiss. The transition from granite to gneiss is marked principally by an increase in proportion of biotite and plagioclase, concomitant with a decrease in microperthite. The process of formation is thought to be as follows: At places where the alaskitic differentiate of the granite magma was emplaced into biotite-quartz-feldspar gneiss it was injected along planes of structural weakness. This facies of the granite magma was preceded, and perhaps accompanied, by hot, gaseous fluids, which permeated short distances into the gneiss and rendered it somewhat mobile; thus the separate identities of the original and introduced components were lost. Microperthite was introduced into the gneiss, and biotite was assimilated by incorporation from the gneiss. Local layers of the gneiss were not completely modified and these remain as inclusions within the biotite granite. Following consolidation of most of, if not all, the biotite granite, pegmatite was injected locally into and along the foliation planes, and subsequently both granite and pegmatite were locally slightly deformed by late deforming stresses.

This mode of formation does not differ materially from that proposed by several French geologists, notably Lacroix (1900, p. 26), to explain lit-par-lit gneisses. It also is similar to the process described by Fenner (1914) to explain the formation of certain gneisses in the New Jersey Highlands. Recently Prucha (1949, Doctorate dissertation, Princeton University) has suggested that the widespread Hermon (biotite) granite of the northwest Adirondacks was formed in a similar manner.

GRANITE PEGMATITE

The granite pegmatite associated with the hornblende granite and related granites contains perthite as the dominant feldspar, and it is interpreted to be the last differentiate of the magma that consolidated to form hornblende granite and alaskite. The pegmatite generally is undeformed and cuts across the gneissic structure of the granites and metasediments, indicating that it was emplaced at the end, and perhaps in part after the cessation, of the deforming stresses.

HORNBLENDE GRANITE GNEISS

The hornblende granite gneiss was formed by cataclastic deformation and subsequent recrystallization of hornblende granite. This origin is indicated by the pronounced cataclastic texture of the hornblende granite gneiss, the presence of porphyroblasts, and the gradation of this rock into undeformed hornblende granite. The microperthite of the hornblende granite was crushed and finely granulated, so that the microperthite was separated into two discrete minerals: microcline and sodic plagioclase feldspar. Microcline porphyroblasts 1 mm or more in diameter were developed by recrystallization that followed the granulation. Evidently the deforming stresses continued during and after the development of the microcline porphyroblasts, for locally they show the effects of deformation, as described on an earlier page. Quartz was granulated and in part recrystallized as leafy aggregates and pencils as much as 4 cm long. The hornblende of the hornblende granite was changed into a bluish-green variety that differs markedly from the ferrohastingsite in the undeformed hornblende granite. Epidote, which pervades the modified hornblende granite, and sphene, which commonly forms reaction rims around magnetite, were developed by the same deformation. Pegmatite was introduced along the secondary foliation planes of the granite.

ROCKS OF PALEOZOIC AGE

Sedimentary rocks of Cambrian and Silurian ages disconformably overlie the pre-Cambrian igneous and metasedimentary rocks along the northwest edge of the Dover district (pl. 1). These rocks have been mapped by Kümmel and Weller (1902), and Kümmel (Bayley and others, 1914) and hence were not studied, except locally on Copperas Mountain, by the writer. They are mapped on plate 1 as undivided sedimentary rocks of Paleozoic age.

According to Kümmel (Bayley and others, 1914, p. 10–13) the rocks of Paleozoic age in this region, from oldest to youngest, are the Hardyston quartzite of Cambrian age, the Kittatinny limestone of Cambrian and Ordovician ages, the Jacksonburg limestone and Martinsburg shale of Ordovician age, the Green Pond conglomerate, Longwood shale, and Decker limestone of Silurian age, and the Kanouse sandstone and Cornwall ("Pequanac") shale of Devonian age. Only the Hardyston quartzite and the Green Pond conglomerate are discussed in this report, because they are the only formations in contact with the pre-Cambrian rocks in the Dover region.

HARDYSTON QUARTZITE

The Hardyston quartzite of Cambrian age, the oldest formation of Paleozoic age in the region, is inferred to overlie the pre-Cambrian rocks in the valley south of Picatinny Lake (pl. 1). It forms a narrow belt near the base of the hills overlooking the valley known as Succasunna Plains that extends from Picatinny Lake southward to beyond Ironia (Bayley and others, 1914). The Hardyston quartzite has not been observed in place in this area, but its presence is indicated by local boulders of quartzite in the valley south of Ironia. The quartzite ranges in thickness from a few feet to more than 200 feet in the Raritan quadrangle.

The Hardyston quartzite, according to Kümmel (Bayley and others, 1914, p. 10), is steel blue when fresh and rusty brown when weathered. Typically it is conglomeratic and contains pebbles generally less than an inch in diameter, but in places as much as 4 inches in diameter, of quartz, feldspar, granite, gneiss, and amphibolite. At places the quartzite is a somewhat friable calcareous sandstone.

GREEN POND CONGLOMERATE

The Green Pond conglomerate of Silurian age (Kümmel and Weller, 1902, p. 14) crops out on both Copperas and Green Pond Mountains (pl. 1), on the northwest side of the Dover district, where it directly overlies rocks belonging to the pre-Cambrian. The older formations commonly present in this region, the Hardyston quartzite and the Kittatinny limestone, are absent. Throughout the length of Copperas Mountain, the Green Pond conglomerate rests disconformably upon the eroded surface of the pre-Cambrian rocks, and at several places it is exposed within a distance of 25 or 30 feet of the pre-Cambrian, although it is not seen in actual contact.

The Green Pond conglomerate for the most part is a red to gray, coarse-grained conglomerate that contains subangular pebbles of white quartz in a matrix composed of dull-red quartz sandstone, but parts of the formation are considerably different. The basal part of the conglomerate at many places is a gray or greenish conglomerate and the upper part commonly is a purple-red quartzite (Kümmel and Weller, 1902, p. 9–10).

A fair to good bedding generally is visible in the conglomerate, but locally it appears massive. On Copperas Mountain the formation dips 45° to 70° NW. except at the south end, where the dips are more irregular (pl. 1). Opposite Lake Denmark the conglomerate dips nearly vertical on the crest of Copperas Mountain, but at the base of the westward slope it locally dips about 25° SE. According to Kümmel and Weller (1902, p. 27) this variation in dip is due to folding, and the eastward-dipping beds constitute part of the western limb of a northeastward-plunging syncline, the Copperas Mountain syncline. These rocks are separated on the northwest from pre-Cambrian rocks by the Green Pond fault (pl. 1).

ROCKS OF MESOZOIC AGE

Diabase of Triassic(?) age, the only rocks of Mesozoic age known in the Dover district, form dikes and narrow dikelets that intrude the pre-Cambrian gneisses and granites and cut the ore bodies.

DIABASE

OCCURRENCE

Five diabase dikes that form linear ridges are present in the region north of Denville (pl. 1) and several small ones have been intersected in mine workings. The longest, and one of the widest bodies is well exposed on the hill east of Cooks Lake and in a road cut along the Diamond Springs road. It was traced for more than a mile, and both ends are covered.

Although the dikes appear on the geologic map (pl. 1) to be concordant, in the field they can be seen to transect the structure in the country rocks on both a small and a large scale. In the exposure east of Cooks Lake the diabase locally contains angular xenoliths of biotite-quartz-feldspar gneiss, and small apophyses extend a short distance into the country rock. The contacts with the biotite-quartz-feldspar gneiss are always sharp, and evidences of fusion are absent.

PETROGRAPHY

The diabase is a dark-greenish-gray, aphanitic to fine-grained, massive rock with a felty texture. Weathered surfaces are always brown or brownish gray, and exposures are marked by several prominent intersecting closely spaced joint sets that contrast sharply with the jointing in the pre-Cambrian rocks. All the dikes have a chilled microcrystalline border facies.

The diabase consists chiefly of calcic plagioclase and pyroxene intergrown in a diabasic texture. The pyroxene is colorless augite. The plagioclase is intensely altered to sericite and its composition could not be determined. A few percent of quartz forms interstitial grains closely associated with plagioclase. Pyrite is a ubiquitous accessory mineral and is visible megascopically.

AGE

The diabase is definitely younger than the pre-Cambrian rocks it intrudes. There is no evidence of crushing and recrystallization, and furthermore the contacts of the dikes with the gneiss are chilled, indicating hypabyssal intrusion into relatively cold country rock.

The diabase could have been emplaced any time after the close of the cycle of deformation that produced the structural features now observed in the pre-Cambrian rocks, but because of the known existence of diabase of Triassic age in New Jersey, the writer favors a similar age for those dikes found in the Dover district.

QUATERNARY SEDIMENTS

Unconsolidated surficial deposits of Quaternary age irregularly mantle the bedrock in the Dover district, except in the extreme southwest part. The deposits consist of clay, sand, gravel, and boulders and are predominantly of glacial origin; but some are of fluviatile or alluvial origin.

The terminal moraine of the Wisconsin glacial stage covers the central part of the district, forming a belt from 2 to 3 miles wide that in general parallels the Rockaway River. South of the moraine, a belt of pre-Wisconsin drift, as much as 3 miles wide, occurs in irregular patches in the valleys and on the slopes; and north of the moraine, till of Wisconsin age fills all the valleys and depressions.

These surficial deposits have been studied by Salisbury (1902), Bayley and others (1914, p. 16–18), and MacClintock (1940), and no particular attempt was made by the writer to add to the existing knowledge. However, a brief description of the surficial deposits, largely after Salisbury, is given on the following pages, as their distribution and thickness is of concern in the interpretation of the bedrock geology of the district and in the exploration for ore deposits. For a map of the surficial deposits in the Dover district, the reader is referred to the surficial geologic maps of the Passaic (Darton and others, 1908) and Raritan (Bayley and others, 1914) quadrangles. The area within the Dover district that is covered by thick surficial deposits, irrespective of type or origin, is shown on plate 1.

Alluvium and humus (swamp muck) constitute a small part of the surficial deposits. Alluvium occurs along the flood plains of the rivers in the area and in the valleys of the small streams; humus deposits occur in the small swamps that are abundant north of the Wisconsin terminal moraine.

GLACIAL DEPOSITS

The glacial deposits of the Dover district represent two or possibly three of the stages into which the Pleistocene of North America has been subdivided. They consist chiefly of drift but include also fluviatile or estuarine deposits that probably are contemporaneous with one of the ice advances. The glacial deposits in the Raritan quadrangle were mapped by Salisbury (Bayley and others, 1914) as Jerseyan and Wisconsin, but earlier Salisbury (1902, p. 781) had recognized the probable existence of two separate drifts of pre-Wisconsin age. The existence of two pre-Wisconsin drift sheets later was substantiated by MacClintock (1940, p. 113) on the basis of the mean weathering of gneissic rocks in the drift. Little is known of the distribution and character of the pre-Wisconsin drift sheets, however, and in the section that follows these deposits are discussed together.

PRE-WISCONSIN GLACIAL DEPOSITS

Pre-Wisconsin glacial deposits form a belt across the Dover district, locally as much as 3 miles wide, that is south of the terminal moraine of the Wisconsin glacial stage (Bayley, Salisbury, and Kümmel, 1914). The deposits form irregular patches, generally less than 20 feet thick, that mantle the valleys and slopes; the crests of the higher hills, with the exception of the hill northeast of Dover, are not covered. The glacial deposits consist predominantly of till, but stratified deposits of sand and gravel a few feet thick are interbedded with the till at several places in the valleys. The till consists of pebbles and boulders that are embedded in a matrix ranging from fine sand to clay. The boulders are largely angular and consist predominantly of fragments of pre-Cambrian crystalline rocks; fragments of the Green Pond (Silurian) conglomerate are sparse. The material, so far as known, probably was derived entirely from a local source.

WISCONSIN GLACIAL DEPOSITS

Glacial deposits that belong to the Wisconsin glacial stage mantle much of the northeastern two-thirds of the Dover district. The material is till, sand, gravel, and lacustrine silt and clay. The deposits can be grouped into 3 general classes: terminal moraine, ground moraine or till, and stratified drift. The deposits that constitute the terminal moraine are thick and completely obscure the bedrock over a wide area, but the other deposits are patchy and mostly thin.

The terminal moraine mantles the central part of the Dover district, forming a belt from 2 to 3 miles wide that in general is parallel to the Rockaway River. The terminal moraine completely obscures the bedrock. In the region between Dover and Mount Hope (pl. 1), where the moraine is widest, the drift is locally more than 150 feet thick, as indicated by well borings; it is considerably thinner, however, on the hill crests in the vicinity of Wharton and Mine Hill, where it is generally less than 50 feet and in places less than 10 feet thick.

The inner or northern margin of the terminal is for the most part abrupt and clearly discernible, but the outer or southern margin is poorly defined and indistinct. The inner margin in the region between Dover and White Meadow Lake, where the moraine is thickest, is abrupt. (See pl. 15.) It is poorly defined, however, in the vicinity of Mount Hope and farther west, where the moraine is much thinner. The outer margin is irregular and everywhere indistinct, largely because the moraine is bordered by older drift. The irregularities in the border also are in part due to the irregularity of the surface on which the moraine lies. The sharp reentrant in the moraine near Rockaway (Bayley and others, 1914) is caused by the high hill just northeast of Dover, which held the ice back.

The terminal moraine, though distinct, is not conspicuous topographically, largely because of the great relief of the surface on which it lies. It is most conspicuous in the valley of the Rockaway River east of Rockaway and between Dover and White Meadow Lake. In the region northeast of Dover the moraine has an irregular knob-and-kettle topography characteristic of terminal moraines, as shown in plate 15, but elsewhere this characteristic is poorly developed.

The moraine consists of subangular to angular pebbles and boulders in a matrix of clay and silt. The coarse material in the Dover district consists predominantly of pre-Cambrian rocks with lesser quantities of Green Pond (Silurian) conglomerate. The conglomerate boulders, because of their distinctive red color, are conspicuous, and they constitute a much greater proportion of the Wisconsin till than the older pre-Wisconsin till.

Till or ground moraine of the Wisconsin glacial stage irregularly mantles the region north of the terminal moraine. It obscures the bedrock in the stream valleys and depressions and is as much as 20 feet thick. Outside the valleys the cover is sporadic and generally less than 10 feet thick. The till for the most part is composed of rock fragments from the underlying bedrock.

Stratified drift of the Wisconsin stage is widely distributed in the valleys south of Dover and in the Succasunna Plains, west of Dover; and locally in the larger valleys north of the terminal moraine (Bayley and others, 1914, p. 18). South of the moraine, at Dover and along the valley of Rockaway River for 2 miles east of Dover, stratified drift is abundant. In Dover it forms an outwash plain, but farther east, where it is not in contact with the moraine, the form disappears. On Succasunna Plains, for about 3 miles along the front of the moraine, the stratified drift slopes southward and becomes noticeably finer away from the moraine.

ALLUVIUM AND HUMUS

Deposits of alluvium and humus occur in the stream valleys, depressions, and swamps in the Dover district. The most continuous deposits of alluvium are along the major stream valleys; smaller deposits occur in the depressions and swamps, the most numerous of which are north of the Wisconsin terminal moraine. With the exception of the larger stream valleys, the alluvium generally is thin, being only a few feet thick. It lies upon thicker deposits of glacial material in all the stream valleys in the northern two-thirds of the district.

Deposits of humus, in varying amount intermixed with alluvium, occur in all the swamps and along many of the lakes and streams. This material, formed largely by the decay of vegetable matter, has been formed since the last glacial stage and is probably thin.

STRUCTURE

The Dover district is within a large block of pre-Cambrian rocks about 8 miles in width and many miles in length that is bounded on the southeast by a large northeastward-trending fault which separates the pre-Cambrian from the Triassic rocks. To the northwest a second block of pre-Cambrian rocks is bounded on the southeast by a large fault. Infolded and faulted rocks of Paleozoic age separate the two blocks. Both blocks have been tilted northwest, and later reduced to their present form by erosion.

Throughout the Dover district the pre-Cambrian rocks trend northeast and dip steeply southeast, but there is considerable local variation as shown in plate 1. This prevailing regional pattern is produced by northeastward-trending isoclinal and open folds and by conformable sheets of granite that have been emplaced along the limbs of the folds. Granite phacoliths occur in the axial regions of some of the larger folds. Transverse and longitudinal faults of small displacement are common in the mines and probably are present throughout the district.

STRUCTURES IN THE PRE-CAMBRIAN IGNEOUS AND METASEDIMENTARY ROCKS

DEFINITIONS

In the absence of a standardized terminology of structural geology, the following definitions of terms frequently used in this report are given:

Foliation or planar structure. Parallel arrangement of mineral grains or rock layers with or without linear alinement of the individual components. May be either primary or secondary in origin.

Linear structure. Parallel alinement of the long axis of mineral grains or rock fragments or other elongate elements in a rock.

Linear elements. Individual components responsible for the linear structure.

Lineation. A descriptive and nongenetic term for any kind of linear structures within or on a rock (Cloos, 1946, p. 1).

Plunge. The angle that a line makes with a horizontal line measured in a vertical plane (Billings, 1942, p. 44).

Rake. The angle that a line in a plane makes with a horizontal line in that plane (U. S. Geol. Survey usage). Is equal to pitch (Billings, 1942, p. 135).

Coordinate system. A reference system useful for the discussion of space relations of structural elements: *b* is the fold axis and is generally parallel to lineation; *a* is perpendicular to *b* in the movement plane, and *c* is perpendicular to *ab* (Sander, 1930, p. 119; Cloos, 1946, p. 6).

Other terms used in a more restricted sense are defined in the body of this chapter.

FOLIATION

The pre-Cambrian rocks in the Dover district characteristically have a fair to excellent foliation produced by the dimensional orientation of platy and tabular minerals and by the parallelism of layers, streaks, and lenses.

The lithologic layering almost always is parallel to the dimensional orientation of the mineral components in the rock and is the result of slight to marked differences in composition or texture, or both. In metasedimentary rocks the layering reflects in part relict bedding inherited from the original sediments. To some extent, however, it is formed by the lit-par-lit injection of magmatic material, the concentration of different minerals into layers as a result of rearrangement or reconstitution during metamorphism, the preferential metasomatic replacement of certain layers, or microshearing. In the igneous rocks the layering is principally marked by conformable xenoliths or pegmatitic streaks.

Differences exist between the degree of development of foliation in the metasedimentary rocks and the igneous rocks, and also within each group. In general, foliation is more conspicuous in the metasedimentary rocks, because they have been more strongly metamorphosed and contain a higher percent of platy and tabular minerals. Foliation is generally more evident on the limbs of the folds in the district and is poorly defined on the noses of these structures.

The textures and structures of the different rock units indicate that the foliation is in part primary and in part secondary. In the granitic rocks the foliation is for the most part of primary origin, but secondary gneissic structures locally were superimposed upon the earlier primary ones. In the metasedimentary rocks the foliation is entirely secondary.

LINEATION

Lineation (Cloos, 1946) is remarkably uniform throughout the Dover district, as shown in figure 2—a contour diagram of the plunge of 660 measurements plotted on a Schmidt equal-area net (see Billings, 1942, p. 119). The resultant value of 17° N. 52° E. for the mean lineation includes measurements from both igneous and metamorphic rocks. Although throughout the Dover area the linear elements predominantly plunge northeast, in the eastern part of the district, north of Denville, they are nearly horizontal and locally plunge southwest.

Lineation is expressed in several ways. Commonly it is produced by the subparallel alinement of elongate or rodlike minerals, such as quartz, hornblende, and sillimanite (mineral lineation); rarely it is indicated by the intersection of two planar structures, such as longitudinal joints and foliation, but not all intersections are significant. At many places the lineation is shown by crinkles or fluted structures (see Sims, 1953, fig. 60), and less often by grooves and ridges. These structures that are apparent on the foliation surfaces are parallel to the mineral lineation in the rock and generally also to the intersection of longitudinal joints and foliation. They are conspicuous on the walls of many magnetite deposits, as, for example, the walls of the opencuts along the Hibernia ore body. In strongly folded rocks the axis of tight crumples and crenulations, or drag

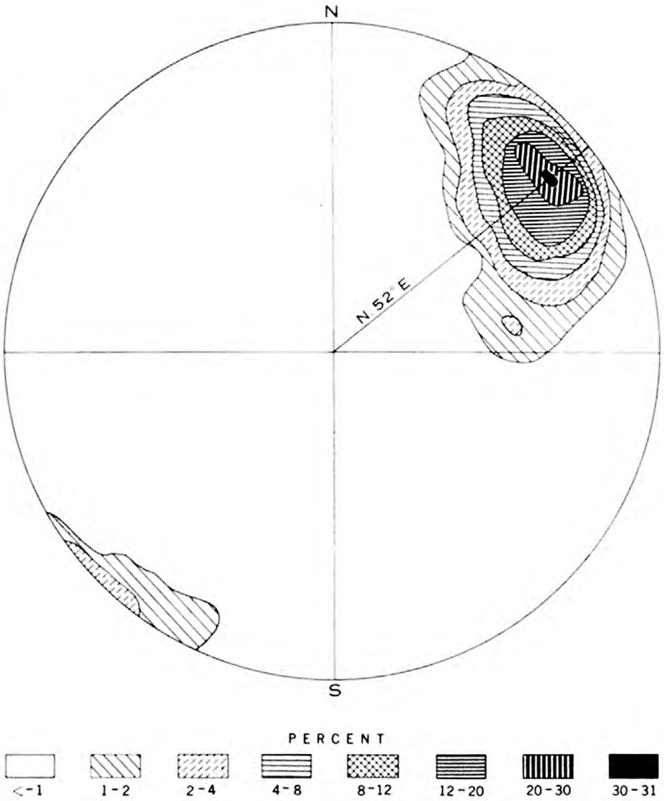


FIGURE 2.—Contour diagram of 660 lineations in the Dover district. Lower-hemisphere projection on Schmidt equal-area net.

folds, produces a linear structure, and where the folds are particularly tight a rod structure may be developed. Boudins also locally produce a linear structure. In the igneous rocks elongate inclusions tend to be alined, thus producing a lineation.

The long dimensions of the ore bodies are parallel to the linear elements in the surrounding rocks, and accordingly the ore bodies plunge northeast. Ore shoots and pinches within the deposits likewise conform to the lineation. The structure of the ore bodies is discussed on pp. 64–67.

Most lineations are essentially parallel to the axis of minor as well as major folds, thus conforming to the direction of intermediate elongation of folding deformation, the *b*-axis of the coordinate system (Sander, 1930, p. 119).

The most notable departure from the *b*-axis lineation occurs on the east limb of Splitrock Pond syncline. In this region the mineral lineation and small cross folds and crumples plunge moderately steeply to the east. (See pl. 1.) This lineation is diagonal, and even locally essentially normal, to the synclinal axis and in places is parallel to the dip of the foliation. Similarly-oriented linear structures in the northwest Adirondack Mountains have been interpreted by Buddington (oral communication) to be *a*-axis lineations, resulting from intense deformation and overturning; and there is evidence that the lineation in the Splitrock Pond locality is of similar derivation.

BOUDINAGE

Boudinage is a term coined for sausage-shaped structures in rocks; a boudin is a sausage (Cloos, 1947, p. 626).

In the Dover district boudinage is not uncommon, and it usually is shown by amphibolite boudins in feldspathic-quartzose gneisses, particularly in areas of mixed rocks (fig. 3). On a larger scale, pod-form marble and skarn masses may be boudins formed by the disruption of the original limestone layers during dynamic metamorphism.

FRACTURE CLEAVAGE

A fracture cleavage consisting of closely spaced, slightly curved shear surfaces transects the foliation in some places. The cleavage is the result of fracturing with subordinate rearrangement of minerals, largely by mechanical reorientation, without recrystallization.

S-shaped fractures similar to those described by Shenon and McConnel (1940, p. 443) are present in some places, particularly in the relatively competent layers that are folded into gentle flexures. In this type of cleavage there is no rearrangement or growth of new minerals along the cleavage planes.

A fracture cleavage along which there has been notable rearrangement of minerals is somewhat less common; nevertheless it can be observed in some places. Figure 4 is a diagrammatic sketch showing fracture cleavage in an exposure along State Highway 10, near the west edge of the Dover district. A prominent cleavage has evolved parallel to the axial plane of the syncline, and there is a marked rearrangement of some minerals at least along the cleavage planes. The cleavage is parallel to the layering in the overturned limb of the syncline, but it transects the layering in the axial area and in the normal limb.

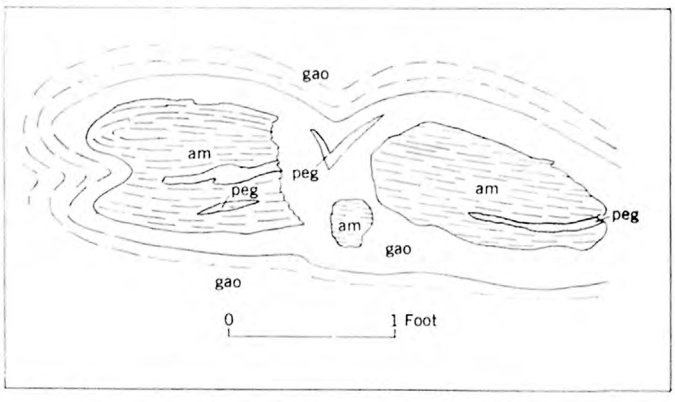


FIGURE 3.—Boudinage, showing broken amphibolite (*am*) enclosed within albite-oligoclase granite (*gao*), near Beach Glen mine, Boonton quadrangle; peg, pegmatite.

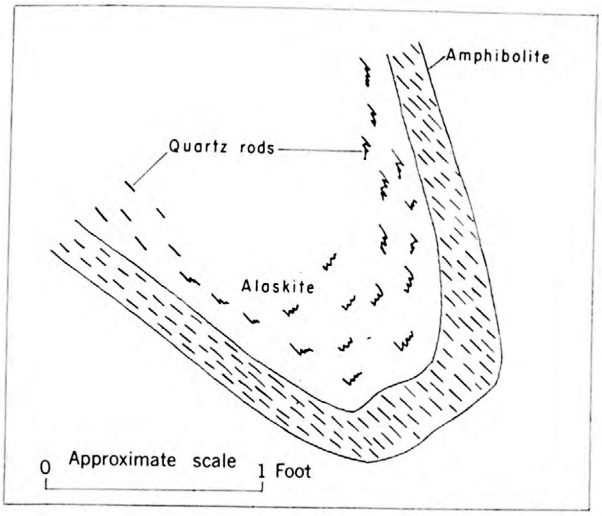


FIGURE 4.—Cross section showing fracture cleavage developed parallel to axis of small synclinal fold; road cut along State Highway 10, southeast of Canfield mine, Mendham quadrangle. Note parallelism of cleavage and amphibolite layer in overturned limb and angular relationship in normal limb. Quartz tablets and rods in the alaskite are sheared and crinkled and partly reoriented parallel to fracture cleavage.

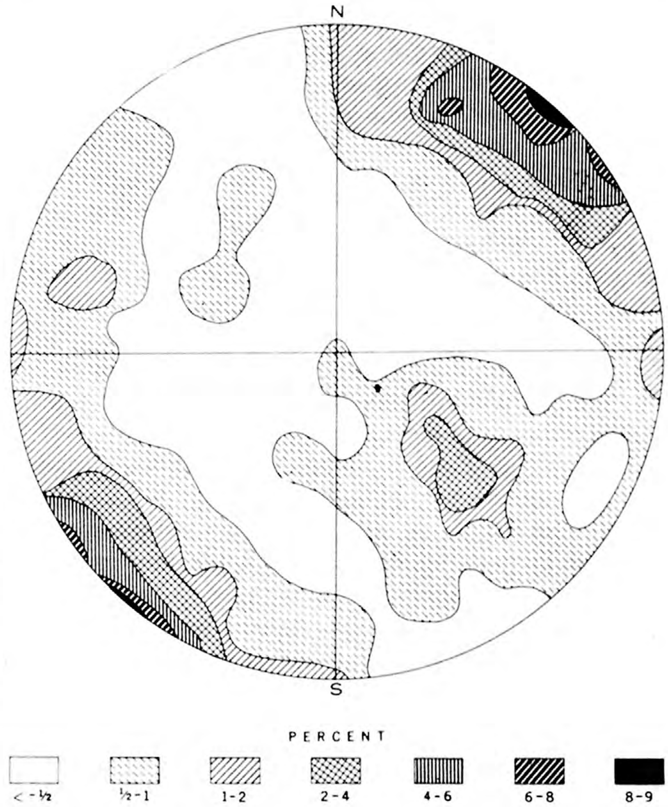


FIGURE 5.—Contour diagram of joints, upper-hemisphere plot of 452 poles. Lower-hemisphere projection on Schmidt equal-area net.

A fracture cleavage, at places marked by subparallel quartz grains, is conspicuous in some exposures on the hill east of Beach Glen mine. The cleavage, which dips about 80° NW, transects an intricate series of small-scale folds that are overturned to the northwest.

JOINTS

Joints are a prominent feature of the crystalline rocks of the Dover district and are well-developed both in igneous and in metasedimentary rocks. They may be observed in nearly every rock exposure, and because they commonly have a systematic angular relation to the gneissic structure that is generally related to regional deformation, a great number of measurements were made throughout the area.

The joints in the New Jersey-New York Highlands have not been systematically studied, although several studies either of a local or a reconnaissance nature have been made. Thompson (1936) discussed the joints in the Hudson River gorge region of southern New York, and further studies at Bear Mountain were recently made by Lowe (1950, p. 162–171). In New Jersey, Broughton (1940 unpublished thesis, Johns Hopkins Univ.) compared the joints of the crystalline rocks and rocks of early Paleozoic age throughout a part of the northwestern portion of the State. Later, Appleby (1942) made a reconnaissance study of jointing over a large area in northern New Jersey.

A contour diagram of pole projections on an equal-area net (Billings, 1942, p. 116) of the principal joint systems was prepared to facilitate recognition and interpretation of the joints (fig. 5). As the joint patterns in the metasedimentary rocks are similar in orientation to those in the igneous rocks separate diagrams were not prepared for the rocks.

Only the principal joint systems were recorded; obscure fractures and those that seemed to be of only extremely local development were omitted. Foliation joints also were not recorded, even though they are locally quite common, as it is difficult to evaluate their significance. They seem to be most abundant in those rocks that possess a strong foliation; therefore, they are very likely of recent origin and are formed by unloading and weathering. This interpretation is borne out by the almost complete absence of joints of this type underground in the mine workings.

There are three principal joint systems in the Dover area, which can be classified on a purely geometrical basis with respect to the prevailing structural trends as transverse, longitudinal, and diagonal joints. Other less well defined joint sets are present, but they are decidedly subordinate to the three main sets.

Transverse joints are not only the most abundant but also are the most prominent. They are smooth plane surfaces that are generally rather evenly spaced within a single exposure; but the spacing may range from a few inches to several feet over a large area. The joints are usually barren of vein minerals, but locally pegmatite dikelets, chlorite, and epidote are found. Very rarely diabase dikes also occur in fractures of this type. As can be seen in figure 5, two maxima occur for these joints, which strike respectively N. 35° W. and N. 50° W. Both sets have a nearly vertical dip.

The transverse joints (fig. 5) depart notably from typical cross joints or *AC* joints as defined by Cloos (1937, p. 74) and others, in that they are not normal to the *b*-axis. Instead, their dip is more nearly normal to the earth's surface. It was noted, however, that the transverse joints in the mine workings, at depths of 1,000 feet or greater, were nearly normal to the lineation. The joints mapped in the underground workings were not plotted in figure 5, as they represent a local concentration of observations.

Longitudinal joints, striking N. 45° E. and dipping 45° NW., are next in abundance. They are generally smooth plane surfaces with a highly variable spacing. They are in part nearly parallel to the fold axis, and their intersection with the foliation at places produces a lineation that is parallel to the mineral lineation.

Diagonal joints are represented by the statistical concentration of steep fractures striking slightly east of north (fig. 5). They are decidedly subordinate to the transverse and longitudinal joints and are most abundant in the folded rocks in the Splitrock Pond area.

Flat or gently dipping joints, generally referred to as sheeting (Billings, 1942, p. 128), are found locally. They tend to be closely spaced and are nearly parallel to the earth's surface. Similar closely spaced joints, which may well not be related to these, are also found locally in mine workings at considerable depth below the surface. They are well-developed in granite at the Mount Hope mine to depths below 1,600 feet.

Joint sets of local occurrence, roughly parallel to the transverse and, less commonly, the longitudinal and oblique faults, can be seen adjacent to faults in mine workings, but they are not visible at the surface. These joints commonly are closely spaced and they are conspicuous for distances of at least 50 feet from most transverse faults. Many of these joints contain a thin film of chlorite.

Studies of joints in the New Jersey Highlands (Broughton, 1940, unpublished thesis, Johns Hopkins Univ.; Appleby, 1942) indicate that there is a generally uniform regional pattern to the joints, and furthermore, that the joints developed in rocks of diverse composition or texture are similar in orientation regardless of whether the rocks are Proterozoic or Paleozoic in age. Because of this observed fact, Appleby (1942, p. 25) relates the jointing in all these rocks to the Appalachian orogeny and does not believe it is genetically related to the Proterozoic folding. He further explains the jointing by shearing stresses that emanated from the east. Broughton (1940, p. 16) believes that his "strike" and "cross" joints are closely related to primary flowage during emplacement of the pre-Cambrian igneous rocks, as they rotate in the same direction and same order of magnitude as the foliation. He states further, though, that a joint set that strikes roughly northward and dips 35° W. (diagonal joints) may be ascribed to Paleozoic stresses because the joints coincide very closely with "shear joints" in the slate of Ordovician age.

I believe that the jointing was produced for the most part during the late stages of the regional orogenic deformation that induced the secondary gneissic structures, but I do not attempt to explain fully the mechanics of jointing in the district, because of the limited scope of this investigation. After the intensity of the stresses diminished and the rock temperatures declined, the rocks no longer could yield by internal rearrangement of the individual mineral grains; but they did yield by fracturing along generally well-defined parallel joint sets. A systematic relationship of joints to the gneissic structures is therefore expected, as the two items were developed by the same deformational forces during the waning stages of the orogeny.

It seems reasonable to postulate that some of the joints in the intrusive granitic rocks may have been started as primary fractures directly associated with emplacement, as Balk (1937) and others have demonstrated. This is suggested by the local development of late-stage pegmatite dikes in transverse joints in the granites. The continuation of the same deformational forces that acted during the emplacement of the igneous rocks, however, resulted in the superimposition of secondary fractures upon the earlier primary ones, and in the local obliteration of the earlier ones. The jointing evident in the rocks of early Paleozoic age probably reflects prominent joint sets in the pre-Cambrian rocks.

FOLDS

The distribution of the rock units and the attitudes of foliation indicate the presence of a complex series of folds in the district (pl. 1). Detailed structural studies are handicapped, however, by the general absence of reliable markers and by the locally thick mantle of surficial deposits. Structures in the area north of the Wisconsin terminal moraine are better known than those in the central and southern parts of the district.

The smallest folds are only a few feet in width; the largest known folds in the region are the Splitrock Pond syncline, which has a width of more than a mile, and the Hibernia anticline, which has a width of more than 1 mile and a length of nearly 7 miles.

SPLITROCK POND SYNCLINE

Splitrock Pond syncline plunges about 37° NE. Quartz diorite forms the core, and hornblende granite, with local biotite granite facies and included layers of metasedimentary rocks, constitutes the limbs and keel of the syncline. The synclinal structure is indicated by the gradual change in trend of the rock units and foliation from northeast along the east limb to east and then to north-northeast along the west limb. The dips of the layers and also foliation are almost consistently inward toward the axis and are gentlest in the axial area, west of the lower end of Splitrock Pond. The east limb dips steeply and locally is vertical, whereas the west limb is more gentle, the dips averaging about 60° SE. to E. Some of the metasedimentary units follow around the keel of the syncline; others are thickened there and pinched off along the limbs. The synclinal structure is prominently reflected by ridges and intervening valleys that formed by differential weathering of the rock units.

The rocks in the axial areas of the syncline are crumpled and folded into tight isoclines that plunge northeast, probably parallel to the axis of the main syncline, but because of an abundance of pegmatite in this part of the fold, reliable data on the dip of the axial plane were not obtained. From the slightly asymmetrical shape of the fold the axial plane is inferred to dip steeply southeast. The axial trace (Billings, 1942, p. 44) of the syncline trends about N. 60° E. to a point opposite the center of Splitrock Pond, where it curves to a more northeasterly direction. The trend of the axis north of the swamp is not known (pl. 1).

COBB ANTICLINE

The Cobb anticline is a complex northeastward-plunging, overturned fold that lies east of the Splitrock Pond syncline (pl. 1). The anticline is a tight isoclinal fold whose axial trace trends about N. 60° E. south of the Lyonsville-Marcella road, then swings to N. 45° E. north of the road. Interlayered metasedimentary rocks and hornblende granite with local alaskitic facies constitute the limbs; hornblende granite occurs on the nose of the fold. The foliation dips steeply in both limbs, but is gentle in the axial area. A strong lineation is developed at the nose of the fold where the metasedimentary rocks are complexly crumpled into a series of tight folds that plunge 30° to 35° N. 50° E., and the granite is intensely granulated and recrystallized. The metasedimentary layers along the northwest limb of Cobb anticline are locally pinched off.

TELEMARK ANTICLINE

The Telemark anticline is northwest of Splitrock Pond syncline. The village of Telemark is just west of the axis and near the nose of the structure. The axial trace of the fold trends about N. 35° E. and the axis plunges 25° to 30° northeastward; the axial plane seems to dip steeply to the southeast. A large curved body of hornblende granite is present in the nose of the plunging fold, where the granite attains a width of a mile; southwest of the hornblende granite body, and separated from it by a migmatite zone about 800 feet wide, is a curved body of albite-oligoclase granite. The foliation in the hornblende granite dips about 55° NNW. on the west side of the axis and 35° to 65° SE. on the east side of the axis (pl. 1).

HIBERNIA ANTICLINE

The Hibernia anticline is a well-defined, overturned fold about 1 mile wide and 7 miles long that is between the Wharton and Dalrymple ore belts. The village of Hibernia is on the east limb of the fold. The anticline contains a lens-shaped core of dioritic rocks that is surrounded by alaskite. The lens shape of the dioritic core suggests that it may be doubly plunging, but the writer did not find any evidence for a southwest plunge. The domical foliation in the alaskite, observed locally, indicates that the alaskite mass probably is a phacolith. Albite-oligoclase granite and metasedimentary rocks locally form the limbs of the fold.

The axial trace of Hibernia anticline trends about N. 45° E.; in the region north of White Meadow Lake the axis plunges 15° NE. The axial plane is inferred to dip about 45° SE. parallel to the axial planes of small (drag?) folds in metasedimentary inclusions exposed near the nose of the anticline. Both limbs of the fold are overturned and dip on the average about 60° SE. South of White Meadow Lake the limbs are covered by a thick mantle of terminal moraine and the fold is poorly defined.

KINNELON SYNCLINE

The Kinnelon syncline, north of the village of Kinnelon and about 4 miles west of Butler, contains a folded concordant pluton of quartz diorite and diorite in the core. A lenticular sheet of hornblende granite cuts the dioritic rocks along the west limb, and a smaller mass lies in the trough of the syncline. The axial trace of the syncline trends about N. 37° E., and the axis plunges 12° to 28° northeastward. The rocks that constitute the west limb of the syncline dip rather uniformly east; the average is about 35°. The east limb of the structure is outside the limits of the Dover district for the most part, but on the north shore of Payson Lake the rocks are about vertical. A strong lineation produced by tight folds and crumples in the dioritic rocks and hornblende granite is characteristic of the axial area of the fold.

MOUNT HOPE SYNCLINE

The Mount Hope syncline, named from the Mount Hope mine, is a tight overturned isocline whose axial trace trends about N. 45° E. and whose axis plunges 12° to 20° NE. (pl. 3). The axial plane dips steeply to the southeast in the upper part of the fold but seems to flatten at depth to dip about 45° SE. At the surface the limbs are parallel and dip about 50° SE., except in the axial area above the convergence of the Leonard and Finley ore bodies. Here they dip toward the axis, and the southeast limb has the steeper dip. This syncline contains many of the important ore deposits in the district. A phacolithic mass of alaskite, marked by a strong lineation produced by quartz pencils, occupies the axial area in the upper part of the fold.

BEACH GLEN ANTICLINE

The Beach Glen anticline is a complex overturned fold, and the axial trace of the fold is just southeast of the main ore deposit at Beach Glen mine. The anticline consists predominantly of albite-oligoclase granite with abundant intercalated layers of amphibolitic rocks; the albite-oligoclase granite is flanked by alaskite. At the surface, about 3000 feet northeast of the mine, the albite-oligoclase granite plunges beneath the alaskite. The axis trends N. 52° E. and plunges about 11° NE. A prominent lineation, marked by fluting on the walls of the ore body and by small folds, plunges parallel to the axis of the fold. A number of prominent small-scale drag folds are exposed on the southeast limb of the anticline that are sufficiently asymmetrical to use in determining the attitude of the main fold axis. The axial planes of these folds dip about 50° SE. Locally a fracture cleavage transects the limbs of these folds, dipping steeply northwest. Northwest of the Beach Glen anticline a number of small folds are exposed on the steep southeast slope of the prominent ridge between the Beach Glen and the Hibernia mines. The folds are slightly overturned to the northwest and plunge about 15° NE.

OTHER FOLDS

Folds of a smaller amplitude are common in the district and are conspicuous in most large exposures of metasedimentary or dioritic rock. At places the granites contain folded xenoliths of metasedimentary rocks. The folds range from small warps a few feet wide to the larger structures described above. They are principally isoclines that plunge northeast, nearly parallel to the major folds. For the most part the axial planes of these small folds dip southeast, but it is difficult to determine the dip of the axial plane in most folds in gneissic rocks. The attitude of the axis indicates that the minor folds are overturned to the northwest.

Rolls or minor corrugations and gentle undulations that plunge parallel to the axis of the larger folds are obscure at the surface, but they are known by detailed mapping to be present in the Scrub Oaks mine.

STRUCTURE OF THE PRE-CAMBRIAN METASEDIMENTARY ROCKS

The metasedimentary rocks, except locally in the axial regions of the large-scale folds, form layers or belts that trend northeast, parallel to the fold axes. This apparent simplicity of the structure, however, is deceptive, for close examination shows that the layers are almost everywhere deformed into small-scale isoclinal folds, many of which are too small to be shown on plate 1.

The individual bodies of metasedimentary rocks vary greatly in size and shape. In general, the feldspathic-quartzose gneisses form long, continuous layers, whereas the rocks derived from carbonate sediments form discontinuous and in part, at least, podlike masses.

The biotite-quartz-feldspar gneiss occurs as large layers as much as 8 miles in length, relatively uniform in width; and these layers are extremely helpful in the determination of the major structural pattern (pl. 1). Similarly the oligoclase-quartz-biotite gneiss forms tabular layers that generally can be traced for several thousand feet along strike. So far as known, these rocks extend indefinitely along the plunge of the folds.

The calcareous rocks, on the other hand, are extremely heterogeneous in structure; also they commonly occur as inclusions within the igneous rocks. The marble, pyroxene gneiss, and skarn form small bodies, less than 100 feet wide, that generally are lenticular along the strike and plunge; a notable exception is the hornblende skarn. The structure of the skarn bodies that contain ore deposits is described separately on pp. 64–67. The marble exposed in Timber Brook valley forms a layer 50 feet wide that pinches along strike, but because of the sparse outcrops the nature of the pinch is unknown. The marble at the Splitrock Pond mine, is closely associated with skarn, and together these rocks apparently constitute two lens-shaped bodies that pinch at shallow depths. The pyroxene gneiss occurs as layers as much as 100 feet wide and a mile long and as lenses commonly a few feet to a few tens of feet in width and length. So far as known the gneiss never occurs as xenoliths in igneous rocks.

The structure of the pyroxene skarn bodies differs greatly from that of hornblende skarn bodies, but only the pyroxene skarn is described here because all bodies of hornblende skarn, so far as known, contain ore deposits, and accordingly are described in the section on ore deposits.

Pyroxene skarn occurs as discrete bodies intercalated with marble, pyroxene gneiss, and amphibolite; as small podlike bodies associated with biotite-quartz-feldspar gneiss; and as thin layers and small lenticles or pods in plagioclase-quartz gneiss. Where the skarn is associated with marble, pyroxene gneiss, and amphibolite it is thin and conformable; commonly the layers are less than 25 feet thick. In the Kitchell area (pl. 1), pyroxene skarn occurs as lenticles or pods from an inch or less to as much as several feet in size in plagioclase-quartz gneiss and biotite-quartz-feldspar gneiss. Although the pods are isolated, they are abundant in certain layers and sparse in others. So far as known, all of these skarn bodies pinch and swell along their plunge; commonly the bodies pinch out entirely. The pitch length (Lindgren, 1933, p. 192) of the small bodies that were observed rarely exceeds 10 times the width of the bodies, and commonly is less; but there is insufficient data to determine an average plunge-width ratio.

Amphibolite, in addition to forming continuous layers intercalated with other metasedimentary rocks, commonly occurs as inclusions in igneous rocks; and probably it is the most common rock type that occurs as xenoliths. At places amphibolite occurs as boudins, particularly in areas of mixed rocks. As can be seen on plate 1, the amphibolite bodies vary from small, elongate bodies to lens-shaped masses. The largest body is a lens 2,000 feet in maximum width and about 17,000 feet long. The bodies within the igneous rocks, generally too small to be mapped, form generally concordant tabular layers, schlieren, and rodlike lenses, commonly less than 50 feet wide and only a few tens of feet long, but locally they are much larger.

TYPE OF DEFORMATION

During folding, the metasedimentary rocks generally behaved as competent units, and the deformation is interpreted to have taken place by plastic flowage in the solid state; but because none of the rocks were examined to determine the space-lattice orientation of the mineral grains, it is not possible to discuss the mechanism of plastic flowage. However, petrofabric diagrams of similar pre-Cambrian gneisses from the area near Oxford, N. J. (Broughton, 1940, unpublished thesis, Johns Hopkins Univ.), indicate the existence of quartz girdles around the lineation, suggesting that the lineation was an axis of rotation.

The prevailing northeastward-trending folds and foliation and elongate intrusive igneous sheets, phacoliths, and ore bodies that parallel the folds indicate that throughout the orogeny the direction of principal tectonic motion within the rocks has been northwest. The local anomalous structural trend in the region north of Splitrock Pond, recognized earlier by Appleby (1942, p. 26), probably is related to a local inhomogeneity of the rock sequence that caused a change in the direction of tectonic motion. The mass of dioritic rocks that forms the core of Splitrock Pond syncline may have acted as a buttress during deformation, and the structures in the surrounding relatively less competent rocks developed parallel to the internal structure of these rocks. The stable mass of dioritic rocks probably produced unbalanced stresses that resulted in a local, more easterly direction of tectonic motion in the northern part of the district. During the deformation the rocks on the east limb of the synclinal mass of dioritic rocks were concomitantly crumpled into moderately steeply plunging cross folds.

The differences in the structure of the various types of metamorphic rocks indicate anisotropism in their behavior during deformation. Although most of the rocks tend to form long, continuous layers, the marble and the alteration products of limestone, with certain exceptions, generally have a lenticular or podlike shape. Most of the known bodies are isolated and erratically distributed. In the Splitrock Pond area, however, the distribution of individual bodies of marble, pyroxene gneiss, and skarn is such that the bodies can be inferred to belong to a single "stratigraphic" zone. (See pl. 1.) Probably they represent part of an original thin layer of considerable areal extent that, during the orogeny and prior to the emplacement of the granites, was squeezed and locally constricted between the more competent enclosing rocks. The carbonate served as a lubricant, and eventually the layer was segmented into several relatively small isolated pods. Deformation of this type is common in metamorphic terranes that contain rocks of variable competence. Within the Dover district, because intricate structures characteristic of incompetent flowage are not generally visible, the flowage of the calcareous rocks probably was controlled by the enclosing, more competent feldspathic-quartzose gneisses; these rocks prevented the development of billowing, highly irregular structures so common where marble is the predominant rock in the metasedimentary sequence, as in parts of the northwest Adirondacks (Engel, 1949, p. 777).

Although the carbonate rocks typically pinch along their longitudinal axes (pitch length), the hornblende skarn bodies, and perhaps some other rock types of carbonate derivation, consistently extend indefinitely along their longitudinal axes. The development of these unique hornblende skarn bodies, referred to as lath-shaped bodies, presents a problem of considerable structural as well as economic importance.

It is difficult to explain why the hornblende skarn bodies extend for indefinite distances along their longitudinal axes. Within the Highlands (Sims and

Leonard, 1952, p. 14–18), and generally also in other metamorphic terranes, so far as known, the skarns typically are elongate in the *b*-axis of the coordinate system; but they are lenticular and commonly pinch out along their pitch length. To explain the hornblende skarn bodies at Dover the writer assumes that these masses owe their shape to a deep-seated flowage during isoclinal folding. The known hornblende skarn bodies are closely associated with oligoclase-quartz-biotite gneiss, a relatively competent member of the metamorphic sequence, which is known to be folded into tight isoclines with remarkably uniform limbs. During deformation the carbonate members of the series were squeezed into the crests of the initial folds, and as the folding became isoclinal these rocks assumed the shape of the surrounding gneiss. Instead of being deformed into podshaped or lenticular bodies, these rocks, because of the competent enclosing gneisses, developed lathlike bodies with their long dimension parallel to the fold axes. Later the carbonate rocks were metasomatically altered to hornblende skarn, and following the formation of the skarn the alaskite was emplaced, in part surrounding the skarn. There is evidence that the skarn was foliated prior to injection of the alaskite, for in many places the internal structure of the skarn is discordant with that in the alaskite.

STRUCTURE OF THE PRE-CAMBRIAN IGNEOUS ROCKS

The quartz diorite and related facies predominantly form masses with a synclinal structure, or tabular, sheetlike bodies that parallel the prevailing structural trend. Both the Kinnelon mass and the Splitrock Pond mass are synclinal plutons; the dips of both limbs are inward toward the axis of each fold, except locally on the southeast limb where the dips are reversed, indicating overturning. Minor folds on the order of a few feet magnitude, indicated by reversals in the dip of individual layers, are common, and locally abundant, in the axial regions of these folds. Two large sheetlike masses of dioritic rocks were mapped (pl. 1), one on the crest of the Hibernia anticline and the other in the southeast part of the district. The southeast mass averages about 1 mile in width and is more than 10 miles long; it extends to the southwest, outside the mapped area. Although these bodies appear to have a simple structure, detailed studies indicate that each is intricately folded into relatively tight anticlines and synclines.

The granites—albite-oligoclase granite and hornblende granite and related facies—form conformable sheets and phacoliths. Crosscutting relations are rare but are known to occur locally on a small scale.

The structure of the granite sheets is uniform and the foliation is reasonably constant for several miles along the strike. The sheets range from lenticular plutons less than 1,000 feet wide to bodies several miles long and one-half to three-fourths of a mile wide. Without exception these bodies dip southeast to east at an angle of 45° or more. Interleaved conformable layers and streaks of metasedimentary inclusions are common, and are locally abundant. The rocks are similar to those from the Halliburton-Bancroft area in Ontario, described by Foye (1916), to which he applied the term "stromatolith", meaning a rock mass consisting of many alternating layers of igneous and sedimentary rocks in sill arrangement.

Several anticlinal and one synclinal body of granite, interpreted to be phacoliths, are present in the axial regions of the larger folds in the district (pl. 1). The phacolithic mechanism of emplacement is indicated by the conformable relations to the country rock, a moderate thickening in the axial area, and the existence of domical foliation. A phacolithic body of albite-oligoclase granite was mapped on the plunging nose of the Hibernia anticline. The granite body is slightly thickened in the axial region of the fold; the northwest limb is thicker than the southeast limb. Another phacolithic body, composed of hornblende granite and local alaskite, encloses the Wharton ore belt and can be traced around the nose of Telemark anticline and the keel of Splitrock Pond syncline. The granite is moderately thickened in the axial regions of the folds. It does not pinch out on the limbs. A phacolith of comparable size occurs on the nose of Cobb anticline. At places the granite is strongly deformed into hornblende granite gneiss; a conspicuous lineation is present at many places on the crest of the plunging body. Probably the alaskite mass that forms the core of the Hibernia anticline (pl. 1) also should be classed as a phacolith, but this inference cannot be proved because erosion has not cut deep enough to expose sufficiently the limbs of the fold. The contacts of the phacoliths against the country rocks are conformable, so far as known, but exposures of the contact zones are sparse. Evidences of brecciation and disturbance of the country rock are absent.

The granites for the most part have a gneissoid structure and show little or no effects of deformation. Foliation is best developed near the contacts with wall rocks or with xenoliths. Lineation, marked by the subparallel alinement of the mineral constituents in the plane of the foliation, is present in all the granites but is most conspicuous in the axial regions of folds.

Mortar structures, indicative of slight granulation produced by the cataclastic deformation, occur at places in the hornblende granite. Where the deformation was severe, the granite was completely granulated and recrystallized to form augen gneiss or flaser gneiss (Knopf, 1931); and these masses were mapped as hornblende granite gneiss (pl. 1). This type of deformation was primarily confined to local zones in the axial areas of the Splitrock Pond syncline and the Cobb anticline. The deforming forces acted mainly along local zones of weakness, marked by layers of metasedimentary rocks in the axial regions of the larger folds. Deformation was less intense on the limbs of the folds. The shearing stresses may have been dissipated here by minor shearing parallel to the gneissic structures without the development of cataclastic textures.

The inclusions of metasedimentary rocks vary in size and shape, and range from thin tabular lenses and layers a few inches wide to bodies several tens of feet wide and hundreds of feet long. Folded inclusions are not uncommon, and they tend to be abundant in the axial areas of the larger folds. The inclusions range from rounded spindle-shaped masses to angular blocks, the blocks being the more common. Boudins, formed by the rupture of included layers, are observed in some highly deformed terranes.

The internal structure of the inclusions is usually conformable to the structure of the surrounding granite. Likewise, the linear structures formed by the generally parallel alinement of spindlelike inclusions are conformable to, and are indeed part of, the analogous structure in the granite. Discordant relationships are noted to occur, however, and some inclusions have a foliation oriented at an angle to that in the granite. The relationship may be interpreted to indicate that the rock fragment was foliated prior to its inclusion in the magma, which subsequently acquired a foliation independent of that in the xenolith.

The granite pegmatite exhibits some differences in structure, but these may be in part related to age discrepancies of individual bodies. By far the greater proportion of the pegmatite is massive. A few exposures show the pegmatite to be somewhat crackled, and study under the microscope indicates that in these pegmatites the quartz shows strain shadows and the feldspar is locally cracked but seldom broken.

Pegmatite predominantly occurs as irregular crosscutting bodies whose contacts are sharp to somewhat gradational, as indicated by interpenetration of mineral components. In many places pegmatite is developed around linear inclusions as lens-shaped bodies. Less commonly it occurs as well-defined conformable, discontinuous layers.

Ptygmatic folding (Sederholm, 1907, p. 110) is observed in a few places where pegmatite occurs in dioritic rocks. In this type of structure the foliation of the gneiss parallels the crenulations of the pegmatite near the contact, but a short distance away the foliation appears undisturbed. It is evident that plastic flowage of the country rock and both plastic and magmatic flowage of pegmatite is involved. Evidently the country rock was somewhat softened adjacent to the pegmatite and was kneaded by movements in the pegmatitic material, probably subsequent to the solidification of much of the pegmatite.

EMPLACEMENT OF THE IGNEOUS ROCKS

The field relations and textures of the igneous rocks indicate that they were intruded into deformed country rocks during a period of orogeny, and accordingly these rocks are classed as syntectonic intrusives. The emplacement of the intrusives was largely controlled by the preexisting structures.

Quartz diorite and related facies, interpreted to be the oldest of the intrusive rocks, were emplaced early in the orogeny, probably as conformable sheets, which, subsequent to their consolidation, were folded and recrystallized. Much later in the period of orogenic deformation, albite-oligoclase granite was emplaced and soon afterwards hornblende granite and related facies. Although the albite-oligoclase granite probably formed partly by granitization, the large bodies were intruded as sheets and phacoliths. The hornblende granite likewise was emplaced as sheets and phacoliths.

The granitic magmas welled up between and along structurally weak foliation planes in the metasedimentary rocks, following faithfully the preexisting structure in the rocks, and consolidated under directed compressive stresses. That folding largely ceased before the granites completely attained the solid state is indicated by the general lack of evidence of crushing throughout all the rocks. Emplacement of the conformable igneous sheets was accomplished by displacement, without appreciable disturbance of the country rocks.

The interpretation of some of the granite masses as phacoliths is dependent upon the hypothesis that the internal structure of the granite originated prior to the complete consolidation of the magma. Granite from the Telemark anticlinal phacolith and from the Splitrock Pond synclinal phacolith shows no evidence of granulation and recrystallization, except for the narrow linear mass of hornblende granite gneiss intimately associated with biotite-quartz-feldspar gneiss in the pitching trough of Splitrock Pond syncline. The granite on the nose of Cobb anticline is also locally deformed, but for the most part it has an interlocking texture interpreted to be primary in origin. The writer believes the magma in this environment in part made room for itself by entering potential low-pressure zones in the plunging axial areas of the larger structures. The gneisses yielded mainly by flowage, the magma itself acting in conjunction with the fold stresses to create openings.

Field evidence indicates that most of the pegmatite dikes were emplaced by displacement of the host rocks. The schistose septa in arteritic migmatites show abundant evidence of forceful injection of magma and locally unoriented fragments of country rock are found in the pegmatite. Not uncommonly "beaded" structures are observed—that is, small nodules and lenses of pegmatite are strung out like beads on a chain along the foliation. The foliation in the enclosing rock, generally amphibolite, bends around the beads, suggesting that the foliation has been displaced by the injection of the pegmatitic magma. Pegmatite commonly occurs along cross joints, one of the weaker structural zones in the country rock.

Other pegmatites locally have highly irregular and gradational contacts. Many bodies of albite-quartz pegmatite in oligoclase-quartz-biotite gneiss which, in part, cut across the foliation show no evidence of having disturbed the foliation in the host rock, and it may well be that these masses in part made way for themselves by replacement.

FAULTS

The pre-Cambrian rocks of the Dover district constitute part of a large block of pre-Cambrian rocks that is bounded on the southeast and northwest by great northeastward-trending faults that separate these rocks from strata of Paleozoic and Mesozoic age. These faults, whose vertical displacements commonly are measured in thousands of feet, are in part at least Triassic or younger in age, for they displace Triassic rocks. Little is known concerning the attitude of the fault planes, but these dislocations are considered by most geologists to be high-angle normal faults.

Within the Dover district only one large fault—the Green Pond—was mapped (pl. 1). This fault separates the pre-Cambrian rocks from the rocks of Paleozoic age on Copperas Mountain; according to Kümmel and Weller (1902, p. 28) it locally has a throw of about 1,500 feet.

The faults within the pre-Cambrian rocks of the Dover district, in contrast to the great bounding faults, have small displacements. They are not exposed at the surface and accordingly only those that were observed in the mine workings, or those that have been reported in the now abandoned mines, are shown on plate 1. Probably, however, faults occur in similar abundance in other parts of the Dover district.

The faults within the pre-Cambrian rocks of the Dover district can be classified, according to the attitude of the fault relative to the prevailing structural trend, as transverse, longitudinal, and oblique. The transverse faults are high-angle normal (or gravity) faults that strike northwest and generally dip steeply southwest. The longitudinal and oblique faults are reverse faults that strike northeastward and dip moderately to steeply northwestward. They are more abundant, but of smaller displacement, than the transverse faults. The displacement on all the faults, so far as known, generally is small, but nevertheless the faults are important because they present serious mining problems.

So far as known, all faults are later than the magnetite ore, but a more exact age cannot be assigned to them. The post-ore age is demonstrated by the presence of brecciated and slickensided ore at the contacts of ore bodies against faults.

TRANSVERSE FAULTS

The transverse faults can be broadly grouped into two classes. The first class includes the major transverse breaks, which trend N. 70°–80° W. and dip 60°–70° SW. The relative offset along the surface of dislocation is always to the right as one faces the fault plane. The Mount Hope and Erb faults, which are examples of this class, have normal horizontal separations of about 300 feet. The second class of transverse faults strikes more to the northwest and generally has a steeper dip, commonly being nearly vertical. With two exceptions—the North River and Mount Pleasant faults—these breaks also have an apparent horizontal displacement to the right.

A transverse fault is defined (Billings, 1942, p. 149) as one striking perpendicularly or diagonally to the strike of the regional structure. A diagram (fig. 6) illustrating a typical transverse fault in the district, shows a block of the earth's crust that has been broken into two parts, *A* and *B*, by sliding block *A* downward and to the left along an inclined fault plane so that point *a* moves to *a′*. The significance of the terms "net slip" (*a–a′*), "horizontal separation" measured along the fault surface (*b–b′*), and "vertical separation" (*c–c′*) are indicated. Obviously the horizontal separation is particularly important in mining operations, as it represents the horizontal distance along the fault between the separated ends of an ore body as measured on a particular mining level. Unfortunately, the net slip can be calculated for only one fault, the Mount Hope fault, but an exact vertical component of movement for most faults cannot be determined.

Erb fault.—The Erb fault is named from the Erb mine, now part of the Scrub Oaks mine. The fault is 600 feet northeast of shaft 1 at Scrub Oaks mine, and it extends eastward between the Corwin and Sterling mines, toward the Rockaway River valley, where it may unite with the McNeil fault (pl. 1).

This fault has been intersected on every level northeast of shaft 1 at the Scrub Oaks mine (fig. 33). It consists of a broken zone, locally as much as 100 feet

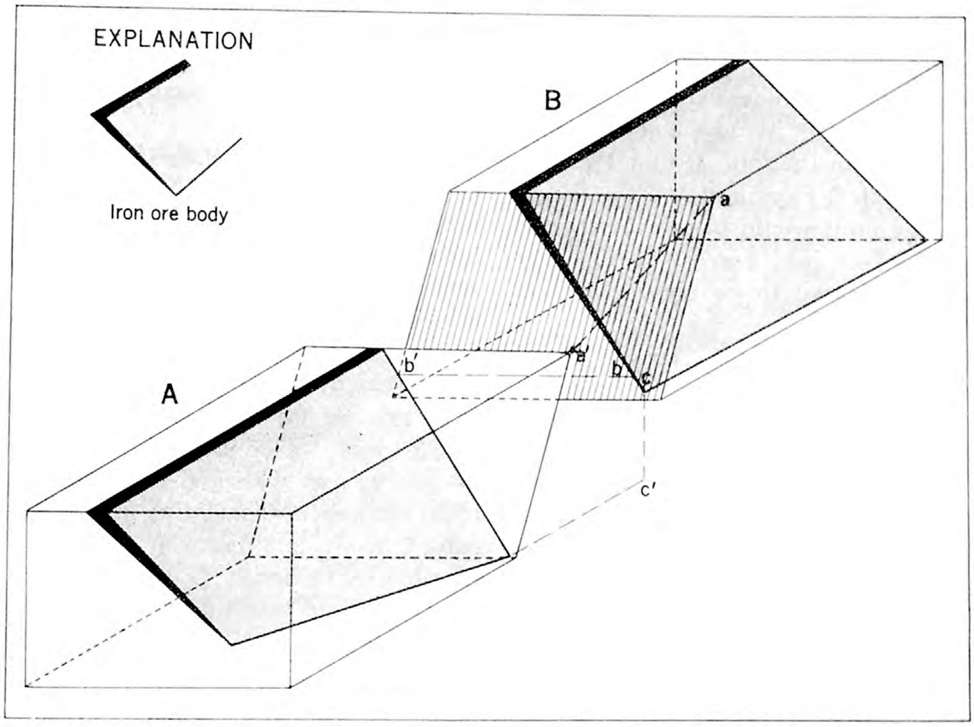


FIGURE 6.—Diagram illustrating a typical transverse fault in the Dover district.

wide, but the fault plane is commonly marked by a 6- to 12-inch gouge zone. Fractures throughout the fault zone, which are generally parallel to the main break, are coated with thin films of chlorite. The Erb fault strikes N. 78° W. and dips 63°–70° SW. A few slickensides rake 53° SE. The north or footwall side has moved eastward relative to the south or hanging-wall side; the true direction of movement along the fault plane is not known. On level 5 of the Scrub Oaks mine the horizontal separation of the footwall of the ore body is 310 feet; the estimated vertical displacement is about 325 feet. A gap of 150 feet occurs between the displaced ends of the ore deposit.

McNeil fault.—The McNeil fault is exposed in the Scrub Oaks mine a short distance south of shaft 1 (fig. 33). It trends essentially parallel to the Erb fault and, in contrast to the Erb fault, has a highly variable dip. On the upper levels of the mine it dips steeply north or is vertical, but below level 4 it has a dip of about 70° SW. and becomes essentially parallel to the Erb fault. The movement along the fault was rotational (Billings, 1942, p. 132) because on level 2 the horizontal separation of the footwall of the Scrub Oaks deposit is said to be 25 feet and on level 5 it is 130 feet. The vertical separation is about 155 feet on level 5, but the gap between the displaced ends of the ore body is only about 30 feet, because the fault strikes nearly normal to the trend of the ore deposit.

The McNeil fault zone consists of about 12 inches of gouge. The rocks adjacent to the gouge are not appreciably shattered, but a prominent joint set, subparallel to the fault, is developed for a distance of about 50 feet from the main break, gradually diminishing away from it (pl. 10). Chlorite pervades both the fault zone and the fractures adjacent to it.

Christmas fault.—The Christmas fault is at the southwest end of Scrub Oaks mine (fig. 33). On sublevel 4 it consists of a zone of badly shattered ground. The flow of water from this zone was so large that a concrete bulkhead was necessary to restrain it; hence the zone was not open for observation during the writer's examination of the mine. Diamond-drill holes indicate a wide area of broken ground at the southwest end of the mine that may be the Christmas fault zone, but surface magnetic maps show no offset of the ore body by the fault.

North River fault.—The North River fault strikes N. 45° W. and dips 85° SW. and separates the workings of the New Sterling and Harvey mines (pl. 1). According to Bayley (1910, p. 389) the fault has a horizontal separation to the left of 130 feet. The offset in the ore zone at prospect 29 suggests that the fault extends westward from the Harvey mine.

Rockaway River fault.—The Rockaway River fault is named from its occurrence near Rockaway River, where it was encountered at the northeast end of the Orchard mine (pls. 1 and 9). The ore in the Orchard mine (Mount Pleasant deposit) terminated at the fault, and its continuation was not found immediately north of the fault (Bayley, 1910, p. 393).

This fault probably is similar to the Erb fault by inferences drawn from unpublished mine maps of the underground workings and the known surface geology, which indicate a strike of N. 80° W. and a steep southerly dip. On the assumption that the Mount Pleasant deposit was worked in both the Orchard and the Washington Forge mines, the fault would have a horizontal separation of about 400 feet (pls. 1 and 9). The vertical displacement is estimated to be about 250 feet (pl. 9).

Mount Pleasant fault.—The Mount Pleasant fault, named from its occurrence in the Mount Pleasant mine, was encountered at the southwest end of the mine and is said to have a horizontal displacement to the northwest of 70 feet (Bayley, 1910, p. 397). (See pl. 1 and fig. 30.) Numerous other transverse faults were encountered in the mine (Bayley, 1910, p. 396), but none of these was large.

No. 4 fault.—The No. 4 fault is exposed 525 feet southwest of shaft 2 at the Richard mine (pl. 1). It does not crop out at the surface, but it was intersected on all underground levels in the mine (pl. 9). It strikes N. 58° W. and according to the mine maps (Richard mine) has an average dip of 82° NE., but Bayley (1910, p. 400) refers to it as dipping steeply southwest. To judge from the company maps of the Richard mine, the fault has a horizontal separation and a vertical displacement of 75 to 100 feet.

No. 1 fault.—The No. 1 fault is a short distance north of Teabo shaft 3 at the Richard mine (pl. 1). It does not crop out, but its surface trace is a curved lineament on aerial photographs. The fault strikes N. 60°–65° W. and dips about 60° SW. It has a horizontal separation of 50 feet on the 1,300-foot level, and a vertical displacement of about 60 feet, as determined by the displaced ends of the Richard and Mount Pleasant ore bodies (pls. 7 and 8). Parallel faults with minor displacements are found near this fault, but their relatively small offsets do not affect mining operations.

Allen fault.—The Allen fault is 334 feet northeast of shaft 3 at the Richard mine (Bayley, 1910, p. 400). It is nearly vertical and according to Mr. Hoster (oral communication) has a horizontal separation of 50 feet to the left and a vertical displacement of 60 feet; the northeast side is downthrown. The fault was encountered on the upper levels, but it has not been recognized below the 700-foot level (fig. 22). Its absence below this elevation may be the result of splitting into several smaller breaks, or more probably to its being cut off by the September fault.

Mount Hope fault.—The Mount Hope fault is named for the Mount Hope mine, where it separates the workings on Mount Hope Hill from those on Hickory Hill (pl. 2). It was discovered during the early mining operations, and Bayley (1910, p. 413) refers to it as the Brook fault, for its intersection with the surface essentially follows the small brook that drains into Mill Pond.

The general strike of the fault is N. 78° W.; its average dip is 60° SW. The mining operations have indicated that movement along the fault was translatory, and there is little, if any, difference in its attitude and displacement between the surface and a depth of 2,100 feet. The net slip is about 300 feet. The horizontal separation of each ore body is dependent upon the dip of the particular deposit, and it is greater for those deposits that have relatively gentle dips. The fault in the mine workings is a brecciated and shattered zone 20 to 30 feet wide. The main surfaces of dislocation are marked by gouge zones from 6 inches to 2 feet wide that have been pervasively invaded by chlorite. Locally, limonite stains are common, and on the 1,000-foot level small crystals of melanterite are found at places in the fault zone. Water circulates freely through the zone; when first intersected on any level, the flow is several hundred gallons per minute, but after the fault is tapped at a lower level, the flow abruptly diminishes.

LONGITUDINAL AND OBLIQUE FAULTS

Longitudinal and oblique faults are much more abundant, but generally of smaller displacement, than the transverse faults, to judge from their size and abundance in the Richard and Mount Hope mines; a few occur in the Scrub Oaks mine. These faults are principally high-angle reverse faults that dip moderately to steeply northwest and have a throw that ranges from less than a foot to about 80 feet. A few, such as the Taylor fault at the Mount Hope mine, are low-angle reverse faults or thrusts.

Even though the vertical displacement along these faults generally can be measured in a few feet, or tens of feet, the faults are of considerable practical importance, as they seriously affect mining operations in some of the mines. These faults are common in the Richard and Mount Hope mines and are reported to have been encountered in several of the abandoned mines, such as the Mount Pleasant mine. The principal longitudinal and oblique faults are discussed under each mine in the section on mines and prospects.

A longitudinal fault that has been named the Green Pond fault (Sims, 1953, p. 269) separates the pre-Cambrian rocks from the rocks of Paleozoic age on Copperas Mountain (pl. 1). Kümmel and Weller (1902, p. 28) described the fault, a mile north of the upper end of Green Pond, as having a throw of about 1,500 feet, with uplift on the west. Northward the throw diminishes rapidly and the dislocation seems to die out within a short distance. They interpreted the fault to dip steeply northwest, thus inferring that it is a high-angle reverse fault, but the writer observed no evidence that indicated the attitude of the fault plane.

AGE OF FAULTING

The relative ages of the transverse and longitudinal faults in the Dover district are not known, because the mine workings are nowhere favorably situated in relation to their intersections. There is some evidence in the Richard mine that the Allen fault, a transverse fracture, is cut off by the September fault, an oblique fault. It is possible, however, that the Allen fault dies out at its intersection with the September fault.

The time of formation of the faults, as well as their relative ages, is not known. The faults may be related to the same period of deformation, or to different periods, but their age cannot be established until a study is made of the entire northern New Jersey region that includes the post pre-Cambrian rocks. If it is assumed that the longitudinal faults that are so abundant locally at the Mount Hope and Richard mines were formed at the same time as the Green Pond fault, then these faults are younger than the youngest rocks displaced by the Green Pond fault, which according to Kümmel and Weller (1902, p. 28) are Silurian in age, and possibly are Triassic or younger. There is no known evidence that can be used to date the other fault systems within the pre-Cambrian rocks. Slickensides and mullion structures that rake at a large angle to the known direction of principal movement indicate that minor adjustments took place along most of, if not all, the transverse faults after their formation.

SUMMARY OF GEOLOGIC HISTORY OF THE DISTRICT

The metasedimentary rocks are the oldest rocks in the pre-Cambrian complex of the Dover district and are the product of the metamorphism of ancient carbonate and alumino-siliceous sediments. Pure carbonate rocks were a minor constituent of the sedimentary series in the region; impure carbonate and alumino-quartzose sediments were much more abundant. The sedimentary rocks were metamorphosed and folded during a long period of Proterozoic orogeny. During folding, the rocks were recrystallized, and the original fabric and texture—except, at places, the bedding—were destroyed. Intrusive igneous rocks of dioritic and granitic composition were emplaced during the orogeny. Because of the intense metamorphism, folding, and injection of igneous rocks, the age sequence of the metasedimentary units is poorly known.

The oldest igneous rocks in the Dover district—quartz diorite and related facies—were emplaced during the early stages of the orogeny as conformable sheets. The magma was dry and produced little or no contact metasomatism. Continued deformation resulted in the folding and recrystallization of these rocks. Later in the orogeny albite-oligoclase granite, generated at depth by anatexis and differential fluxing of oligoclase-quartz-biotite, and perhaps other similar rocks, was emplaced into the level now exposed by erosion as conformable lenticular sheets and phacoliths. A late differentiate of this magma consolidated as albite-quartz pegmatite. Near the close of the orogeny hornblende granite and related facies, derived principally by differentiation of a granite magma, were emplaced as phacoliths and concordant sheets. During the emplacement of this granite thermal solutions moving in advance of, and accompanying, the melt altered and modified the metasedimentary rocks to varying degrees. Of particular importance was the development of skarn by the metasomatic alteration of carbonate rocks. After the consolidation of most of the hornblende granite magma potassic solutions of presumed metasomatic origin migrated upward, particularly along the contacts of the granite with albite-oligoclase granite or oligoclase-quartz-biotite gneiss and partly altered the earlier consolidated plagioclase of the rocks, forming microantiperthite granite. The last phase of the granite magma to consolidate was granite pegmatite. The final stage in the differentiation of the hornblende granite magma was the formation of the magnetite deposits from iron-bearing fluids derived from the alaskitic differentiate of the magma.

So far as known, after the formation of the magnetite deposits in Proterozoic time the region was subjected to erosion and probably reduced to a peneplain. At the beginning of the Cambrian period this region was invaded by the sea and a thick sequence of sediments was laid down. Near the close of the Ordovician period the sea withdrew, and in parts of the Appalachian region the strata of early Paleozoic age were somewhat deformed.

Late in the Silurian period, after a period of erosion during which some of the sediments previously deposited were removed, the sea again invaded at least the western part of the region and deposited another thick series of sediments. The sea withdrew toward the close of the Devonian period as the land began to rise. Near the close of the Paleozoic era the region was deformed by the Appalachian orogeny and the strata of Paleozoic age were folded and faulted.

Late in the Triassic period diabase dikes, thought to be related to the great basalt flows that were erupted upon the surface and interbedded with the sediments in the Triassic lowlands, were injected into the pre-Cambrian igneous and metamorphic rocks.

A long period of erosion followed, but in Late Cretaceous time the sea probably advanced again over the region, depositing sand and clay. Uplift followed; the surface was worn to a lower level, and the landward edge of the Cretaceous strata was removed. During Tertiary time (Von Engeln, 1942, p. 356–364), the region was reduced to a peneplain, the Schooley (or Upland) peneplain, which later was submerged, permitting the sea to advance from the east and deposit a cover of sediments. This surface then was uplifted and degraded, and a new peneplain, the Harrisburg, was developed on the most resistant beds below the level of the Schooley peneplain.

In the Pleistocene the region was invaded by at least two continental ice sheets which slightly modified the topography and left extensive deposits of glacial drift.

MAGNETITE DEPOSITS

The iron-ore deposits are pre-Cambrian in age, and occur in several types of metasedimentary and igneous rocks. Most deposits are massive magnetite of non-Bessemer grade and contain 35 to 60 percent iron; a few consist of disseminated-type ore of Bessemer grade that contains 25 to 35 percent iron. The ores are nontitaniferous; a few percent of hematite is present in the disseminated ores; sulfides are sparse. The deposits occur in belts or ranges and form steeply dipping, veinlike bodies that essentially conform to the gneissic structure in the wall rocks: they strike and dip parallel to the foliation and plunge parallel to the lineation. The lath-shaped bodies, the important sources of ore, average between 10 and 20 feet in thickness and have a surface or stope length of as much as 7,000 feet, but generally less. They rake 10°–40° NE. and extend indefinitely along their longitudinal axes. The pod-shaped bodies, largely because they pinch at shallow depths, are not commercial sources of ore. Unequivocal evidence indicates that the iron was introduced into the various host rocks subsequent to their consolidation, probably by high-temperature metasomatic fluids, whose source is thought to be the alaskite magma.

TYPES OF DEPOSITS

The principal iron-ore bodies in the Dover district are in (1) oligoclase-quartz-biotite gneiss, (2) hornblende skarn, (3) pyroxene skarn, and (4) albite-oligoclase granite; others occur in reconstituted amphibolite and microantiperthite granite. Low-grade magnetite concentrations occur in amphibolite, interlayered biotite-hornblende-pyroxene-feldspar gneisses, and granite pegmatite. The deposits in oligoclase-quartz-biotite gneiss, hornblende skarn, and albite-oligoclase granite have been the most valuable sources of ore. Of the deposits in the other rock types, only those in reconstituted amphibolite and microantiperthite granite have been mined extensively; some deposits in amphibolite and biotite-hornblende-pyroxene feldspar gneisses are potential sources of low-grade ore.

The ore bodies in oligoclase-quartz-biotite gneiss and skarn consist of massive high-grade magnetite with sparse gangue, whereas the ore bodies in albite-oligoclase granite consist of disseminated medium- to low-grade magnetite and some hematite.

CHEMICAL COMPOSITION OF ORE

The iron ores contain 1 percent or less of titanium; accordingly they belong to the ores that have been called "nontitaniferous" magnetites. Phosphorus is a variable but generally sparse constituent. The disseminated ores, after concentration, are of Bessemer grade; the high-grade massive deposits yield non-Bessemer ores.

The chemical composition of the high-grade massive ore in all ore bodies is similar because magnetite constitutes nearly all the ore. The ore of the disseminated type, as at Scrub Oaks mine, however, differs considerably chemically, for it contains a somewhat different suite of ore minerals and considerable quantities of gangue.

Many analyses of iron ores from the district have been published in the 10th Census Report (Pumpelly, 1886) and by Bayley (1910, p. 93–114), and a few of the more reliable and complete ones are reprinted here in table 12. In addition, a new analysis of ore from the Scrub Oaks mine is included.

The chemical composition of the pure magnetite is 72.4 percent iron and 27.6 percent oxygen. The massive, high-grade ore in the Dover district approaches this composition, but never attains it, for some impurities are always present. Analyses 1 to 10 inclusive in table 12 represent massive high-grade ore, which is characterized by high Fe, low Mn, low Ti, low to moderate P, low S, and low to moderate SiO_2. All the recoverable Fe is in the form of magnetite; probably a little soluble, nonmagnetic Fe is yielded by hornblende and pyroxene, which forms sparse grains in some ore; this Fe is not recoverable. The differences in chemical composition, which are small, are caused largely by differences in the quantity and kind of fragments of the host rock in the ore. It is probable, though, that nearly all the V, Cr, Ni, and most of the Mn are contained in the magnetite lattice itself. The P, which occurs in all the massive ores in amounts ranging from 0.02 to 0.81 percent, is contained in apatite. Most of the Ti is in ilmenite, but a small part of it is in sphene and rutile.

Analysis 11 (table 12), of medium-grade ore of the disseminated type from Scrub Oaks mine, is character-

TABLE 12.—*Chemical analyses*[1] *of magnetite ores from the Dover district*

[Analysts: W. T. Schaller, No. 1; R. B. Gage, Nos. 2–10; Charlotte M. Worshaw, No. 11. Sample 10 contains a little chlorine]

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	9.25	7.14	3.77	2.22	3.56	7.63	1.38	8.46	1.51	6.37	26.04
Al_2O_3	1.98	1.23	.79	.59	.44	.49	.55	.77	.37	1.59	2.11
Fe_2O_3	55.71	60.89	61.16	62.76	61.47	55.24	65.26	56.18	64.87	57.46	47.17
FeO	26.64	25.94	29.56	28.59	29.04	26.12	30.20	27.81	31.11	27.23	21.58
MgO	1.11	1.40	.64	.74	1.68	1.89	.10	1.88	.40	1.01	.40
CaO	1.89	1.31	1.23	2.54	1.66	4.34	.68	1.68	.51	2.93	.40
Na_2O	.57	.08	.12	Tr.	.10	.27	Tr.	.22	Tr.	.12	1.06
K_2O	.12	.13	.14	Tr.	.12	.20	Tr.	.36	Tr.	.18	.24
H_2O+	.56	.25	.16	.13	.16	.21	.12	.28	.09	.21	.38
H_2O-	.43										.06
TiO_2	.54	1.25	1.30	.30	1.15	1.05	1.09	1.06	1.05	.70	.49
ZrO_2	.00										
CO_2	.35										.17
P_2O_5	.86	.529	.448	1.89	.541	2.44	.49	.98	.053	2.18	.22
S	.07	.014	.011	.14	.021	.02	.01	.01	.007	.46	
Cr_2O_3	.01	0	0	0	0	0		0	0	0	
NiO	.02	0	0	0	0	0	0	0	0	0	
MnO	.05	.03	.06	.04	.03	.04	.03	.04	.08	.03	.03
CoO	0	0	0	0	0	0	0	0	0	0	
CuO	0										
ZnO	0										
BaO	0	0	0	0	0	0	0	0	0	0	
SrO	0	0	0	0	0	0	0	0	0	0	
Li_2O	0										
V_2O_3	.14	.15	.095	.11	.08	.08	.08	.11	.13	.08	.003
Total	100.30	100.343	99.484	100.05	100.052	100.01	99.99	99.84	100.18	100.136	100.353
Fe	59.78	62.85	65.87	66.23	65.68		69.24		69.68		49.85
P	.37	.23	.19	.81	.23		.18		.02		.09

[1] Analyses 1-10, inclusive, from Bayley (1910, p. 112–114); analysis 11 by U. S. Geological Survey.

1. Cobbed ore, Hibernia mine. Representing shipments of 1906.
2. Hibernia mine. Average sample, 1908.
3. Richard mine. Ore of North (Mount Pleasant) "vein." Average sample, 1908.
4. Richard mine. South (Richard) "vein." Selected sample, 1908.
5. Leonard mine, Mount Hope. Selected sample of Leonard "vein," 1908.
6. Leonard mine, Mount Hope. Average sample of Leonard "vein," 1908.
7. Elizabeth mine, Mount Hope. Selected sample of Elizabeth "vein," 1908.
8. Elizabeth mine, Mount Hope. Average sample of Elizabeth "vein," 1908.
9. Hurd mine, Wharton, N. J. Selected sample of Hurd "vein," 1908.
10. Hurd mine, Wharton, N. J. Average sample of Hurd "vein," 1908.
11. Scrub Oaks deposit, level 5, Scrub Oaks mine, Dover quadrangle. Field No. S05-26.

ized by high Fe, moderately high SiO_2, and low P. Most of the recoverable Fe in this ore is in the form of magnetite, but a small proportion is hematite. Because of the low P content, the ore is classified as Bessemer grade.

MINERALOGY

The iron ores consist of a simple suite of metallic minerals. Magnetite constitutes the only ore mineral in the massive ore bodies and is the principal ore mineral in the disseminated deposits. Primary hematite constitutes about 15 percent of the ore in the disseminated deposits but is sparse in the massive ore. Martite occurs in minor amounts in the deposits that contain hematite. Small discrete grains and oriented lamellae of ilmenite in iron oxides are widespread but are generally negligible in quantity. Pyrrhotite, pyrite, and chalcopyrite constitute more than 1 percent of the ore in the deposits in the Green Pond ore belt, and they locally are present in the deposits in the Splitrock Pond-Charlottesburg ore belt and at the Denmark and J. D. King mines; they are generally absent in other deposits.

The gangue consists predominantly of irregular fragments of the host rock and small amounts of minerals that are believed to have been deposited with the ore. Only the minerals thought to have been introduced by the ore-forming solutions or by later supergene solutions are discussed on the following pages.

OPAQUE MINERALS

MAGNETITE

Magnetite, the principal ore mineral, forms single grains, 1 to 5 mm in diameter, and also aggregates of grains. The grain size and the texture vary somewhat with the grain size, texture, and structure of the host. The magnetite in massive ore occurs as homogeneous masses and irregular grains, generally subpolygonal, that form aggregates of different shapes. The magnetite in low- to medium-grade ore occurs as irregular blotches, disseminations, thin veinlets, streaks, and irregular layers. In the low-grade ore it can be seen that the magnetite embays and corrodes and penetrates along the grain boundaries of the host minerals; commonly it surrounds and isolates some of the grains of the host.

The magnetite appears homogeneous in hand specimens, but polished sections show that some of it contains small bodies of spinel and ilmenite. The spinel occurs as minute blades and spindles, and locally as irregular rods or blebs, that are distributed more or less regularly throughout the magnetite (pl. 16*C*); the ilmenite occurs as oriented blades in magnetite or as discrete blebs that embay the magnetite. The texture resembles the crystallographic texture described by Schwartz (1951, p. 584). Similar textures have also been described by Schneiderhöhn and Ramdohr (1931, p. 581–582).

HEMATITE

Hematite constitutes an average of about 15 percent, and locally as much as 50 percent, of the ore at

Scrub Oaks mine, a disseminated deposit, but it is sparse in the massive ores.

At Scrub Oaks mine the hematite occurs in single grains and aggregates of about the same size and shape as the magnetite. The hematite is crystalline, but it lacks the platy habit and high luster of specular hematite. In hand specimens it is distinguished from magnetite with difficulty by its bluish-gray hue, nonmagnetic character, and reddish streak; in polished sections it appears white in contrast to the brown of the magnetite. The hematite grains are intergrown with magnetite, and they embay and corrode the host.

In massive iron ores collected at or near the surface, hematite locally occurs as sparse thin laths or blades of slightly different widths that generally are alined along the octahedral planes of the magnetite. (See Martite, below.) At the Birch mine (pl. 1) hematite is present as long oriented blades in ilmenite; the blades appear to cut the twin lamellae of the ilmenite and presumably are alined parallel to its basal parting.

The hematite in the disseminated type of ores is similar to the hematite in the granite gneiss ores in the St. Lawrence County magnetite district, which Leonard (1951, unpublished manuscript in files of Princeton Univ.) has called "primary crystalline hematite."

MARTITE

Martite (hematite pseudomorphous after magnetite) was observed at places in the Scrub Oaks deposit, but it is thought to be quantitatively unimportant and probably constitutes only 1 or 2 percent of the ore. It consists of aggregates of hematite that embay and corrode parts of individual grains, and of regular intergrowths in magnetite. Evidences of martitization consist of irregular veinlets and blades of hematite in magnetite (pl. 16*D*) and partial rims of hematite around magnetite. In plate 16*D* it can be seen that the martite forms generally irregular veinlets, which under the microscope extinguish simultaneously—showing optical continuity between separate veinlets—and thin blades, generally with sharp boundaries, in magnetite. The thin blades extinguish separately from the veinlets; they show a definite alinement along the octahedral planes of the magnetite. Completely corroded magnetite crystals were not observed in any of the specimens examined.

Hematite, as blades and tapering laths, in magnetite was observed at the Birch mine, at the White Meadow mine, and at places in other deposits. At the Birch mine the hematite forms two sets of blades in the magnetite. The blades seem to be most abundant near the contacts of magnetite and discrete ilmenite grains. At the White Meadow mine hematite occurs as thin blades and laths that are of variable width and length oriented along the octahedral planes of the magnetite.

The regular intergrowths of hematite in magnetite, which cannot be related to supergene alteration near or at the surface, are probably the result of hypogene replacement, rather than the unmixing of a once-homogeneous solid solution; for Mason (1943, p. 125) states that temperatures of 1,100° to 1,200° C and higher are necessary to increase the solubility of Fe_2O_3 in Fe_3O_4 sufficiently so that unmixing will tend to take place on cooling, and the writer does not believe that these ores ever approached this range of temperatures.

ILMENITE

Ilmenite is present in a few deposits in the Dover district, but it is not distinguishable in hand specimens. Examination of polished ore samples under the reflecting ore microscope shows that the ilmenite occurs primarily as small discrete grains intergrown with magnetite and to a lesser extent as lathlike bodies in magnetite. At the Birch mine, where ilmenite constitutes more than 10 percent of the ore in the specimen examined, the ilmenite forms discrete grains that appear to be intergrown with the magnetite. The grains are irregular and subpolygonal; they show conspicuous twin lamellae. The ilmenite grains contain oriented blades and spindles of hematite and spinel that are thought to lie along the basal parting plane. Ilmenite, as small blades in magnetite, was observed in specimens from the Hibernia mine, the Birch mine, and the Teabo deposit at Mount Hope mine. It was not observed in specimens of the disseminated ore.

PYRITE

Pyrite is an ubiquitous constituent of the iron ores in the Green Pond ore belt, and it is estimated that it constitutes about 1 percent of these ores. It occurs as aggregates of coarse, subpolygonal grains, and less commonly as veinlets, that embay and cut magnetite. In places it is closely associated with pyrrhotite and chalcopyrite, and with these minerals locally forms nodularlike masses. At places adjacent to other massive ore bodies in the Wharton ore belt, and particularly near the upper edge of the deposits, pyrite, similar in appearance, occurs as sparse grains dispersed in the wall rocks and as inch-thin veinlets in the ore.

Fine-grained pyrite, associated with a pink carbonate, is in thin veins, generally less than an inch thick, in fractures that cut both the ore and the wall rocks at some mines.

PYRRHOTITE

The deposits in the Green Pond ore belt characteristically contain about 1 percent of pyrrhotite. Pyrrhotite also was observed at the J. D. King, the Denmark, and the Wood mines (pl. 1); and it may be present locally at the Charlottesburg mine, for the analysis of an ore specimen from the mine shows 3.36 percent S (Bayley, 1910, p. 419). The pyrrhotite occurs as irregular, subpolygonal grains and veinlets that embay and corrode magnetite. It also cuts and appears to replace pyrite.

CHALCOPYRITE

Small quantities of chalcopyrite are present as irregular blebs and curved seams that corrode pyrrhotite in most of the deposits in the Green Pond ore belt. Locally the chalcopyrite and pyrrhotite form concentric nodular masses. So far as known, chalcopyrite never exceeds 1 percent of the ore in the Green Pond deposits.

UNKNOWN METALLIC MINERAL

An unknown metallic mineral that appears bluish gray in polished sections and which has a greater reflectivity than magnetite was observed in an ore specimen from the Teabo ore body, from the 1,000 level at Mount Hope mine. The mineral forms minute irregular patches or blotches that appear to embay magnetite. It is pleochroic and strongly anisotropic. It occurs as tiny bodies that can be observed only under high magnification.

NONOPAQUE MINERALS

APATITE

Apatite, an ubiquitous constituent of all the ores, is common in the massive ores and sparse in the disseminated ores.

In the massive ores the apatite occurs as white to pale-brownish granules that are polygonal to subpolygonal in shape and that tend to form laminae essentially parallel to the ore walls (pl. 17*A*). It constitutes on the average about 1 to 3 percent of this ore, but it is exceptionally abundant in two deposits—Canfield's phosphate and the Gold Diggings at the Mount Hope mine. Canfield's phosphate deposit contains about 25 to 40 percent apatite (pl. 17*B*), and accordingly it was at one time considered as a possible source of phosphorus (Bayley, 1910, p. 381), but a process was never perfected for its recovery on a commercial scale. The Gold Diggings deposit contains an estimated 25 percent apatite.

Apatite also is dispersed through the wall rocks of some massive ore deposits, some of it in the form of large euhedral crystals. Most of this apatite probably is related to the ore, but some of it is clearly related to pegmatites. Apatite is sparse in the disseminated ores and generally cannot be seen megascopically.

QUARTZ

Quartz commonly constitutes 15 percent or more of the disseminated ore. It is clear to white and occurs as small crystals of the same size as the quartz in the albite-oligoclase granite wall rocks. Coarse-grained milky-white quartz is abundant where the disseminated ores are associated with granite pegmatite. Both types of quartz are pre-ore and at places are surrounded by magnetite and occur as isolated grains in the ore.

In some massive ore deposits quartz forms sparse rims around other silicate grains, and around veinlets that penetrate and corrode magnetite, but this type of quartz is never abundant. Another variety—coarse, milky quartz, associated with white calcite—cements breccia fragments of magnetite at places in massive ore deposits.

CARBONATE

The calcite that occurs locally in magnetite breccias (pl. 17*D*) is white and coarse grained and commonly forms crystals half an inch in diameter. Another carbonate, probably calcite, which is white to pink and fine grained, occurs with pyrite in fractures that at places cut both the ore and the wall rocks.

MICA

Nearly all the ore deposits in oligoclase-quartz-biotite gneiss contain selvages, partings, or thin films of biotite, which are similar to one type of sköl, or shell, that has been described from some Fennoscandian deposits (Eskola, 1914, p. 226, 259; Magnusson, 1940, p. 185), and from the northwest Adirondacks (Leonard, B. F., 1951, manuscript in files of Princeton Univ.).

The sköls in the Dover district consist of a dark mica, probably biotite. They contain different proportions of magnetite, but they seldom constitute ore. The most conspicuous sköls are selvages that occur along one or both walls of the deposits, and range from less than 1 inch to more than 1 foot in thickness. In a few deposits these are locally absent. Less commonly the sköls form partings, a few inches thick, or films, which are parallel to the layering in the ore and to the gneissic structure of the wall rocks. The biotite flakes that constitute the sköls nearly always are alined parallel to the ore walls.

Pale-green mica sköls that have a silvery appearance are associated with pyroxene skarn, marble, and serpentine at the Splitrock Pond mine. Little is known concerning the occurrence of the sköls, but to judge from specimens on the mine dump, they form layers within the skarn, and selvages. Generally they contain sparse to moderate amounts of magnetite. These sköls differ in appearance from the more common, dark biotite sköls in the district. They closely resemble in appearance the sköls associated with skarn magnetite deposits in the St. Lawrence County district in New York (B. F. Leonard, 1951, manuscript in files of Princeton Univ.).

In addition to the mica that constitutes the sköls, a dark reddish-brown mica, probably lepidomelane, occurs at places in some massive ore bodies as narrow rims around magnetite grains and as veinlets that cut both the ore and the wall rocks. The relationship of this mica toward magnetite suggests that the lepidomelane(?) is later than the ore; the relation of the lepidomelane(?) to the mica sköls is not known, for the different micas have not been seen in contact, but it is inferred that the lepidomelane also is younger than the mica sköls.

SPHENE

Although sphene ($CaTiSiO_5$) was not observed in the high-grade, massive ore, it is known to be present in the migmatized amphibolite wall rocks adjacent to some magnetite bodies. At Richard mine, adjacent to the Mount Pleasant ore body, sphene occurs as narrow rims around magnetite (pl. 17*C*) and as interstitial grains that embay the rock-forming silicate minerals in the amphibolite migmatite. Because sphene is rare in the Dover ores, it cannot account for much of the titanium. Bayley (1910, p. 115), however, reported sphene in some sections of ore from New Jersey, and accordingly it may be more abundant at other places in the State.

As sphene is not known to be present in rocks other than amphibolites, it probably formed by the reaction between the mafic constituents of the amphibolite and the ore-forming solutions. The titanium in the sphene lattice probably was derived from the original rock, for sphene also is abundant in some amphibolite migmatites far removed from magnetite deposits. Because of a chemical affinity for magnetite, the sphene preferentially formed around or adjacent to magnetite.

Sphene rims on magnetite in the Lyon Mountain, N.Y., iron deposits have been interpreted differently by Gallagher (1937, p. 41), for he concluded that the sphene "was introduced, probably with the magnetite."

PUMPELLYITE

Pumpellyite ($Ca_4(Mg, Fe)\ Al_5Si_6O_{23}(OH)_3$) is found in several deposits in the district. It was first recognized in the Scrub Oaks deposits, and identified by B. F. Leonard, and subsequently was observed in the Beach Glen deposit and the Middle "vein" at the Richard mine. The pumpellyite, which appears to be a ferroan variety, occurs as scattered grains in the rock-forming silicates, rims around magnetite, and veinlets that cut both the magnetite and the wall rocks. It generally is closely associated with the ore but locally at the Scrub Oaks mine it is present as much as 30 feet from the ore body.

So far as the writer knows, the first recognition of pumpellyite in magnetite deposits was made by Leonard (1951, manuscript in files of Princeton Univ.) in the St. Lawrence County district in New York.

CHLORITE

Small amounts of chlorite are found in the massive ores. It occurs as an alteration production of the feldspar and mafic minerals in the ore bodies, as rims on magnetite, and locally as selvages along the margins of ore bodies. Chlorite also is a common alteration product in the wall rocks, but much of it in this environment probably is the result of weathering processes.

TOURMALINE

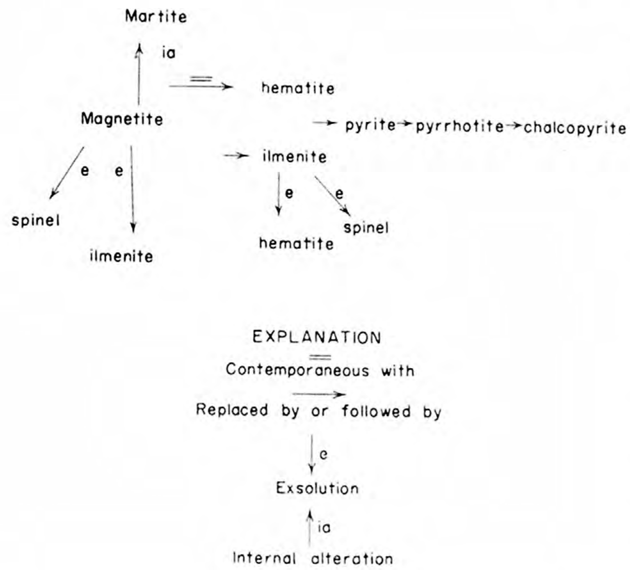
The ore in the Scrub Oaks deposit contains sparse tourmaline, a complex borosilicate of aluminum and other bases, which is present as strongly pleochroic euhedral crystals that range in color from pink to dark olive green. Most commonly the tourmaline occurs with the rock-forming minerals between the magnetite grains in the ore; it was not observed in the wall rocks.

RUTILE

Rutile (TiO_2), as interstitial aggregates that in part embay and replace quartz, is locally present in the ore at Scrub Oaks mine; it was not observed in the enclosing rocks. It is probable that the rutile would be extracted from the ore during magnetic separation, and it should not contaminate the iron concentrate.

PARAGENESIS

The writer believes that the ore minerals were formed during a single period of mineralization. During this period, referred to as the ore-forming period, the following minerals developed as discrete grains: magnetite, hematite, ilmenite, pyrite, pyrrhotite, chalcopyrite, apatite, quartz, calcite, biotite, sphene, tourmaline, rutile, chlorite, and pumpellyite. During cooling, ilmenite and spinel were exsolved from magnetite, and hematite and spinel were exsolved from ilmenite. Martite formed locally by the internal alteration of magnetite. A summary of the paragenetic sequence of the metallic minerals formed during this period is shown below.



The paragenetic sequence of the nonmetallic constituents of the ores is poorly known because many of these minerals are sparse and have not been observed in contact. The mica that constitutes the sköls is believed to be the earliest nonmetallic component of the ores. It was formed before the magnetite, for it is partly replaced by it; probably some of the sköls developed soon after the formation of the skarn. Another gangue mineral that is in part earlier than the iron ore is apatite, for at places it is replaced by the magnetite (pl. 17*B*); much of it, however, occurring as granules in the ore, probably is essentially contemporaneous with the magnetite. Most of the other gangue minerals, because of their relations to the magnetite, probably are later than the magnetite, but their sequence of formation is not known. Some of these—biotite (lepidomelane ?), quartz, sphene, chlorite, and pumpellyite—are demonstrably later, for at places they occur as rims on magnetite.

Following the formation of the ore minerals there was local minor fracturing and crackling along the margin of some of the massive ore bodies and subsequent deposition of small quantities of calcite and quartz, which cement breccia fragments of the magnetite, as shown in plate 17*D*. Possibly some fluorite also was deposited during this stage, for Bayley (1910, p. 455) reports it with narrow veinlets of calcite and crystalline quartz in places along the walls of the Hibernia deposit at Hibernia mine; but it was not identified by the writer.

A second, very minor, period of mineralization, that is much later than the ore forming period, is recognized in the district. During this period small quantities of calcite and pyrite were deposited along fractures that cut both the ore and the wall rocks. The fine texture of these minerals indicates that they were deposited at much lower temperatures than the earlier minerals that were deposited during the ore-forming period, and they may have been deposited by ground waters.

Near the surface, where the deposits have been subjected to weathering, the magnetite locally is slightly altered to martite because of supergene oxidation. The martitization that has been observed is incipient and is indicated by sparse blades and laths of hematite along octahedral partings in the magnetite. Possibly it is more advanced at places near the surface where faults of considerable magnitude cut the ore and provide access to circulating ground waters, but deposits of hematite ores of this origin, like those at Andover mine, in Sussex County (Sims and Leonard, 1952), have not been encountered.

APPEARANCE OF ORE

Because the ores in the Dover district, with the exception of the disseminated type, consist essentially of magnetite, their appearance is largely dependent upon the texture and structure of the magnetite. Most of the high-grade ore is black and hard and is composed of medium- to fine-grained, compact magnetite that has a conspicuous blocky structure produced by 3 intersecting sets of closely spaced joints (pl. 18*A*). A less common, but locally abundant type, known to the miners as "shot ore", is composed of somewhat friable, coarsely crystalline magnetite that appears structureless. Generally, in these ores, one set of joints that parallels the walls is conspicuous.

The gangue in the ore, particularly the apatite, tends to be concentrated into rude laminae that are essentially parallel to the ore walls (pl. 17*A*). The pyroxene and hornblende, which together locally are as abundant as apatite, are more irregular in distribution and shape. At places the long dimensions of these grains have a subparallel alinement to produce a linear structure that is parallel to the linear elements in the wall rocks. The biotite is sufficiently abundant in some parts of the ore to produce layered ore with a schistose structure.

Some ore in hornblende skarn is laminated, for it contains layers of skarn from less than 1 inch to 1 foot thick that are interlayered with magnetite.

The disseminated type of ore is typically dark gray to black, hard, and siliceous. It consists of fine- to coarse-grained granules and aggregates of magnetite and minor hematite with a variable but generally high proportion of admixed gangue minerals, principally quartz and albite (pl. 18*B*); apatite is sparse. The gangue minerals typically occur as grains similar in size to the ore minerals. Streaks and veinlets of magnetite, from a fraction of an inch to a few inches wide, are present locally.

FORM AND SIZE OF DEPOSITS

The iron-ore deposits of the Dover district are veinlike bodies that essentially conform to the gneissic structure of the pre-Cambrian country rocks. At the surface the deposits appear to be tabular, but when observed in three dimensions they are seen to be either lath shaped or pod shaped; they strike and dip parallel to the foliation and plunge parallel to the lineation in the country rock (fig. 7). The lath-shaped deposits—the most important sources of ore—are so designated because their long dimensions (longitudinal axis or pitch length) are of indefinite length; in cross section they resemble double-edged swords. The pod-shaped deposits—those in pyroxene skarn—on the other hand, are lenticular and pinch and swell along their longitudinal axes. Most of the deposits dip at angles greater than 45° and all plunge gently to moderately northeast. The bearing and angle of plunge of an ore body are remarkably constant along its length.

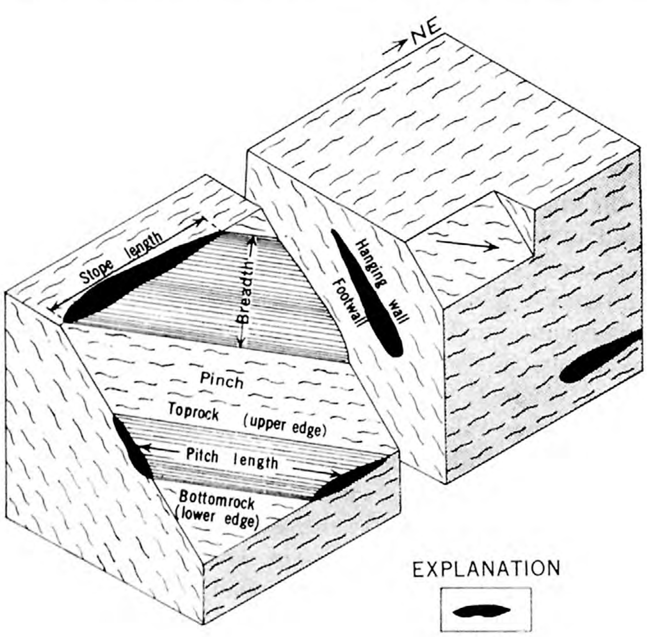


FIGURE 7.—Block diagram showing idealized structure of lath-shaped ore bodies in the Dover district. The deposits extend indefinite distances along their pitch length.

TERMINOLOGY USED IN THE DISTRICT AND IN THIS REPORT

Because of the tabular shape of many of the ore bodies, they are referred to locally as veins. This term, first applied by Rogers (1836; 1840), has since been used throughout the New Jersey and New York Highlands (Bayley, 1910, p. 134). The deposits are not true veins, however, in the sense that they occupy fractures in the host rocks (Lindgren, 1933, p. 155), but as the term is so well established it is used in places throughout this report.

Two other terms used throughout the Highlands but not of general use are "toprock" or "caprock" and "bottomrock". As shown in figure 7, the ore bodies pinch at their upper and lower edges (at the sharp edges of the "sword"). At places the ore pinches entirely out; at other places it thins to a narrow seam, or "leader", that is too thin for profitable extraction. Because the miners encounter rock in the stope faces at these pinches, they have called the ore pinches either the toprock or bottomrock, depending upon which edge of the lathlike body they encountered; and these terms are now widely used throughout the Highlands. The "toprock" is defined, therefore, as the rock overlying the upper edge of a deposit; the "bottomrock" is the rock underlying the lower edge. The terms also are used to designate the pinches at the upper and lower edges of the ore bodies. Throughout this report the writer commonly refers to the toprock of the miners as the upper edge of an ore body and the bottomrock as the lower edge. These terms should not be confused with the terms "hanging wall" and "footwall", which refer to the rock on either side of an ore body (above and below the dip surface of the ore).

LATH-SHAPED BODIES

The lath-shaped deposits, which constitute the ore bodies in oligoclase-quartz-biotite gneiss, hornblende skarn, and albite-oligoclase granite, and probably also the deposits in amphibolite and interlayered biotite-hornblende-pyroxene-feldspar gneisses, are unique among iron deposits because they extend along their pitch length for indefinite distances. The end of an ore body has never been reached although several have been mined for more than a mile along their pitch length (Lindgren, 1933, p. 192), and one ore body, the Mount Pleasant (pl. 9), has been mined for more than 2 miles and to a depth of about 2,000 feet. The deposits plunge northeast; the angle of plunge with a few exceptions ranges from about 10° to 40°, and for each deposit it is essentially constant.

The persistence of these deposits is comparable to, and perhaps exceeds, that of the remarkable gold-ore shoot in the Morro Velho gold mine in Minas Geraes, Brazil (Lindgren, 1933, p. 197, 676–677), which has been mined to a vertical depth of more than 7,000 feet and a pitch length of more than 10,000 feet.

Typically, the lath-shaped deposits in the district are relatively simple tabular bodies that differ greatly in size and shape. They range in thickness from less than 1 foot to about 60 feet and average between 10 and 20 feet. The surface (or stope) length of the deposits ranges from less than 100 feet to as much as 7,000 feet, and the breadth (measured at right angles to the plunge), which is a function of the length and angle of plunge, ranges up to 1,900 feet.

Individually, the deposits appear in plan or cross section as elongate, thinly compressed, doubly convex lenses that are generally uniform in dip and strike, but there is considerable variation within each deposit and among the deposits. Many deposits are sufficiently uniform and thick to be entirely mined from the lower edge to the upper edge, but others, because of pinches, splits, or minor "folds", or because of included "horses" of barren or low-grade rock, are not everywhere minable. At places the irregularities, such as small changes in dip and strike and minor structural features, as warps, are not sufficiently great to appreciably affect the mining.

All deposits pinch and swell to different degrees. The variations in thickness caused by the pinches and swells may be on the order of magnitude of a few feet or several feet. Where the pinches and swells are marked, a shoot structure is developed. If the ore in the pinches is less than 5 feet thick, it seldom is feasible to mine it; if it is more than 5 feet thick, it generally can be mined.

In general, pinches and swells within the magnetite deposits are more pronounced in the ore bodies in hornblende skarn than in the deposits in gneiss. The Mount Pleasant ore body (pl. 8), a deposit in hornblende skarn, for example, contains several prominent pinches and swells. Two of the pinches, which are especially marked, separate the deposit into 3 ore shoots, known from top to bottom as the Kearney, Major, and Baker shoots. The pinch that separates the Kearney and Major ore shoots has a stope length of about 600 feet, and it has been recognized throughout the Richard mine. The pinch is marked by a decrease in width of ore from about 10 feet to 1 or 2 feet, and by the complete absence of skarn. The pinch that separates the Major and Baker ore shoots is less well defined; it is marked by a decrease in width of ore from about 10 feet to about 1 foot. Another deposit in hornblende skarn that contains a conspicuous pinch and swell structure is the Carlton deposit at Mount Hope mine (pl. 5). Pinches of lesser magnitude also have been reported (Bayley, 1910, p. 454–455) from the Hibernia ore body.

A few deposits, as for example, the Mount Pleasant (p. 50; Bayley, 1910, p. 455) and the Teabo (pl. 6), locally contain splits. If the splits are sufficiently thick it may be feasible to mine both segments of ore, but commonly one segment cannot be profitably extracted.

The disseminated deposits, although similar in shape, are more irregular in detail than the massive deposits. The Scrub Oaks deposit (pl. 10) at places is a relatively simple tabular body, but at other places it consists of two or more tabular layers of ore that are separated by mineralized albite-oligoclase granite of sub-ore grade. Not uncommonly the ore layers branch and split or occur as isolated en echelon lenses. Local changes in strike, with concomitant changes in ore thickness, are common.

Because the irregularities in individual ore bodies—pinches and swells, warps in dip and strike, and splits—generally rake essentially parallel to the upper and lower edges of the body, the cross section of a deposit remains remarkably similar regardless of depth. Accordingly, the miner can, with experience, predict to a certain extent the occurrence of thick and thin parts of the ore body in each succeeding stope as depth increases. This is of practical importance, for it aids the miner in the planning of development work in stope preparation.

The irregularities within the ore bodies, described above, are produced in part by structural features of the wall rocks and in part by the lithologic character of the host and wall rocks.

The deposits in oligoclase-quartz-biotite gneiss generally are conformable to the gneissic structure of the wall rocks and accordingly most of the pinches result from a convergence of the foliation of the gneiss on opposite walls. At many places pinches in the ore result from flattening of one wall, commonly the footwall, without a similar change in the attitude of the other wall; at other places both walls flatten, but not equally.

Pinches and swells in hornblende skarn ore bodies are caused principally by pinching or swelling of the skarn host rock, for the ore commonly replaces the skarn from wall to wall, and seldom the adjacent rocks.

The pinches that occur at the upper (toprock) and lower (bottomrock) edges of the deposits (fig. 7), because of their economic and geologic interest, deserve special comment. These pinches in specific types of ore deposits are produced in different ways.

To the miner, the toprock and bottomrock of deposits in gneiss are marked by a pinch in the ore to a thickness

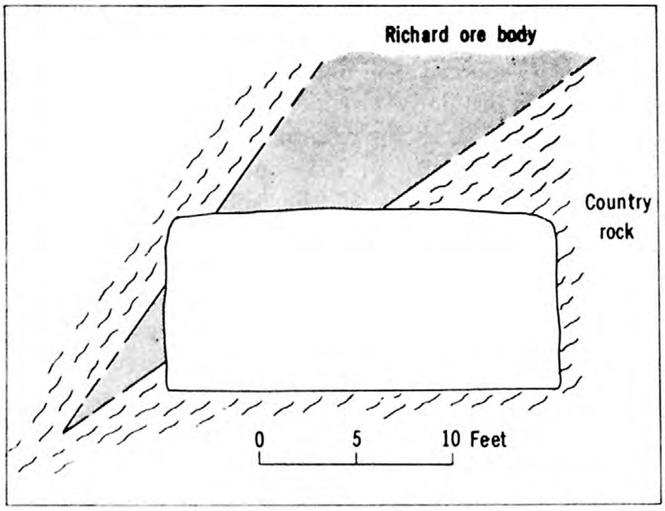


FIGURE 8.—Sketch showing lower edge (bottomrock) of Richard ore body, 900-ft level, Richard mine.

below the economic mining limit, generally about 5 feet. Data on the nature of the pinches are scarce, as mining commonly stops when a deposit thins to 5 feet. The available information indicates, however, that most pinches at the upper and lower edges in this type of ore body are the result of the convergence of the foliation on opposite walls.

The pinch at the lower ege of the Richard ore body, where observed on the 900-foot level of the Richard mine (figs. 8, 29), can be seen to be the result of such a convergence of the foliation. A short distance vertically above the lower edge of the deposit both the hanging wall and footwall dip about 60° SE. Toward the bottomrock, however, the foliation in the footwall gradually flattens to a dip of about 35° SE., whereas the dip of the hanging wall remains uniform; accordingly

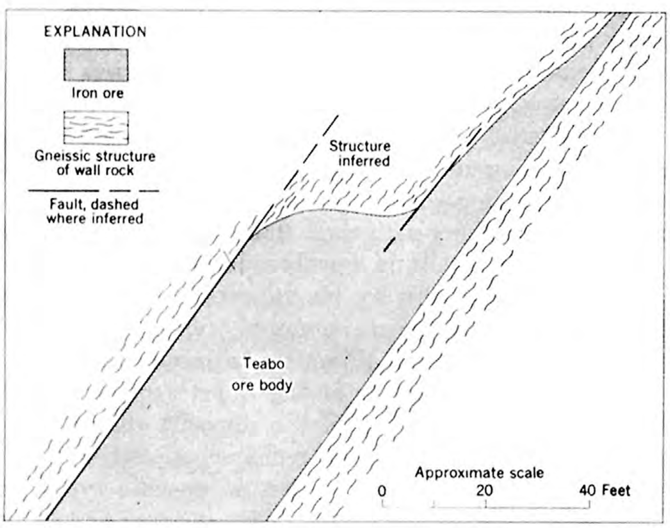


FIGURE 9.—Sketch showing cross section of upper part of Teabo ore body in stope 3, Mount Hope mine. The magnetite is concordant except at roll where it cuts sharply across foliation.

the ore is pinched out just below the drift. Core drilling below this level along the projection of the ore body has failed to intersect any iron ore. The pinch observed at the top rock of the Teabo ore body (fig. 9) in stopes 3 and 7 of the Mount Hope mine differs somewhat. An abrupt pinch takes place where the hanging wall of the ore body flattens abruptly. The flattening occurs where the hanging wall appears to cut across the foliation of the gneiss, probably following a preore joint or shear surface. The structure above the flattened part of the hanging wall, however, is poorly known, for study of this part of the deposit is hazardous because the ore and wall rocks slab off into the open stopes. Above this marked pinch the ore body gradually thins to less than 3 feet in thickness and conforms to the gneissic structure of the wall rock. As shown in plate 6, section A–A′, the ore pinches out completely about 90 feet above the roll in the hanging wall.

Where two or more separate ore bodies in gneiss lie one above the other in the same plane, a thin seam, or several seams, of magnetite or a narrow zone of mineralized rock may extend between the ore bodies. At Mount Hope mine the Richard and Teabo ore bodies (fig. 16) are separated by a thin zone of mineralized rock and locally by massive magnetite; and the Elizabeth and Leonard deposits (fig. 19) are separated by thin layers of massive magnetite. According to the miners, there also is a thin seam of massive magnetite, less than 6 inches in width, that extends between the Teabo and the Elizabeth ore bodies.

The upper and lower edges of ore bodies in hornblende skarn, on the other hand, are marked by a complete pinching out of the skarn, concomitant with a pinch in the magnetite, for the magnetite essentially replaces only the skarn. However, stringers of massive magnetite, a few inches to a foot thick, too small to be mined, commonly extend into the rock enclosing the skarn for some distance in the plane of the deposit.

The upper and lower edges of the disseminated deposits, such as the deposit at Scrub Oaks mine, are the result of a decrease in grade of the ore, together with local pinching and splitting of the ore body (pl. 10). They are not well-defined; accordingly the pattern of the ore bodies differs somewhat from level to level. However, there is a general conformity between the rake of the upper and lower edges of the deposits and the linear elements in the host rock.

POD-SHAPED BODIES

The pod-shaped deposits, which constitute the ore bodies in pyroxene skarn, contrast with the lath-shaped deposits because they pinch and swell greatly along their longitudinal axes and probably terminate at relatively shallow depths. Because the mines in these ore bodies are all abandoned and inaccessible, little is known concerning these deposits; but their structure can be inferred from data given in earlier publications and from field observations of the exposed parts of pyroxene skarn bodies.

The magnetite deposits in the Green Pond ore belt, which are well-exposed locally, are generally small and highly irregular. Individually, they appear podlike or roughly elliptical, rather than tabular in shape. They range from small bodies a few feet across to bodies as much as 40 feet wide and 450 feet long. The breadths of the deposits commonly are less than 200 feet. The pitch lengths of individual deposits are not known, for none have been mined to depths of more than 300 feet, and, by analogy with small pyroxene skarn bodies that can be observed in three dimensions, it can be reasonably inferred that they do not exceed a few hundred feet at the most. The ore bodies, because they replace the skarn but not the adjacent rocks, are essentially coextensive with the skarn. Consequently, pinches, swells, and other irregularities can be directly related to the host. Typically, the pod-shaped deposits occur as isolated bodies within rather narrow "stratigraphic" zones, as can be seen on figure 44, because prior to the mineralization the skarn formed isolated, disconnected bodies.

COMPARISON WITH OTHER PRE-CAMBRIAN MAGNETITE DEPOSITS

The magnetite deposits of the Dover district show many similarities to other pre-Cambrian iron-ore deposits in the New Jersey-New York Highlands and to some deposits in the Adirondack Mountains and in Fennoscandia.

It has long been recognized that the iron deposits throughout the Highlands are strikingly similar, although there are significant differences among deposits. This has been stressed most recently by Bayley (1910) and by Colony (1923, p. 55). The deposits, probably with few exceptions, conform to the gneissic structure of the surrounding rocks and their long dimensions parallel the *b* fabric axis. Details of the structure, however, are generally lacking because there are insufficient accessible workings to determine the pitch length of individual ore bodies. Probably most of the iron deposits in other mining districts in the Highlands are pod-shaped, to judge from the information given by Bayley, Colony, and others, but many resemble the lath-shaped ore bodies of the Dover district. The pod-shaped bodies principally include those in carbonate rocks and their skarn derivatives. Examples include the pyroxene skarn deposits in the Ringwood and Sterling Lake districts (Hotz, 1953), the deposits in marble and skarn at the Ahles mine (Bayley, 1910, p. 211), the Washington and Washington No. 2 skarn deposits at the Washington mine, Oxford, N. J., and the garnet skarn deposit at the Sulphur Hill mine (Sims and Leonard, 1952).

Deposits in the Highlands, outside the Dover district, that are lath-shaped include the Hurd deposit at Hurdtown (Bayley, 1910, p. 139, 333–336) and the Forest of Dean deposit in southeastern New York (Colony, 1923, p. 99–105). Undoubtedly there are many others in the Highlands, particularly those in gneiss, that are also lath-shaped, but information on the pitch length of these deposits is generally lacking. Probably many of the abrupt terminations of the ore described from several mines, are not caused by pinches in the ore along the pitch length of the bodies, as commonly inferred, but are the result of post-ore faults that offset the ore.

In the Adirondacks, magnetite deposits that in many ways are similar to the ore bodies in the Dover district are known in Clinton County, St. Lawrence County, and at Mineville, in Essex County. Descriptions of the Clinton County and St. Lawrence County deposits are available, but nothing has been published on the details of the Mineville deposits.

In Clinton County (Postel, 1952, p. 34), the ore bodies typically occur in synclines, and the ore is usually confined to one limb of the fold. At places the ore constitutes fishhook-shaped deposits.

> Some of the magnetite bodies . . . have a pencillike form. These bodies lie parallel to the foliation of the enclosing rocks, which are synclinally folded, and they plunge parallel to the axes of the folds and to the mineral lineation of the surrounding rocks. The ore shoots are not separated or isolated from each other. They are connected along the foliation either by thin, noneconomic stringers of rich magnetite or by relatively thick zones of weakly disseminated noneconomic magnetite.

The deposit at the Chateaguay mine, which plunges on the average about 20° NE., has been mined to a vertical depth of about 2,700 feet (Postel, A. W., oral communication).

In the St. Lawrence County district in New York (Leonard, manuscript in files of Princeton Univ.) distinct lathlike or pencillike ore bodies are absent, so far as known, but mining has not extended to sufficient depths to determine the vertical dimensions of the deposits. Pod- or lens-shaped deposits, as the pyroxene skarn body at Clifton mine, however, are known. The Clifton deposit, probably because of multiple periods of deformation, though, is more irregular than the pod-shaped deposits in the Dover district.

The iron deposits in the Klodeborg area, Arendal district, in Norway (Bugge, 1940), are strikingly similar to those in the Dover district. In the southeast part of the area the ore bodies occur in skarn within a northeastward-trending, isoclinally folded pre-Cambrian complex. The deposits are arranged along several parallel zones separated by a few meters of barren rock. They dip about 65° SE. and have a pronounced rake of about 23° toward the southwest, parallel to the linear elements in the country rock. According to Bugge (1940, p. 104) the bodies are lens shaped or ruler shaped. Unfortunately, Bugge does not give data on the length of the ore shoots (or rulers); neither does Vogt (1910; 1918), who studied the area earlier.

Magnusson (1940, p. 105–110) describes deposits of magnetite, associated with abundant sulfides, from the Kaveltorp field, Lyusnarsberg parish, in Västmanland, that are controlled by a dominant lineation. The ore, found in several types of skarn, replaces parts of four principal limestone layers within the folded leptite formation and forms bodies that have a prominent lineation—apparently a pencil structure. So far as known, the limestone layers pinch out at about the 125-meter level, possibly concomitant with a reversal of plunge.

RELATIONS OF DEPOSITS TO COUNTRY ROCKS

RELATION OF MAGNETITE DEPOSITS TO FOLDS

The magnetite deposits are concentrated into ore belts or ranges (see p. 77) that parallel the rock units and foliation. As most of the ore belts are on the limbs of major folds, they trend northeastward (pl. 1). An exception is the Hibernia Pond-Hibernia ore belt, which is on the nose of the Hibernia anticline and accordingly has the shape of a fishhook.

Five of the ore belts—the Wharton, Hibernia Pond-Hibernia, White Meadow-Cobb, Beach Glen, and Dalrymple—are related in a general way to the prominent Hibernia anticline, as can be seen on plate 1. The Wharton ore belt is on the northwest limb of the anticline; the Dalrymple, White Meadow-Cobb, and Beach Glen ore belts are on the southeast limb; the Hibernia Pond-Hibernia ore belt is on the nose of the anticline. The Splitrock Pond-Charlottesburg ore belt presumably is on the east, overturned, limb of Splitrock Pond syncline; the deposits in the Green Pond ore belt are on the limbs and in the keels of relatively small complex isoclinal synclines.

Because of the lack of accessible underground workings, sparse exposures, and complex folding, little is known about the structural environment of many individual ore bodies throughout the belts. The structure of parts of some ore belts is quite well known, however, and accordingly it is possible to infer with some confidence the structure of those parts for which little data are available.

The individual ore bodies in the Wharton ore belt are arranged in tandem or en echelon and are essentially parallel to the trend of the ore belt. The deposits occur on the limbs of tight folds on the flank of the larger Hibernia anticline. At places, as at the Mount Hope mine, two deposits on opposite limbs of a syncline join in the keel of the syncline to form V-shaped bodies. (See pls. 3 and 4.)

The deposits in the Dalrymple and White Meadow-Cobb ore belts (pl. 1) resemble the linear bodies in the Wharton ore belt and presumably are on the limbs of small(?) isoclinal folds. The Cobb deposit is on the southeast limb of Cobb anticline, near its crest. The Beach Glen deposits, in the Beach Glen ore belt, are on the northwest limb of the Beach Glen anticline. At the surface the main "vein" at the Beach Glen mine dips northwest, in contrast to most other deposits in the Dover district.

The deposits in the Hibernia Pond-Hibernia ore belt are on the nose and both limbs of the Hibernia anticline (pl. 1). The deposits at the Hibernia Pond anomaly (63), prospect 70, prospect 71, the Fairview mine (67), the Birch mine (69), and prospect 68 constitute a fishhook-shaped body on the northwest limb and nose of the Hibernia anticline. The Hibernia ore body is on the southeast limb of the anticline, and although there is no indication that it connects with the deposit at the Fairview mine, there is a small magnetic anomaly about midway between these deposits.

Fishhook-shaped deposits, other than that in the Hibernia Pond-Hibernia ore belt, are not known elsewhere in the Dover district, but several have been described from other pre-Cambrian metamorphic terranes. The ore body at the Hurd mine, at the north end of Lake Hopatcong in Morris County, N. J. (Bayley, 1910, p. 138–139), has the shape of a fishhook both in plan and in cross section. In contrast to the fishhook-shaped deposit in the Hibernia Pond region, the Hurd ore body occurs in an isoclinal syncline. Magnetite deposits of similar shape are present in the Sterling and Ringwood districts in New York and New Jersey (Hotz, 1953, pl. 19), the St. Lawrence County magnetite district in New York (Leonard, 1951, manuscript in files of Princeton Univ.) the Central Swedish district (Geijer and Magnusson, 1944), and elsewhere. Other types of ore bodies with a fishhook shape, in similar rocks, include the well-known zinc deposits at Franklin and Sterling Hill, N. J. (Spencer and others, 1908; Spencer, 1909, p. 25–52).

The deposits within the Green Pond ore belt are on the limbs and in the axial regions of relatively small, complex, isoclinal synclines (pl. 1 and fig. 44).

RELATION OF ORE TO METASEDIMENTARY ROCKS

Aside from the ore bodies in albite-oligoclase granite and the local concentrations in granite pegmatite and microantiperthite granite, the magnetite deposits are in metasedimentary host rocks. As stated on page 58, magnetite concentrations occur in several types of metasedimentary rocks: oligoclase-quartz-biotite gneiss, hornblende skarn, pyroxene skarn, amphibolite, and recrystallized and reconstituted amphibolite. Within each type the relations of the magnetite to the host are similar. The ore corrodes and embays individual fragments of the host and forms anastomosing veinlets and blebs that locally surround small grains of the silicates. This relationship is best shown in the low-grade deposits. In plate 18*C*, a photo of low-grade ore in oligoclase-quartz-biotite gneiss, it can be seen that the irregular grains and aggregates of magnetite embay and corrode the quartz and feldspar of the host. Similarly in gneiss ore rich in phosphate (pl. 17*B*), the magnetite embays both the apatite and the silicate minerals. Thin sections of this type of ore in oligoclase-quartz biotite gneiss (pl. 18*D*) reveal that at many places the magnetite occurs in granulated parts of the gneiss and that, in addition to replacing the host minerals, it penetrates along tiny irregular fractures.

The ores in skarn rocks show similar relations to the host minerals. In plate 19*A*, a photomicrograph of ore in hornblende skarn, the magnetite is seen to embay and corrode the hornblende, leaving irregular relicts of the host.

A replacement origin is less obvious for the high-grade, massive ores, but it is clear in thin sections of this ore that the sparse fragments of the host are corroded, indicating that the magnetite formed by replacement.

The ore in oligoclase-quartz-biotite gneiss characteristically forms massive bodies with well-defined walls. Typically, the contacts of the ore against the walls are sharp; the change from massive ore to wall rock containing variable but generally sparse amounts of magnetite is abrupt. At places small veinlets of ore extend outward into the walls for a few inches. The wall rocks of most of these deposits are oligoclase-quartz-biotite gneiss, but at places they are biotite sköls or amphibolite.

Although the ore is generally conformable, a feature stressed by earlier workers, it is distinctly disconformable to the wall rocks at many places. Disconformable relations at the edges of a deposit have been described on page 66. At Mount Hope mine both the Teabo and Richard ore bodies show disconformable relations to the enclosing gneiss at many places. Near the southwest end of the 1,700-foot level (pl. 6), the foliation of the gneiss in the footwall of the Richard ore body locally bends from the average trend, and the ore cuts across the gneissic structure at each of the bends. In stopes on both ore bodies the discordant relationship is even more evident and can be seen at several places. In Teabo stope 4 the footwall of the Teabo deposit at places transects the foliation in the footwall gneiss at nearly right angles.

In the Richard mine, at the top of raise S 1380 E, near the northeast end of the mine, the Richard ore body cuts across the foliation in the gneiss (fig. 10). The ore here cuts across the flexure of an isoclinal anticline and the fracture cleavage; it is essentially parallel to the axial plane of the fold.

As a general rule, the ore bodies in hornblende skarn are concordant with the wall rocks, but locally they are discordant. For example, the Mount Pleasant ore body, in Richard mine, cuts across the structure of the wall rocks in a few places (pl. 20); and the layering in the Taylor ore body diverges several degrees from the foliation of the alaskite wall rocks at several places on the 1,700- and 1,900-foot levels in Mount Hope mine. This divergence in structure is most evident on the 1,900-foot level, where the layers of different mineral composition in the ore near the northeast end of the drift dip moderately southeast and the foliation in the alaskite dips nearly vertical. Probably this discrepancy in structure is caused by folds in the skarn.

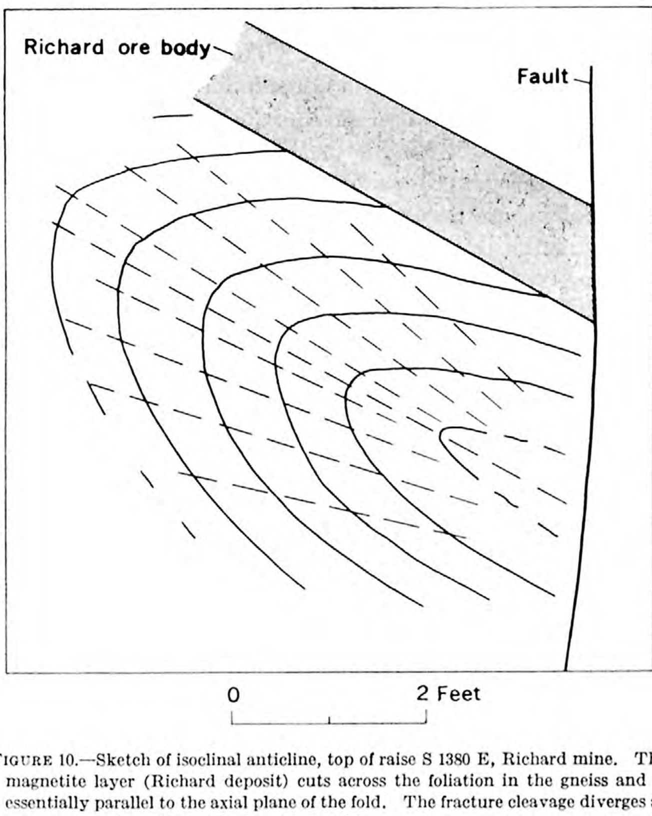


FIGURE 10.—Sketch of isoclinal anticline, top of raise S 1380 E, Richard mine. The magnetite layer (Richard deposit) cuts across the foliation in the gneiss and is essentially parallel to the axial plane of the fold. The fracture cleavage diverges at a small angle from the axial plane of the fold.

Because the ore in the pyroxene skarn deposits replaces only part of the skarn, the wall rock of the ore is skarn. In the Green Pond ore belt the skarn is surrounded by oligoclase-quartz-biotite gneiss, plagioclase-quartz gneiss, pyroxene gneiss, layered amphibolite, and alaskite; and in the Splitrock Pond-Charlottesburg ore belt, by pyroxene-hornblende gneiss and albite-oligoclase granite.

As the deposits in amphibolite and the interlayered biotite-hornblende-pyroxene-feldspar gneisses have not been extensively mined, little is known concerning the relations of the ore in these deposits to the host and wall rocks. The deposit in amphibolite at the Birch and Fairview mines (pl. 1) consists of both massive and disseminated magnetite. The massive ore forms compact layers as much as 6 inches thick that are separated by layers of amphibolite, from 6 inches to 1 foot thick, containing sparse grains and aggregates of magnetite. Probably all the host contains some secondary magnetite; the wall rocks—albite-oligoclase granite and granite pegmatite—so far as known are barren.

Recrystallized and partly reconstituted amphibolite is locally the host for magnetite. At places, particularly in association with hornblende skarn deposits, coarse-grained, recrystallized hornblende amphibolite contains seams and disseminations of magnetite. The ore-bearing layers generally range from an inch or less to about a foot thick. At Hibernia mine ore occurs at places, to judge from the dumps, in a medium-grained green pyroxene aggregate (pl. 19*B*). The pyroxene, clearly an alteration product of the hornblende in the amphibolite, is light to medium green in color, whereas the hornblende is black. Magnetite selectively replaces the pyroxene rock; small quantities of ore also occur in the amphibolite, and accordingly the ore walls are not sharp.

The magnetite in the interlayered biotite-hornblende-pyroxene-feldspar gneisses, the host rocks for the ore in the Hibernia Pond deposit, occurs as disseminations, or less commonly as inch-thin stringers and veinlets. Massive magnetite, so far as known, is absent. The hanging wall and footwall, also probably the toprock and bottomrock, of the deposit are poorly defined and are marked by assay boundaries, to judge from cores of drill holes. The wall rocks are albite-oligoclase granite and pyroxene amphibolite.

RELATION OF ORE TO IGNEOUS ROCKS

The magnetite that formed the iron-ore deposits is later than all the pre-Cambrian igneous rocks, but it occurs in concentrations in only a few types. Magnetite concentrations are known locally in albite-oligoclase granite, granite pegmatite, alaskite, and microantiperthite granite, but only the deposits in albite-oligoclase granite have been important sources of iron ore. The diabase (Triassic?) is later than the magnetite, and the dikes that cut the iron ore have chill borders against it.

The deposits in albite-oligoclase granite vary from small to large and are low to medium in grade. They conform to the foliation and lineation of the enclosing rocks. The ore minerals form irregular grains and aggregates of grains that embay and corrode the host minerals and penetrate along microscopic fractures that are adjacent to and penetrate through the silicate minerals. Because the replacement is incomplete, variable but generally moderate quantities of silicates remain as gangue in the ore. A typical specimen of medium-grained ore in albite-oligoclase granite is shown in plate 18*B*.

The contacts between minable ore and albite-oligoclase granite wall rock generally are well-defined, and are marked by a moderately sharp transition from ore to mineralized country rock. The ore walls are not as abrupt, however, as in deposits in oligoclase-quartz-biotite gneiss and hornblende skarn; instead, the wall rocks generally contain a few percent of magnetite and in places may be low-grade ore. At the Scrub Oaks mine, the best known deposit of this type, where the footwall and the hanging wall are fairly well-defined throughout the mine, the miners generally can determine the ore walls by megascopic inspection. Locally, though, the walls have "assay limits." The bottom and top rocks, on the other hand, are poorly defined and commonly are determined by assays.

Some pegmatites that are closely associated spatially with ore bodies contain appreciable quantities of magnetite, and according to Bayley (1910, p. 132) a pegmatite at the Beach Glen mine was utilized for a short time as low-grade ore. The pegmatites away from ore bodies generally contain only accessory magnetite.

The magnetite in granite pegmatites occurs as (1) subhedral to euhedral grains, at places embedded in feldspar or hornblende, that are essentially the same size as the silicate minerals, but locally smaller; (2) irregular grains and aggregates that embay the rock components; and (3) thin veinlets, a fraction of an inch thick, along cleavage planes of the feldspar and fractures that cut through the host minerals (pl. 19*C*).

Bayley (1910, p. 150–151) recognized that the magnetite in pegmatites occurred as a primary constituent, which crystallized before any of the silicate minerals, and as a secondary mineral introduced after consolidation of the pegmatite; but he did not state the quantitative importance of each type. The writer agrees with this interpretation: the well-crystallized magnetite is mostly a primary accessory mineral, whereas the magnetite that corrodes and veins the host minerals is secondary. The highest concentrations of magnetite in pegmatites observed by the writer occur where pegmatites are within, or adjacent to, ore bodies.

The genetic and paragenetic relations of the ore to pegmatites have long been a controversial subject in the Highlands. Bayley (1910, p. 152) was of the opinion that "the pegmatite magma had not entirely cooled at the time the iron-bearing solutions were extruded, and, therefore, was more or less pasty. . . ." Many miners, because the pegmatites commonly trend diagonally to the ore bodies and are relatively barren at the vein crossings, believe that the pegmatites are later than and crosscut the ore. In the Ringwood, N. J., and Sterling Lake, N. Y., districts Hotz (1953) demonstrates that the pegmatites are preore. In the Dover district, likewise, the pegmatites are believed to be preore because they contain abundant secondary magnetite only where they are cut by magnetite "veins." They contain smaller amounts of magnetite that the adjacent ore-bearing host rocks because they were less easily replaced. As most of the magnetite replaces the silicate minerals and occurs in cleavages and fractures within these minerals, it probably was deposited after the complete consolidation of the pegmatite. Also, at most places the feldspars of the pegmatite are bleached adjacent to ore (pl. 19*C*), indicating disequilibrium conditions.

Concentrations of secondary magnetite are known at only a few places in the hornblende granite and related facies. At places where alaskite constitutes the walls of skarn deposits the alaskite locally shows incipient replacement by magnetite adjacent to the skarn, as indicated by corroded feldspars. At other places, as in the Richard mine (pl. 8), seams and layers of massive magnetite (known to the miners as "leaders"), or disseminations, occur in alaskite between ore shoots in the plane of the ore body.

FACTORS CONTROLLING LOCALIZATION OF ORE BODIES

The field and laboratory data collected during this investigation are interpreted to indicate that the localization of the iron-ore deposits in the Dover district was directly influenced by several interrelated factors: a favorable host rock, favorable structures, and a close spatial relation to the source for the iron-bearing solutions. The effects of the host rocks and structures on the localization of deposits is discussed below; the relation of the deposits to supposed sources is treated on pages 72 to 73.

The metasedimentary rocks, because they were favorable host rocks, were selectively replaced by the iron-bearing fluids. Skarns were particularly susceptible to replacement and, so far as known, all that consist of pyroxene of the composition of salite or ferrosalite (see p. 18), or of hornblende, contain concentrations of magnetite. Skarns composed of diopside, on the other hand, are barren. Evidently the precipitation of appreciable quantities of iron oxide in the skarn depended, at least in part, upon the presence of several percent of iron in the lattice of the skarn minerals. It is improbable that the chemical composition of the oligoclase-quartz-biotite gneiss, amphibolite, and the interlayered biotite-hornblende-pyroxene-feldspar gneisses influenced the deposition of iron, for some bodies of these rocks do not contain concentrations of secondary magnetite. More probably these rocks, because they provided a favorable structural environment, were suitable centers for the deposition of ore.

Igneous rocks were less favorable host rocks than the metasedimentary rocks, and although all of them formed prior to the formation of the iron deposition, ore deposits were developed only in certain parts of some bodies of albite-oligoclase granite and microantiperthite granite. The occurrence of the ore in dispersed discrete grains and thin irregularly distributed streaks and layers, rather than as high-grade massive bodies, probably is partly the result of a relatively poorly developed layering in the granite. Perhaps the ore-bearing solutions, instead of being confined between sharply defined walls that would tend to confine them, were more dispersed.

The structure of the iron deposits is closely related to structures formed by plastic flowage of the country rocks. The ore bodies occur in belts that are on the limbs and, locally, the noses of folds. Most of the deposits are on the limbs of the isoclinally folded Hibernia anticline; less important ore bodies occur in smaller synclines. The relations of the ore to the host rocks and the apparent absence of deformed ore clearly demonstrates introduction of ore into the host rocks after their deformation.

Although the massive deposits of magnetite are locally discordant to the wall rocks, they generally conform to the gneissic structure; and this feature has been stressed by nearly all the earlier workers in the New Jersey Highlands. The general conformity of the magnetite deposits and the wall rocks indicates that the gneissic structure of the enclosing rocks has largely determined the form of the ore bodies. Evidently the solutions from which the iron was deposited could move along the planes of the foliation, but could not easily migrate across them.

Microscope studies of thin and polished sections of ore, particularly the low-grade material, indicate that in many deposits the magnetite occurs in microbrecciated zones in the host rock (pl. 18*D*). This texture is more apparent in ores in gneiss (pl. 16*A*) and albite-oligoclase granite than in ores in skarn; it is also present locally, however, in hornblende skarn deposits.

The magnetite in these zones is clearly later than the granulation, for it replaces the crushed grains and forms veinlets along fractures in the host. The absence of similar microbrecciation in the surrounding wall rocks is interpreted to indicate that the granulated zones provided the principal channelways along which the ore-bearing solutions moved; where they transect the gneissic structure of the country rock, the magnetite ore bodies also are discordant. The microbrecciation resulted from cataclastic deformation that took place during the waning stages of the orogeny; and it probably developed by "interbed" shearing that, because of relatively homogeneous rocks, essentially paralleled the axial planes of the folds. For some unknown reason conditions favorable for the development of microshearing apparently occurred only within the ore belts.

Microbrecciation or microshearing has been described from other magnetite deposits in the eastern United States outside of the Highlands. In Clinton County, N. Y., Postel (1952, p. 39–40) found it to be characteristic of most of the ores in granites. Ross (1935, p. 110) also describes granulation of the host rocks that contain the magnetite ores at Cranberry, N. C.

ORIGIN OF THE IRON ORE

The deposits in the Dover district are believed by the writer to be high-temperature metasomatic replacement bodies that formed after the orogeny that deformed the pre-Cambrian metasedimentary rocks and after the emplacement of the youngest granitic rocks in the pre-Cambrian complex. The ore probably is older Proterozoic, but the absolute age is not known. Similar ores from the New Jersey Highlands have a helium age ranging from 410 to 640 million years (Hurley and Goodman, 1943). Possibly, however, the helium ages are low; an explanation that may account for low helium ages of magnetites has recently been given by Hurley (1950).

METASOMATIC REPLACEMENT

The iron-ore deposits, regardless of their type, have many features in common, and it is probable that they stem from a common source. The ore occurs in a variety of host rocks, including rocks that probably have an igneous origin, and the relationship between the ore and the different host rocks clearly demonstrates that the iron was introduced into these rocks after their formation. The absence of structures and textures in the ore that could be interpreted as resulting from deformation, further indicates that the ore was introduced after deformation of the country rocks. Magnetite is the principal ore mineral in all deposits. The magnetite in all the massive ore bodies is similar in grain size and texture, and it shows essentially the same exsolution phenomena. The magnetite in the disseminated ore bodies differs considerably in mineralogic character and texture from that in the massive ore, but the close spatial association and structural similarities of the massive and disseminated ore bodies indicates that the iron in the two contrasting types has a common source. The manner in which the metallic minerals replace the host is the same in all types of deposits.

The source of the iron is thought to be alaskite magma, a volatile-rich differentiate of the magma that consolidated to form hornblende granite, but this assumption cannot be proved with the existing information.

Several lines of evidence point to alaskite as a possible source for the ore. Aside from the deposits in the Green Pond region, alaskite is coextensive with the ore belts. The deposits in the Wharton and Dalrymple ore belts are enclosed by bodies of alaskite, and the deposits in the other ore belts are near large bodies of alaskite; commonly alaskite occurs along one or both walls of these deposits. Deposits of iron ore, so far as known, are absent to the southeast and northeast of the ore belts of the Dover district, where alaskite is sparse to absent. The alaskite is probably the youngest granite in the pre-Cambrian complex, and locally it contains small concentrations of secondary magnetite. (See p. 71). Accordingly, the ore clearly was introduced into the host rocks after the formation of the alaskite. Further, there is evidence that during crystallization, the residual fluids of the alaskite magma were enriched in iron. The evidence for this is given principally by the skarns, which were formed by metasomatic solutions derived from this magma. The original skarns probably had the composition of diopside, to judge from the skarns distant from bodies of alaskite, and they formed by solutions that moved in advance of the magma. Accordingly they must have developed before much of the magma had consolidated. With further crystallization, and probably after most of the magma had consolidated, the skarns in the vicinity of the magma were enriched further in iron. The original diopside was altered to salite, and locally to ferrosalite (see p. 18); at places, adjacent to the skarn, where sufficient volatiles were present, the pyroxenes were largely converted to hornblende, and locally micas were developed. At some later unknown stage, probably when the Fe could no longer be accommodated in the lattice of these minerals, it was deposited as oxides of iron; and this stage was closely followed at places by the deposition of simple iron-bearing sulfides.

The iron-bearing fluids that escaped from the crystallizing magma, in addition to replacing the skarns, also replaced other rocks that contained granulated zones which provided "channelways" for the migration of the solutions.

Because the pegmatites associated with the hornblende granite and alaskite contain only average quantities of accessory magnetite and locally are impoverished, the alaskite magma is believed to have been split off prior to the crystallization of the pegmatites.

The character of the metasomatizing solutions is not known. The mineral associations are interpreted by the writer, however, to indicate that the solutions were initially pneumatolytic and at some later stage became hydrothermal. The agents best adapted to effect separation of the iron-bearing material from the alaskite magma and transport it into the sites of deposition are belived to be gaseous emanations. The gases would condense with falling temperatures to yield dilute water-rich solutions, and perhaps these would mingle with attenuated residual aqueous solutions from the cooling magmatic chamber. Because of the confining pressure of the overlying rocks, the gas phase probably could not form until the parent magma was largely crystallized. It has been demonstrated that iron and titanium, as well as other metals, can enter gas phases in appreciable quantities in the form of volatile halogens (Zies, 1924, p. 159–179). The transportation of iron as halogens in the formation of contact-metamorphic deposits has been discussed by Geijer (1925), Postel (1952, p. 44–45), and others, and need not be reviewed here. In the Dover district the volatile constituents, which dominate in the gas phase, apparently were largely removed by later solutions, for quantitatively they are unimportant components of the ores. Evidence of the existence of these "mineralizers", however, is found both in the ores and in the rocks that probably are of metasomatic origin. Fluorine and chlorine are present in apatite, chondrodite, and scapolite; phosphorus occurs in apatite; hydroxyl is common in the micas and amphiboles; and boron is present in tourmaline—a sparse mineral in the disseminated ores.

It is generally agreed that gaseous emanations, on first escaping from the magma, are acid in reaction (Fenner, 1933, p. 78). In the Dover district there is evidence that the ore-forming fluids, at least locally, probably eventually became alkaline. The hematite in the disseminated ores indicates a higher state of oxidation of iron relative to that required for the formation of magnetite, and, because the oxidation of ferrous to ferric iron takes place much more readily in alkaline than in neutral or acid solutions (Mason, 1943, p. 128), it is probable that it formed in an alkaline environment.

DISCUSSION OF PREVIOUS HYPOTHESES

In the past, many theories were advanced to account for the origin of the magnetite ores of the Highlands, but because most of these have been reviewed by Bayley (1910, p. 147–182), only the principal hypotheses are discussed in this report.

The first to discuss the origin of the magnetite ores in the New Jersey Highlands was Rogers (1840, p. 22) who proposed that the deposits "are real veins of injection, and not true beds, contemporaneous with the adjoining gneiss. . . . " He recognized that the ores were formed before the deposition of the rocks of Paleozoic age. Several years later Kitchell (1857, p. 11–13), presented evidence that he believed indicated that the magnetite deposits were intensely metamorphosed sedimentary iron beds, and this hypothesis was widely accepted by most geologists for the next half century (Cook, 1868, p. 532–533; Smock, 1873, p. 18–19). The principal argument for a sedimentary origin was the occurrence of the magnetite in layers essentially conformable with the surrounding gneisses, which generally were thought to be entirely metamorphosed sedimentary rocks.

Some geologists still believe that the deposits represent metamorphosed iron formation, but several arguments can be presented against this hypothesis. The strongest evidence against a metasedimentary origin of the magnetite deposits of the Dover district is the complete absence from the entire New Jersey-New York Highlands of rocks resembling the known sedimentary iron ores. Sedimentary iron ores that have been regionally metamorphosed characteristically are quartz-banded ores. Even in regions that have undergone regional dynamothermal metamorphism of rather high grade many of the original characteristics of the iron formations are preserved, as, for example, at Norberg in central Sweden (Geijer, 1936, p. 153). At Norberg quartz-banded ores are associated with skarn ores and manganiferous iron ores in limestone. The quartz-banded ores consist of layers of quartz, which sometimes is red, and crystalline hematite or magnetite. They are bed shaped, although now strongly deformed. The ores occur in leptites, which are supracrustal rocks approximately of the chemical composition of granite or related igneous rocks, with a recrystallized texture and a grain size between 0.03 mm and 1.0 mm. The leptites are flanked on both sides by granites belonging to the oldest intrusive group ("urgranites"). Amphibolite dikes are present but are not abundant. Geijer (1936, p. 158) believes that the quartz-banded ores represent metamorphosed chemical sediments, which are analogous with banded ironstones elsewhere.

Additional evidence against a metamorphic origin for the magnetite deposits in the Dover district is the occurrence of the iron ore in a wide variety of host rocks. Within the Dover district ore bodies occur in oligoclase-quartz-biotite gneiss, albite-oligoclase granite, microantiperthite granite, hornblende skarn, and pyroxene skarn; and magnetite concentrations, which are not sufficiently rich to be ore, occur in amphibolite, modified amphibolite, and granite pegmatite. Outside of the Dover district, in the New Jersey Highlands, magnetite deposits of similar character are found in several other types of host rocks. At the Edison mine, Sussex County, the magnetite occurs in sillimanitic biotite-quartz-feldspar gneiss (Buddington, written communication); at the Sulphur Hill mine, in the Andover mining district, magnetite is in andraditic garnet skarn (Sims and Leonard, 1952); and at several localities it is found in marble and silicated marble (Bayley, 1910; Hotz, 1954). It seems to the writer that the occurrence of similar magnetite ores in such a wide variety of rock types precludes a metamorphosed sedimentary origin. The widespread evidence of replacement of the host rocks by the ores, as described on previous pages, also is incompatible with a sedimentary origin. In addition the ore bodies in the Dover district locally are discordant to the gneissic structure of the enclosing rocks, indicating that they are not contemporaneous with the host rocks. (See p. 66.)

In 1904 Spencer revived the hypothesis of igneous origin. His view differed from Rogers' in many respects, though. He states (1904, p. 381):

> Instead of being bog ores or carbonates deposited in sedimentary rocks and later changed to magnetite by metamorphism, as formerly suggested, they apparently have been introduced as products of igneous activity.

Bayley (1910, p. 147–156) also favored an igneous source for the magnetite, and his hypothesis was similar to that proposed by Spencer. He stated (Bayley, 1910, p. 149):

> In all cases the ores are regarded as being of magmatic origin—that is, the source of their material is thought to have been the deep-seated magmas, portions of 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 were in turn 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. In their transit to the surface these solutions or vapors deposited additional magnetite in the intruded ferruginous rocks and made the ore lenses that now comprise the ore bodies.

From a study of the relation of magnetite to the minerals in the pegmatites, Bayley concluded that there were two generations of magnetite. The first crystallized before any of the other constituents of the pegmatite; the second after all the pegmatite minerals had been formed (Bayley, 1910, p. 151). He believed that the earlier generation of magnetite was clearly a product of the crystallization of the magma that solidified as pegmatite and that the later generation was introduced by hot aqueous solutions or vapors after the normal components of the pegmatite had crystallized (Bayley, 1910, p. 151). He noted that the late magnetite in some places replaced the silicate minerals. Bayley concluded also that the important ore bodies in "dark gneiss" were formed in a manner analogous to those in the pegmatite, except that very acid siliceous material was lacking in the first stage in ore production (Bayley, 1910, p. 152). In these deposits, which characteristically contain hornblende and pyroxene, in addition to magnetite, he assumed that the magnetite crystallized from the same magma that consolidated to form the mafic layers (1910, p. 152). He recognized, though, that the stringers of nearly solid magnetite that connect the shoots in the plane of the foliation were formed "by solutions passing between the ore bodies." (Bayley, 1910, p. 153).

The writer differs from Bayley in believing that all the magnetite in the ore bodies was introduced after the crystallization of the pegmatites, and that it was effected by the metasomatic replacement of favorable host rocks in a favorable structural environment. There is no evidence that some of the magnetite crystallized from iron-rich portions of the granite pegmatites, for many pegmatite bodies are nearly barren. Those pegmatites that do contain magnetite concentrations clearly are closely associated with known ore bodies, and further there is evidence that the magnetite was introduced after the consolidation of the pegmatite and that it replaced the minerals of the pegmatite.

In the dark-gneiss deposits of Bayley (those in skarn and amphibolitic rocks), the writer has concluded that the mafic granules in the ore were not deposited by ore-forming solutions, as Bayley held (1910, p. 152); but, instead, that they represent unreplaced fragments of the host rock. There is no evidence that hornblende or pyroxene was introduced during an early stage in the ore formation. Veinlets of this composition were not observed by the writer to cut across the foliation of the country rock as would be expected if the mafic minerals were deposited from vein-forming solutions.

Smith (1933, p. 669–671) agrees in the main with Bayley's views, but he believes that practically all the magnetite was deposited later than the primary silicate minerals. Smith (1933, p. 669) says:

> That the ore solutions may be differentiates of the same solutions from which the pegmatites were deposited, is indicated by the intimate association of the ore and pegmatite. At Oxford and elsewhere the ore grades into the different phases of pegmatite which may be associated with it.

He believes that the magnetite was deposited from "ore magmas" that originated in a deep reservoir. In contrast to the beliefs of other workers (Bayley, 1910; Colony, 1923, p. 70), Smith (1933, p. 671) proposes that, with the exception of the disseminated-type ore at Scrub Oaks mine, the magnetite was "emplaced" both by replacement and displacement. It is thought by the present writer, though, that the crushing and fracturing in the host rocks, which Smith considered the result of dilation caused by the growth of magnetite grains, is due to preore microbrecciation.

Hotz (1953) was the first to propose a metasomatic-replacement origin for magnetite deposits in the New Jersey Highlands, although Colony (1923) earlier suggested that the magnetite deposits in southeastern New York were replacement bodies formed by metasomatism. Hotz proposed that the magnetite was deposited from late-stage iron-rich solutions derived from the magma that consolidated to form the Byram granite.

MAGNETIC EXPLORATION

Magnetite is by far the most strongly magnetic substance that occurs naturally. The susceptibility of magnetite is several times greater than the less common magnetic minerals ilmenite, pyrrhotite, and franklinite, and it is 10,000 times more magnetic than most rock-forming minerals (Heiland, 1940, table 35, p. 310–311). The most effective methods known, therefore, for the exploration for magnetite are those dependent upon magnetic susceptibility.

Magnetite occurs in nearly all the rocks in the Dover district. It is sparsely disseminated through the country rocks and locally is concentrated into deposits that constitute ore. The ore bodies primarily consist of massive magnetite, but a few consist of disseminated magnetite. The magnetite that is sparsely disseminated through the country rock presents no particular problem in exploration; it is essential, though, to distinguish between deposits of commercial importance and magnetite concentrations of no economic value.

Exposures of magnetite deposits in the district are sparse. It is reported that the Taylor (or Jugular) deposit cropped out as a massive ledge of ore, but probably most other deposits were covered to different depths by unconsolidated surficial material. The buried deposits, therefore, were primarily discovered by magnetic instruments.

HISTORY OF MAGNETIC EXPLORATION

Prior to about the middle of the 19th Century, magnetic exploration was by means of a magnetic needle, or surveyor's compass. This instrument successfully demonstrates the presence of magnetite concentrations, but it does not indicate the extent of the deposits, and after the development of the dip needle, about 1860, this method was little used (Cook, 1868, pp. 536–537)

The first known magnetic map in the New Jersey Highlands, prepared by George M. Hopkins, was published in 1868. This map shows the location of the principal magnetite deposits in the region near Dover (Bayley, 1910, p. 358).

A few years later, in 1880, a magnetic map of the Washington mine property near Oxford, showing both inclination and declination, by W. H. Scranton (1879), was published (Bayley, 1910, p. 200).

About 1890 Thomas A. Edison formed a company that explored much of the New Jersey Highlands, using both a magnetic compass and a dip needle; and his data were largely incorporated on the State maps published by Bayley (1910). Since the survey by Edison, magnetic exploration has been largely confined to detailed studies of certain mine properties. In the early 1920's the Wharton Steel Co. surveyed the Scrub Oaks and adjacent properties with a dip needle, and this survey was the basis for the drilling that disclosed the extent of the Scrub Oaks deposit. In 1938 the Jones and Laughlin Ore Co. made a dip-needle survey of the White Meadow mines and of the Richard Ore Co. property. During the same year Hans Lundberg, Ltd., of Toronto, surveyed the Mount Hope mine and adjacent property belonging to the Warren Foundry and Pipe Corp. with an Askania vertical magnetometer (Schmidt type). This survey did not disclose any new deposits at Mount Hope mine, but it did indicate that the Hibernia Pond deposit was potentially of economic importance. In 1942 a magnetic survey was made of the Richard Ore Co. property with a Hotchkiss Superdip by Sherwin F. Kelly, Geophysical Services, Inc., and a survey with an Askania vertical magnetometer was made of the Canfield estate by Fred Keller (1942, manuscript in files of Rutgers Univ.). In 1950 and 1951, after the completion of the present field study, the Dover district, together with other regions in the New Jersey-New York Highland, was flown by the U. S. Geological Survey with an airborne magnetometer, and a preliminary aeromagnetic map of the Dover district has been placed in open file.

EVALUATION OF MAGNETIC INSTRUMENTS

The various ground magnetic instruments have not been compared in the field by the present writer, but comparisons of them have been made over anomalies of a smaller order, ranging from 20 to 5,000 gammas, in the Iron River-Crystal Falls iron-mining district of upper Michigan. This study indicated that the dip needle is fitted for the range of anomalies above a critical value of 600 gammas, the vertical-intensity magnetometer of the Schmidt type is fitted for the range of anomalies between 5 and 3,000 gammas, and the Superdip is fitted for the range of anomalies between 75 and 10,000 (James, 1948, p. 11).

Experience in the New Jersey Highlands has demonstrated that the common dip needle is the instrument best adapted to the ground exploration, for it is suited to the measurement of large anomalies. The common dip needle measures the relative degree of distortion in the earth's magnetic field (Stearn, 1929, p. 358). It is sufficiently sensitive to detect the presence of magnetite concentrations. The dip needle has an added advantage of being a rapid and inexpensive method of exploration, and any nontechnical person can use the instrument effectively with only a few hours' training. The main limitation to its use in exploration for the magnetite ore bodies in the New Jersey Highlands is its effective depth, which possibly does not exceed 50 feet. For a detailed description of the dip needle, field procedure, and treatment of results, the reader is referred to Stearn (1929, p. 345–363) and Brant (1938, p. 501–516).

More sensitive ground instruments may also be used advantageously, and both the Hotchkiss Superdip and the Askania vertical magnetometer have been employed in the detailed investigation of certain ore deposits in the district. An advantage of the magnetometer is that it yields consistent values in gammas. The instrument is not ideally suited, though, for the measurement of large anomalies such as those produced by the ore bodies in the Dover district. The Superdip is admirably suited for work in areas where anomalies have a wide range of value, yet it too has a sensitivity much greater than that needed for exploration in this area.

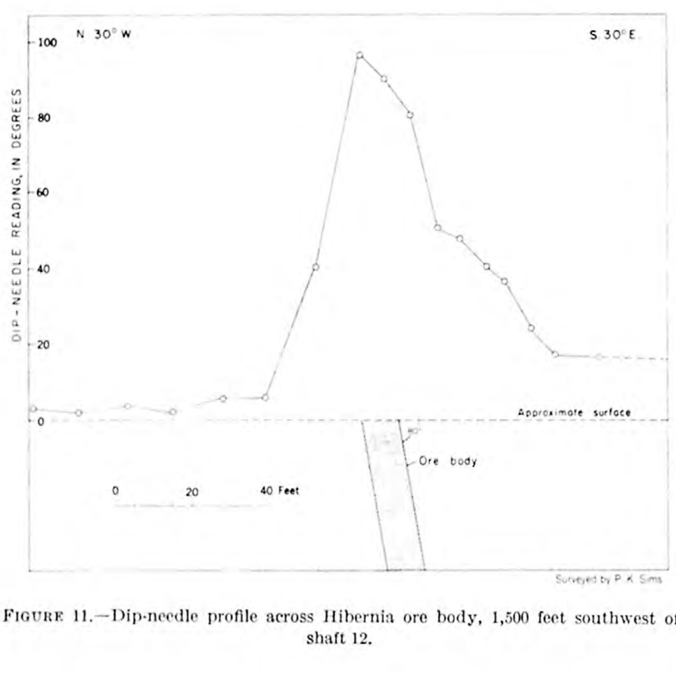


FIGURE 11.—Dip-needle profile across Hibernia ore body, 1,500 feet southwest of shaft 12.

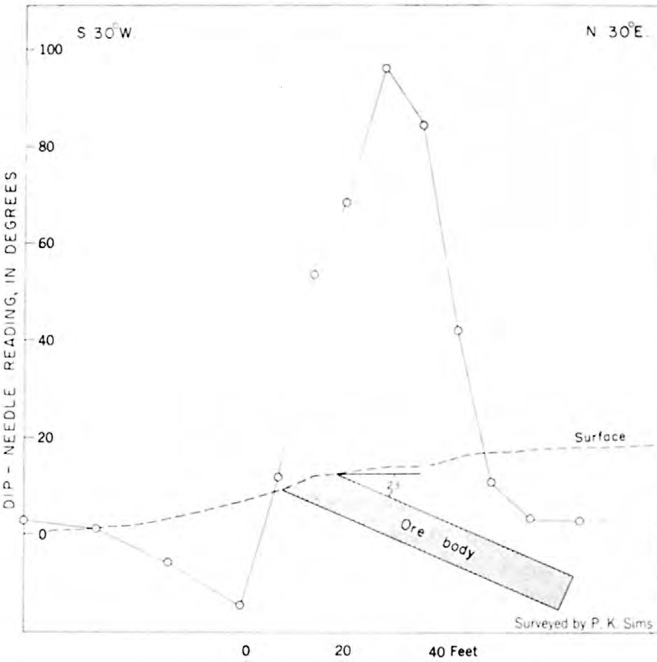


FIGURE 12.—Dip-needle profile across ore body at Birch mine.

The known ore bodies in the district are marked by prominent positive anomalies that continue in the direction of the strike. The values (in gammas) of the anomalies are poorly known, but they vary over a wide range. Fred Keller (1942, unpublished thesis in files of Rutgers Univ.) measured positive anomalies of as much as 34,000 gammas in his survey of the Canfield property. The length of the anomaly is an indication of the surface (outcrop) length of the deposit. Its shape in cross section offers a clue to the attitude of the deposit—that is, whether it is flat lying or steeply dipping, its thickness, and its depth. Most of the deposits in the Dover district dip moderately to steeply southeast, and magnetic profiles across these deposits are slightly asymmetric; the southeast limb is normally more gentle than the northwest limb. This is illustrated in figures 11 and 12. In steeply-dipping deposits the maximum dip angle measured with a dip needle lies above the deposit (fig. 11); in flatly dipping deposits the maximum dip angle is shifted somewhat southeast of the upper part of the deposit (fig. 12). The thickness of the deposit can be estimated only in a general way from profiles of the anomaly, and supplementary geologic information generally is necessary. A thick deposit of low-grade ore will produce an anomaly very similar to a thin deposit of massive high-grade ore. An added complication, of course, is the depth of the deposit. Generally, if the body is near the surface the values of the dip increase from, or decrease to, approximate normal in a relatively short distance; but if the body is deeply buried, the increase of dip to, and decrease of dip from, the maximum values takes place in general very gradually and over a considerable distance.

FUTURE OF THE DISTRICT

The Dover district, one of the oldest mining regions in the United States, has been almost continuously active for more than 200 years. Nearly all the deposits were discovered at an early date. There have been no important new discoveries in recent years, and it is doubtful if any new deposits will be found that will constitute ore bodies. The future of the district is therefore dependent primarily upon the exploitation of the known deposits of commercial value and upon the efficient handling of some of the deposits now considered to be subeconomic because of their low grade or their small size.

The deposits most favorable for future exploitation are those that are being mined in the Mount Hope, Richard, and Scrub Oaks mines. Mining has demonstrated that the ore bodies in the district, with the exception of the deposits in pyroxene skarn in the Green Pond and Splitrock Pond-Charlottesburg ore belts, extend for long distances along rake and to great depths without appreciable change in grade and size. It is probable, then, that these deposits can be mined profitably to depths of 3,000 feet or more, depending upon economic conditions. Other deposits not now being mined, which are near present mine plants or the underground openings, may also be mined under favorable economic conditions. Deposits distant from existing mine plants, regardless of size or grade, are less promising at present as potential producers. There is sufficient ore in the active mines to provide iron ore for several more generations at the present rate of extraction.

Two of the deposits that are inactive show particular promise as future sources of iron ore: the Hibernia and the Hibernia Pond. The Hibernia deposit, from which about 5 million tons of iron ore has been produced, contains large reserves of high-grade ore. It could be opened through shaft 12, now inaccessible, or through workings extended from the Mount Hope mine. Diamond-drill exploration indicates that the Hibernia Pond deposit contains a large reserve of low-grade ore. The deposit, however, was not considered to be of economic value in 1951.

A large number of abandoned mines in the district, principally in the Wharton ore belt, contain reserves of magnetite that could be mined only under the stimulus of much higher market prices. The deposits in these mines generally are thin, and for the most part they have been mined to moderate depths. Reopening of the mines would be costly; deep shafts would have to be sunk to reach the deposits.

In summary, the future of the district is promising. Large reserves of ore exist in the active mines. One abandoned mine—the Hibernia—contains important reserves of high-grade iron ore that could be exploited; and one deposit—the Hibernia Pond—which recently was explored, contains large tonnages of low-grade ore that could be mined under the stimulation of more favorable market conditions. The probability of finding large new ore bodies, however, seems slight.

MINES AND PROSPECTS

Of the 91 mines and prospects in the Dover district 58 are known to have yielded some iron ore. All the accessible mine openings were examined by the writer, and their locations and geologic setting are shown in plate 1. Insofar as possible the principal shafts are plotted on plate 1. Because most of the mines were opened more than 100 years ago and many have been abandoned for more than 50 years, the walls of several old openings have slumped, and vegetation has partly, or even completely, obscured the deposits. In the region near Wharton most of the abandoned mine openings have been filled in and nearly all features of the workings have been obscured. The descriptions of many deposits, therefore, are almost wholly based upon data published by Bayley (1910), Cook (1868), and others, supplemented by notes on the geology gained from observations of dumps and a knowledge of the broader geologic setting. The operating mines—Mount Hope, Richard, and Scrub Oaks—were studied intensively, and detailed descriptions are given of the mine workings and geology of these deposits.

Production from individual mines is given in table 13. The production data for the abandoned mines were obtained largely from published sources, principally Bayley (1910), and from the New Jersey State Geologist; data for the active mines were obtained from the mining companies. Production figures have not been recorded for many of the mines now abandoned, and the writer has estimated the yield of these from all available data: size of mine workings, grade of the ore, and thickness of the ore bodies. These data are believed to be accurate to within several thousand tons.

The magnetite deposits in the Dover district are grouped according to geographic distribution into 7 ore belts: (1) Wharton, (2) Dalrymple, (3) Beach Glen, (4) White Meadow-Cobb, (5) Hibernia Pond-Hibernia, (6) Splitrock Pond-Charlottesburg, and (7) Green Pond.

WHARTON ORE BELT

[The numbers following the names of the prospects and mines in this belt refer to locations on plate 1]

The Wharton ore belt contains nearly all the large mines in the district, including the Mount Hope,

TABLE 13.—*Total production of mines of the Dover district that have yielded iron ore*

[Data as of 1950. Production probably accurate to a few hundred thousand tons. Based upon data from Bayley (1910); M. E. Johnson, New Jersey State Geologist; private companies; and estimates by the writer]

Mine	Long tons	Mine	Long tons
Wharton ore belt			
Cogill mine	1,000	Scrub Oaks mine [3]	3,713,932
Denmark mine	1,000	Spring mine (not located)	10,000
Spencer mine	1,000	Corwin mine	150,000
Mount Hope mine [1]	5,640,497	Sullivan mine (not located)	5,000
Allen mine	150,000	Jackson Hill mine	100,000
Richard mine [2]	5,560,657	Randall Hill mine	135,000
Baker mine	400,000	Baker mine (at the base of the hill)	100,000
Dolan mine	5,000	Baker No. 1 mine	100,000
Mount Pleasant mine	400,000	Millen mine	50,000
Huff mine	150,000	Byram mine	600,000
Johnson Hill mine (not located)	5,000	Canfield mine	25,000
Meadow mine (not located)	75,000	Brotherton mine	55,000
Washington Forge mine	50,000	Evers mine	10,000
Orchard mine	375,000	Dickerson mine	1,016,000
Hurd mine	800,121	Black Hills mine	4,000
Harvey mine	50,000	King mine	10,000
Hubbard mine (not located)	75,000	C. King mine	1,000
North River mine (not located)	20,000	Bryant mine	50,000
Sterling mine	250,000		
Dalrymple ore belt			
George mine	5,000	DeHart mine	5,000
Dalrymple mine	200,000	David Horton mine	1,000
Trowbridge mine	1,000	Henderson mine	1,000
Lawrence mine	15,000		
Beach Glen ore belt			
Beach Glen mine	131,318	Swedes mine	200,000
White Meadow-Cobb ore belt			
White Meadow mines	5,000	Cobb mine	25,000
Hibernia Pond-Hibernia ore belt			
Hibernia mine	5,230,311		
Splitrock Pond-Charlottesburg ore belt			
Splitrock Pond mine	5,000	Charlottesburg mine	100,000
Green Pond ore belt			
Green Pond mine	50,000	Winter mine	10,000
Davenport mine	40,000	Pardee mine	5,000
Others			
Combs mine	1,000	Munson mines (not located)	500
Total, all ore belts			26,175,336

[1] Includes about 200,000 tons production from the Teabo mine. Published by permission of Warren Foundry and Pipe Corp.

[2] Published by permission of the Colorado Fuel and Iron Corp.

[3] Published by permission of Alan Wood Steel Co.

Richard, and Scrub Oaks mines, that were active in 1950. The ore belt is 10 miles long and from 900 to 3,000 feet wide; it extends from near Ironia to a point about 1 mile northeast of Mount Hope village. The deposits north of Mount Hope are generally well exposed, but those to the south are largely covered to variable depths by glacial deposits.

Several of the deposits in the Wharton ore belt because of their great length were worked in two or more mines. (See pl. 1.) The largest of these deposits, the Mount Pleasant (pl. 9), one of the two largest sources of ore in the district, has been worked in the Hubbard, North River, Harvey, Hurd, Orchard, Washington Forge, Bull Frog, Mount Pleasant, West Mount Pleasant, Baker, and Richard mines. In all these mines, except the Baker and Richard, the Mount

Pleasant deposit supplied nearly all the ore that was hoisted.

PROSPECT (1)

This prospect (1) is in Rockaway Township, on the hill one-fourth of a mile northwest of Hibernia Brook. The workings consist of a single small shallow pit that is caved and largely overgrown with vegetation. To judge from the material on the dump, the magnetite in the deposit occurs as thin stringers and as disseminated grains in oligoclase-quartz gneiss, probably a facies of the oligoclase-quartz-biotite gneiss. Dip-needle data indicate that the deposit is a short linear body that is too small to warrant further prospecting.

PROSPECT (2)

This prospect (2) is one-fourth of a mile northeast of the Cogill mine, on the hill northwest of Lake Telemark. It consists of two groups of surface workings, about 500 feet apart, that are on the same mineralized zone. The southwest openings consist of a caved shaft and open stopes that now are filled with water; the northeast openings consist of two shallow test pits. Material on the mine dumps indicates that the magnetite occurs as disseminated grains and as inch-thick layers that replace oligoclase-quartz gneiss, and locally granite pegmatite. The deposit is estimated to have a maximum thickness of about 6 feet in the southeast group of mine workings. Dip-needle data indicate that a narrow zone of moderate magnetic attraction extends between the surface workings and that the deposit has a maximum length of at least 500 feet.

COGILL MINE (3)

The Cogill, or Cogswell, mine (3) is on the west slope of the hill northwest of Lake Telemark. The deposit was explored and a shaft was sunk to a depth of 70 feet prior to 1868; it was worked intermittently between 1868 and 1900, but was again abandoned before 1910 (Bayley, 1910, p. 47). There are 3 shafts on the deposit; the main shaft is just below the crest of the hill, 85 feet northwest of an opencut that is 100 feet long and 5 feet wide.

The deposit is about 1,200 feet long. It trends N. 38° E. and at the surface dips 70° SE. The lineation in the wall rocks plunges 16° NE. The deposit contains low- to medium-grade magnetite that is 18 inches thick in the northeast face of the opencut; the mined portion, however, probably exceeded 2 feet in thickness. The magnetite is in discontinuous branching veinlets, commonly less than one-eighth of an inch thick, that replace the host rock—greenish-gray, medium-grained oligoclase-quartz-pyroxene gneiss. The ore walls are sharply defined, although the wall rocks contain a few percent of disseminated magnetite. The host-rock gneiss is enclosed within microantiperthite granite, which in turn is enveloped by hornblende granite, as shown in plate 1. Production from the mine is estimated by the writer to be less than 1,000 tons.

PROSPECT (4)

This prospect (4) consists of 3 small pits on the saddle of the hill on the north side of Hibernia road, three-fourths of a mile northwest of Hibernia Pond. The pits are caved, and the character of the deposit was not determined. Reconnaissance dip-needle data indicate that the pits are located on small concentrations of magnetite.

DENMARK MINE (5)

Denmark mine (5) consists of 3 separate groups of mine openings on the broad low hill south of Lake Denmark. The history of discovery and development are not known. The northernmost group of openings consist of a shaft and some abandoned stopes. The stopes apparently are on a concealed, thin deposit that strikes N. 25° E. The central group of openings consists of 2 small pits on opposite sides of the road, about 400 feet south of the shaft. The main opening here exposes a thin deposit of medium-grade ore that strikes N. 85° W. and dips 80° S. The magnetite is in coarse-grained pyroxene-hornblende skarn; amphibolite forms the footwall of the deposit. The southernmost group of workings consists of several pits, the largest of which is an opencut, 50 feet long, that was filled with water in 1948. To judge from the dump material, the ore is a massive granular magnetite that replaces the skarn. Pyrite and pyrrhotite cut the magnetite and constitute several percent of the deposit. An analysis of ore from a stock pile gave 49.76 percent Fe and 0.056 percent P. (Pumpelly, 1886, p. 172). Production is estimated by the writer to be about 1,000 tons.

The geologic setting and structure of the deposits is little known because of the sparse outcrops. Amphibolite is exposed south of the central group of deposits; elsewhere the bedrock is obscured by a mantle of glacial deposits. A dip-needle reconnaissance of the mine area indicates that the mine openings probably are on separate magnetite concentrations; there is no evidence that the workings are on a continuous deposit.

PROSPECT (6)

This prospect (6) is a small caved pit in the saddle of the hill on the south side of Hibernia road, 1½ miles northeast of Mount Hope mine. Neither the deposit nor the wall rocks are exposed. The pit, though, is probably on the same mineralized zone as the Bush mine.

PROSPECT (7)

This prospect (7) consists of a trench 150 feet long, which is 1,000 feet north of the prospect (6) on the lower slope of the hill. The trench did not penetrate bedrock.

BUSH MINE (8)

The Bush mine (8) is 2,800 feet northeast of the Spencer shaft, Mount Hope mine (pl. 1), and apparently on the same mineralized zone as the Spencer mine. The mine is owned by Warren Foundry and Pipe Corp. The workings consist of 2 cribbed shafts, 400 feet apart, and several small test pits. The northeast shaft is reported to be 45 feet deep; the southwest shaft 35 feet deep. In 1937 the Warren Foundry and Pipe Corp. cored three diamond-drill holes to test the deposit, but none of the holes penetrated minable ore. Analyses and observations of these drill cores indicate that the deposit, like that at the Spencer mine, is low in grade and consists of alternating layers of magnetite and country rock.

MOUNT HOPE MINE

The Mount Hope mine, owned and operated by Warren Foundry and Pipe Corp. of Phillipsburg, Pa., is at Mount Hope, 3 miles north of Dover. The mine includes the workings on nine ore bodies, of which four were on Mount Hope Hill, three on Hickory Hill (pl. 3), and two on the hill to the southwest of Mount Hope hill, locally referred to as Mount Teabo (fig. 18; see also Bayley, 1910, p. 408). The principal shafts at the mine, shown on plate 1, include the Spencer shaft (9), Fowler shaft (10), Brown shaft (11), New Leonard shaft (12), Elizabeth shaft (13), and Carlton shaft (14). All except the Fowler and New Leonard shafts are inaccessible. The New Leonard shaft is the principal operating shaft. The Mount Hope mine ranks as the largest producer of iron ore in New Jersey, and it has yielded 5,640,500 long tons of shipping ore (table 14). The production before 1899 is estimated; since that time accurate records have been kept. A large proportion of the production has been lump ore, and since 1937 the mine has provided about 1,000,000 tons of this ore. In 1950 the concentration ratio (ratio of crude ore hoisted to shipping ore) was about 1.6 : 1.

HISTORY OF OWNERSHIP AND DEVELOPMENT

The Mount Hope mine is said to be the oldest operating iron mine in the United States with a production history dating back at least to 1710 (Roche and Stoddard, 1915, p. 171). The History of Morris County, N. J., from 1739 to 1882 says that the mines were being worked in 1665.

Some of the ore bodies cropped out at the surface, and the Taylor deposit, formerly known as the Great Jugular "vein", is known to have formed a cliff of nearly solid ore 100 feet high on Mount Hope Hill. Prior to 1749, when the mine was first surveyed and recorded, the ore was free to all, and the mining was done by hand. The ore was picked up from the projecting ledges and was carted by wagon to Dover, where a forge was in operation in 1722. There was no forge at Mount Hope because of the lack of adequate water power. Between 1749 and 1831, when the Mount Hope Mining Co. acquired the property, the mine tract changed hands several times. The

TABLE 14.—*Iron-ore production in long tons, Mount Hope mine, to December 31, 1950*

[Published by permission of Warren Foundry and Pipe Corp. Shipping ore includes both lump and concentrate]

Year	*Crude ore hoisted*	*Shipping ore*	*Year*	*Crude ore hoisted*	*Shipping ore*	*Year*	*Crude ore hoisted*	*Shipping ore*
Before 1880	([1])	[2] 1,000,000	1916	273,826	215,184	1935	([5])	----------
1880-99	----------	[3] 100,000	1917	218,427	142,800	1936	([5])	----------
1899 [4]	----------	3,594	1918	177,671	132,292	1937	145,882	106,714
1900	----------	20,468	1919	177,804	143,076	1938	157,087	112,558
1901	----------	34,895	1920	198,207	147,212	1939	170,000	113,618
1902	----------	20,456	1921	19,892	16,741	1940	193,831	133,137
1903	----------	58,793	1922	55,145	41,616	1941	199,051	133,472
1904	----------	46,704	1923	164,813	126,295	1942	252,437	139,521
1905	----------	21,297	1924	([5])	----------	1943	246,430	111,542
1906	----------	33,087	1925	182,130	134,562	1944	194,936	131,242
1907	----------	50,050	1926	205,288	141,004	1945	209,139	128,213
1908	----------	55,930	1927	198,993	133,625	1946	255,061	140,289
1909	132,261	98,179	1928	206,181	151,651	1947	234,981	127,225
1910	102,890	59,979	1929	212,340	147,274	1948	220,673	118,077
1911	60,937	35,174	1930	176,474	118,140	1949	223,310	109,167
1912	86,243	42,111	1931	134,889	96,148	1950	295,009	178,434
1913	66,777	36,484	1932	43,535	30,845			
1914	125,457	82,909	1933	([5])	----------	Total	6,406,922	5,640,497
1915	188,915	138,713	1934	([5])	----------			

[1] No record before 1909.
[2] Estimate by Bayley (1910, p. 411).
[3] Estimate by Sims.
[4] 1899–1950 Data from Warren Foundry and Pipe Corp.
[5] Inactive.

Mount Hope Mining Co. considerably extended the operations, and in addition to mining the ore bodies on Mount Hope, they exploited the deposits that later were found on Mount Teabo to the southwest and on Hickory Hill to the northeast. By 1868 the company was operating 9 different mines on separate ore bodies, with an annual production of about 72,000 tons.

The workings on the Jugular "vein" (Taylor deposit) were in the Blue mine which was on the northeast side of Mount Hope hill. Entrance to the workings was by means of two 25° inclines that descended to a depth of 100 feet. The ore was worked down from the surface, producing a great open pit known as the "open workings." About 1868 a crosscut adit, the Side Hill adit or the Big Tunnel (pl. 3 and fig. 13), was completed by the Scranton Iron Ore Co. It intersected 5 different deposits that are now known as the Brennan (or Brannin), Leonard, Finley, Hawkins, and Taylor.

In addition to the deposits on Mount Hope Hill that were mined by means of the Side Hill adit, the Elizabeth ore body, on the northeast slope of Mount Teabo, also was exploited prior to 1868. It was mined from an adit at the base of the hill that was driven southwest along the trend of the deposit; the ore above the adit level was mined from 3 shafts, the largest of which was the Painter shaft.

A third group of deposits that were actively mined prior to 1868 crop out on Hickory Hill. These are separated from those on Mount Hope by the Mount Hope fault (pl. 3).

Mining of all the deposits continued for a number of years after 1868 with slight interruption, most of the ore being obtained from the Taylor, Finley, and Leonard veins on Mount Hope. In 1874 the Taylor and Hickory Hill mines were shut down, but the

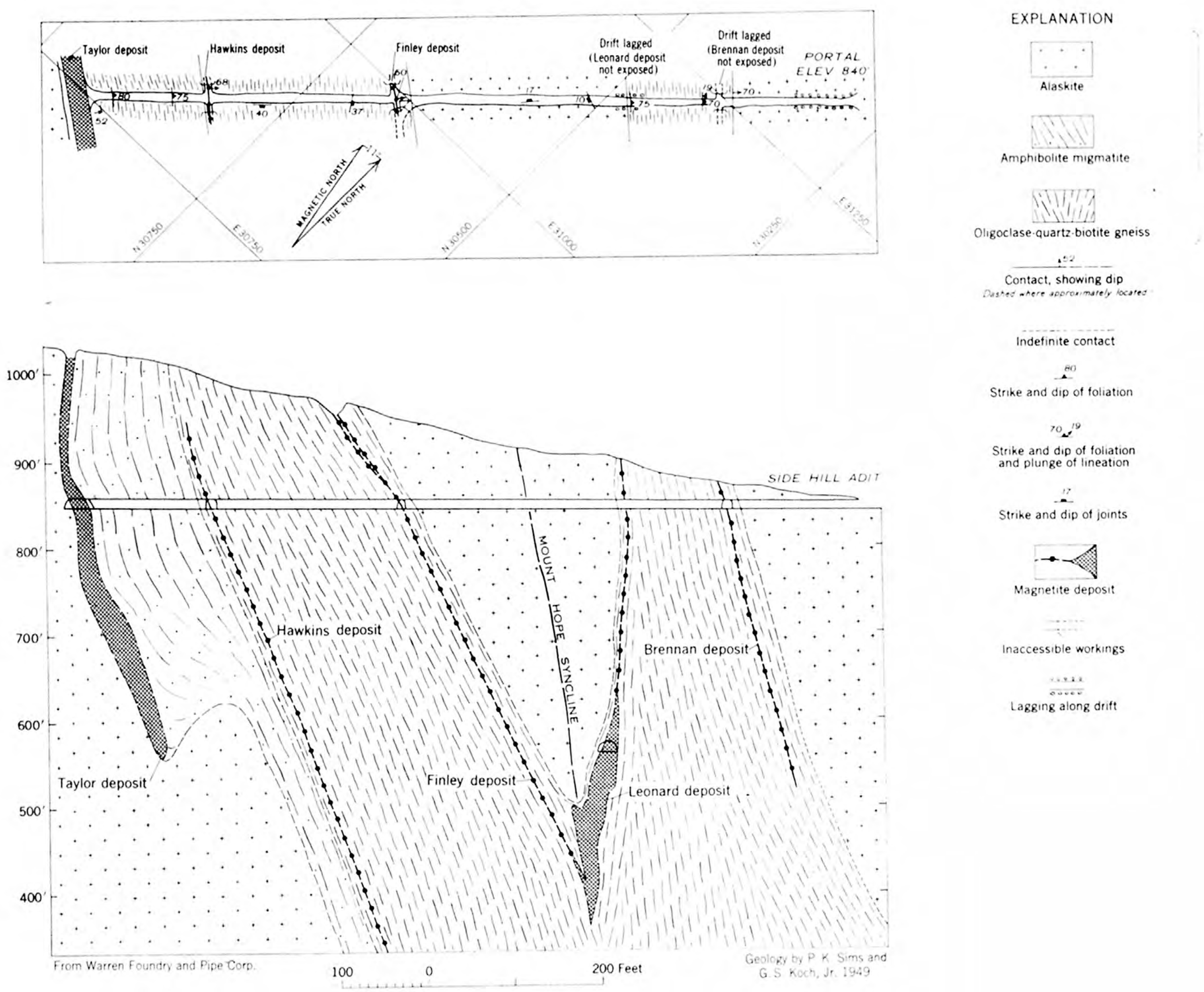


FIGURE 13.—Geologic map and section of Side Hill adit, Mount Hope mine.

Taylor was reopened in 1880. The Elizabeth mine was operated continuously throughout this period, yielding about 30,000 tons of ore annually. The aggregate production of the entire group of mines to the end of 1880 is estimated at 1,000,000 tons (Bayley, 1910, p. 411). The Elizabeth mine was closed shortly after 1880, but work continued on the Taylor, Finley, and Leonard (Side Hill) veins. In 1883 the Elizabeth mine was reopened, but it did not get in production until 1889 or 1890.

All the mines were idle in 1893, and they remained closed until 1899, when the Elizabeth mine was reopened. By 1900 practically all the ore had been removed from the southwest end of the Elizabeth deposit necessitating the sinking of the Elizabeth shaft (fig. 18) farther northeast along the deposit. The Elizabeth shaft, which is inclined 72° to 79° to the southeast, encountered the ore at about 200 feet. It was continued through the ore and in 1909 it had a depth of about 500 feet. Later it was deepened to 1,120 feet (fig. 18).

The Taylor mine also was unwatered in 1899, when the Empire Steel and Iron Co. of New Jersey purchased the Mount Hope properties, and 6,000 tons of ore was raised during that year. In the following year the Brown shaft was sunk at an angle of 64° to the southeast, to the bottomrock of the Taylor ore body. In 1906 a new shaft, the Leonard, was opened to mine the ore from the Leonard or Side Hill deposit (pl. 3); and in 1907 the Carlton shaft was sunk on the Carlton vein.

The Taylor, North and South Elizabeth, North Leonard, and Carlton ore bodies were worked from the Brown shaft (pl. 2). The workings were on 3 main levels: the 300-, 400-, and 1,000-foot. The North and South Taylor were mined from the 300-foot level; the North and South Leonard were mined from the 400-foot level. After exhaustion of the ore above the 300- and 400-foot levels, inclines were driven along the bottom rocks of both the North Taylor and North Leonard deposits, and the inclines were connected on the 1,000-foot level with the Brown shaft, after it was deepened. The Taylor deposit between the 300- and 1,000-foot levels was developed by 2 intermediate levels from the Taylor incline. A description of the mine workings on the 300-, 400-, and 1,000-foot levels is given by Sweet (1932, p. 9–16).

Mining was started on the North Taylor deposit in 1912, and the deposit yielded from 50 to 80 percent of the mine output between 1914 and 1921. In 1913 the Finley deposit, on the south side of the Mount Hope fault, was the principal source of ore in the mine, supplying 74 percent of the aggregate production.

In 1922 the Replogle Steel Co. obtained the property from the Empire Steel and Iron Co., and from 1924 to 1927 the property was owned by the Warren Foundry and Pipe Co., and operated by the Replogle Steel Co. under lease. In 1927 the Warren Foundry and Pipe Corp. was organized and took over the assets of the Replogle Steel Co. and operated the mine under lease to the Warren Foundry and Pipe Co. till December 31, 1930, when the Warren Foundry and Pipe Corp. took over the assets of the Warren Foundry and Pipe Co. (Sweet, 1932, p. 3).

After extraction of the ore above the 1,000-foot level, the North Taylor, North Leonard, and North Elizabeth inclines were extended, and mining was conducted from these inclines. On the south side of the Mount Hope fault, the Elizabeth and Teabo ore bodies were mined from the 1,000-foot level; the Elizabeth was mined principally in stopes developed from the Elizabeth incline. During the late 1930's an incline was driven along the bottom of the Teabo ore body to permit mining below the 1,000-foot level.

In 1941 a vertical three-compartment shaft, the New Leonard, was sunk, and in 1944 it was completed to a depth of 2,694 feet. The workings on the 1,000-foot level were connected with this shaft. In addition, four new levels were established: the 1,700-, 2,100-, 2,300-, and 2,500-foot. In 1947, the South Teabo deposit was being worked from the 1,000-foot level; the North Taylor, North Elizabeth, and North Leonard deposits were being worked from the 1,700-foot level. At that time the Teabo and Taylor deposits ranked as the principal sources of ore. In 1948 the Teabo deposit was opened on the 2,100-foot level; in 1950 the level was being extended southwestward to reach the bottom rock of the Richard deposit. The Richard deposit was opened in 1948 on the 1,700-foot level.

The modernization program at Mount Hope mine during World War II included the erection of a new magnetic concentrator (Davenport, 1945), an 1,800-hp ore hoist, and a 900-hp man hoist, to make the surface plant one of the finest in the country.

MINE WORKINGS AND MINING METHOD

The principal mine workings are shown in plate 2. The new Leonard shaft, through which all ore is now hoisted, is situated near the central part of the present mine workings and connects with the 1,000-, 1,700-, 2,100-, 2,300-, and 2,500-foot levels. On the 1,700-foot level the workings extend from the shaft 1 mile southwestward to the Richard Ore Co. property line and 6,000 feet northeastward to the top rock of the Taylor ore body. On the 1,000- and 1,700-foot levels the ore bodies are connected to the shaft by drifts and crosscuts. Development work on the 2,100-foot level was in progress in 1950 and a drift was being driven to open up the Teabo and Richard ore bodies on the south side of the Mount Hope fault.

The mining methods that were used at the Mount Hope mine to 1932 are described in detail by Sweet (1932, p. 9–20) and hence are only summarized here. Open-pit mining was first used and was followed by underground mining with open-stull-timbered stopes. In 1910 shrinkage stoping without timbering or filling was started, being used first on the 300-foot level (Taylor deposit); and this method was used exclusively until 1949. In 1949 sublevel stoping was begun to mine the Richard ore body on the 1,700-foot level, and later this method was extended to the other wide ore deposits. The narrow deposits are not mined by this method because of excessive development costs (Allan James, personal communication). Shrinkage stoping was abandoned in favor of sublevel stoping, where possible, primarily because of dilution of the ore. Another factor that favors sublevel stoping is that this method will provide the operators with more data on the faults that displace the ore bodies.

ORE BENEFICIATION

The ore at the Mount Hope mine is treated by a magnetic concentrator that produces about half of the concentrates in the lump-ore plant, the remainder being produced by wet magnetic concentration in the fine-ore plant (Davenport, 1945). The fine concentrate is sintered at the furnace. In 1948 the lump ore averaged 60.55 percent Fe and 0.66 percent P; the fine concentrate averaged 65.8 percent Fe and 0.121 percent P. The lump ore was shipped to Bethlehem Steel Co., Bethlehem, Pa., and to American Rolling Mills, Ashland, Ky.; the concentrate was shipped to E. and G. Brooks Iron Co., Birdsboro, Pa.

GEOLOGY

Eleven deposits have been mined at the Mount Hope mine. Of these the Taylor, Leonard, Finley, Elizabeth, Teabo, and Richard have yielded the greater part of the ore. The other deposits—the Carlton, Spencer, Hawkins, Brennan, and Gold Diggings—were worked only from the surface to relatively shallow depths.

ROCKS

At the Mount Hope mine (pl. 3) metasedimentary rocks, mixed rocks, and granitic igneous rocks of Proterozoic age, constitute the bedrock. Oligoclase-quartz-biotite gneiss, the most abundant metasedimentary rock, is exposed at places on the surface and throughout most of the mine. It forms the host rock and wall rock of many of the ore bodies. At places the gneiss contains bodies of amphibolite, biotitic amphibolite, biotite schist, and augen gneiss as much as 10 feet wide. Amphibolite layers as much as 2,200 feet long are exposed at several places; most of the amphibolite, however, contains thin interlayers of granite or pegmatite and is mapped as amphibolite migmatite. Hornblende skarn, the host rock for the ore in the Taylor and Carlton ore bodies, is exposed in a few opencuts along the Taylor ore body, but because the bodies are small they are not mapped on plate 3.

A plagioclase-pyroxene gneiss is exposed at places in the valley northwest of the Taylor ore body. It has not been found underground. Albite-oligoclase granite forms a lenticular(?) layer that is exposed locally near the crest of the ridge northwest of the Taylor ore body. This body of granite probably is equivalent to the albite-oligoclase granite that contains disseminated magnetite of subore grade (Hilltop deposit) at the Richard mine.

Alaskite, the most widespread rock type at the Mount Hope mine (pl. 3), forms sheets and a synclinal phacolith. The synclinal structure of the phacolith can be seen at the surface and at places in the mine (pl. 3 and fig. 13). At both the northwest and southeast margins of the mine (pl. 3) the alaskite grades laterally into hornblende granite. The youngest igneous rocks (pre-Cambrian) are granite pegmatite. Granite pegmatite can be seen at many places in the mine, and it is particularly common near the ore bodies. The pegmatite forms conformable layers for the most part, but locally it forms conspicuous crosscutting bodies. Two large bodies, more than 400 feet in length, were mapped at the surface (pl. 3).

Fine-grained diabase dikes of Triassic(?) age have been cut locally in the mine workings (pl. 3) and in drill cores. The dikes are small, generally less than 2 feet wide, and are discontinuous. For the most part they trend northwestward.

STRUCTURE

FOLDS

The rocks at the Mount Hope mine have been deformed into isoclinal folds that trend and plunge northeast, as shown on plate 3. The gross structure of the ground that has been opened by the mine workings at the Mount Hope mine is well understood, but the structure of the rocks adjacent to the mined area is poorly known. The principal structural features within the mine are shown in plate 4.

The most conspicuous fold at the Mount Hope mine is an overturned syncline that has been named the Mount Hope syncline (Sims, 1953). The synclinal structure is indicated at the surface by the dips in the alaskite that forms the core of the syncline between the Finley and Leonard deposits (pl. 3). The bottom of the phacolith can be seen on the 1,700-foot level in the North Leonard drift, 200 feet northeast of 1019 crosscut (fig. 20). Oligoclase-quartz-biotite gneiss constitutes the limbs of the syncline and also, below the phacolith, the axial area. As can be seen in plate 3, the southeast limb dips 65°–85° SE.; the northwest limb is more gentle and dips 65°, or less, SE. The fold axis trends N. 45° E. and plunges 15°–18° NE. The axial plane dips 65°–75° SE. in the upper part of the fold but probably flattens somewhat in the deeper workings of the mine. Little is known concerning the lower part of the syncline because of the absence of distinctive rock units that would serve as marker "beds" and because of the uniform southeast dips that reflect the isoclinal folding. Possibly the axial plane of the syncline dips about 55° SE. and is essentially coincident with the Elizabeth and possibly the Teabo and Richard ore bodies, or possibly it lies to the southeast of these deposits. The Taylor and Mount Pleasant deposits are on the northwest limb of the syncline; the Carlton is on the southeast limb of the syncline.

The structure of the rocks to the southeast and northwest of the Mount Hope syncline is poorly known because of sparse exposures at the surface and the absence of mine workings in this ground (pl. 3). A sheet(?) of alaskite borders the oligoclase-quartz-biotite gneiss on the northwest and is exposed in the same position in the Richard mine. Southeast of the syncline, on the northeast side of the Mount Hope fault (pl. 3), alaskite is exposed on the surface, but it does not extend far in depth, as shown in section A–A′ (pl. 3), because oligoclase-quartz-biotite gneiss occurs along the projected dip of the alaskite in the underground workings. This suggests the presence of a fold, but this cannot be proved with the existing data.

Isoclinal folds that have an amplitude of 1 to 10 feet were observed locally in the oligoclase-quartz-biotite gneiss. These folds plunge northeastward essentially parallel to the mineral lineation in the gneiss, and the axial planes usually dip southeast.

The gneiss layers involved in the folding are essentially uniform in thickness in all parts of the fold. In a few places, however, a slight to moderate thickening in the axial area, concomitant with a slight thinning on the limbs, was noted.

FAULTS

The principal fault in the mine, the Mount Hope, is a major transverse break that separates the mine working into a northern and a southern part. It has been described earlier (p. 56) and therefore is not discussed in detail here.

Longitudinal faults are common and constitute serious mining problems in many parts of the Mount Hope mine. These faults are chiefly of two types: high-angle reverse faults and low-angle reverse faults, or thrusts. The displacement on the faults is usually small, ranging from a few inches to about 50 feet, and almost invariably the northwest side is displaced upward relative to the southeast side. Mining has demonstrated that movement along the longitudinal faults is for the most part rotational. None of the faults are continuous over great distances. Longitudinal faults are present throughout the mine and intersect all the ore bodies, but they are most common in the Teabo, Richard, Elizabeth, and Taylor ore bodies.

The Taylor thrust fault was observed in the 1700-foot North Taylor drift, 700 feet northeast of the Taylor-Leonard crosscut. (See pl. 27, Sims, 1953). The fault is a compound fracture zone that trends about N. 70° E. and dips 30° to 45° NW. It produces a separation of the ore body of about 40 feet at the top of manway raise 25 and 60 feet in manway raise 27. The fault forms the back of stopes 24 and 25.

MAGNETITE DEPOSITS

The commercial magnetite deposits at the Mount Hope mine (pl. 4) are in gneiss and hornblende skarn. All the deposits that have been mined, with the exception of the Taylor and Carlton deposits, which are in hornblende skarn, are replacement bodies in oligoclase-quartz-biotite gneiss. The Finley and Leonard deposits are on the northwest and southeast limbs respectively, of the Mount Hope syncline (pl. 3) and join near the axial plane. The Elizabeth, Teabo, and Richard deposits are near the axial area and are below the Finley and Leonard deposits. The Taylor deposit is on the northwest limb and the Carlton deposit on the southeast limb of the syncline. All the deposits plunge northeast, but at slightly different angles; there is no evidence that the deposits change in size with depth.

The following descriptions of the individual ore bodies are, insofar as possible, brief, and only the more important features are discussed.

SKARN DEPOSITS

Taylor ore body

The Taylor ore body, which has been the largest source of ore at the Mount Hope mine, cropped out on both Mount Hope Hill and Hickory Hill. The two groups of opencut mine workings, separated by the Mount Hope fault, are shown on plate 3.

The deposit strikes N. 40°–45° E., dips 50° SE. to about vertical, and rakes about 18° NE. It lies on the northwest limb of the Mount Hope syncline, about 500 feet from the Leonard deposit (pl. 3), and it is in the same zone and about 3,000 feet vertically above the Mount Pleasant deposit. The Taylor ore body is tabular and ranges from 10 to 30 feet in thickness on the 1,700- and 1,900-foot levels. In Taylor stope 25 it averaged nearly 20 feet in thickness. In general, the deposit is thicker near the bottom rock and thinner near the toprock. In the upper levels of the mine the deposit has a breadth of 450 feet or more and a stope length of 1,500 feet, but in the workings below the 1,000-foot level the breadth is only 200 to 300 feet and the stope length is proportionally shorter. (See fig. 14). The decrease in breadth in this part of the deposit is the result of faulting. In Taylor stopes 24, 25, and 26 the Taylor thrust fault cuts through the ore body about 275 feet above the bottom rock; mining has stopped at this fault, for it is not profitable to mine the segment of ore that remains above the Taylor fault. It is probable that another reverse fault, possibly a thrust, was encountered at the top of Taylor stopes 12 and 15 (fig. 14), for the breadth of the deposit here is only about 300 feet. Supporting evidence for a fault here is given by the local superimposition of the North Taylor intermediate level 11 over the North Taylor intermediate level 12. The approximate position of this inferred fault is shown in plate 4.

The ore in the Taylor deposit replaces hornblende skarn, a rock with a conspicuous compositional layering that is produced by inch-thin pyroxene layers and thin biotite sköls that are intercalated with the hornblende. Locally, granite pegmatite forms irregular, but generally conformable, layers in the skarn. A typical detailed section across the ore body is given below.

Footwall rock: alaskite with a thin amphibolite layer at contact.	*Feet*
Magnetite ore, massive, blocky	1
Alaskite, unmineralized	1
Magnetite ore, massive, blocky, fine-grained	1
Alaskite, unmineralized	2
Biotite sköl with some disseminated magnetite	1
Magnetite ore, massive, fine-grained, high-grade	6
Magnetite ore, massive, medium-grained, high-grade	6
Magnetite ore, low-grade, biotitic	1
Ore, coarsely crystalline, massive, with several percent of disseminated granules of amphibole and pyroxene	2
Magnetite ore, massive, blocky, with abundant apatite laminae	4
Hanging-wall rock: alaskite.	

The skarn is replaced to different degrees by the magnetite. Where the replacement has been nearly complete, the magnetite ore is blocky, and it contains conspicuous granules of apatite that tend to be alined parallel to the layering in the skarn. In other places the ore is laminated, and it contains varying amounts of amphibole and other mafic minerals, which form layers or disseminated granules. In a few places the magnetite replaces the alaskite wall rocks for a distance of an inch or so from the skarn. The grade of the ore varies some from place to place, but it averages 45 to 65 percent Fe. The skarn in the Taylor deposit generally conforms to the structure of the surrounding alaskite wall rocks. Here and there, though, the contacts are disconformable. On the 1,900-foot level, for example, near the face, the layering in the skarn dips 30° to 70° SE., whereas the foliation in the alaskite wall rocks is nearly vertical (Sims, 1953, fig. 27).

Carlton deposit

The Carlton deposit (pl. 1) cropped out on Teabo Hill and was mined from the Carlton shaft (Bayley, 1910, p. 414). The deposit, however, has not been mined, except locally, in the Mount Hope mine. It was opened on the 1,000-foot level on both sides of the Mount Hope fault, but attempts to mine the deposit were not successful, because the ore is too spotty to be extracted at a profit. On the 1,000-foot level, the Carlton deposit is about 475 feet southeast of the Elizabeth ore body (pl. 5). It strikes N. 40° E., dips 50° to 70° SE., and plunges about 18° NE. The deposit has a stope length of approximately 500 feet. The thickness of the deposit varies greatly, as shown in figure 14; the average thickness is less than 10 feet.

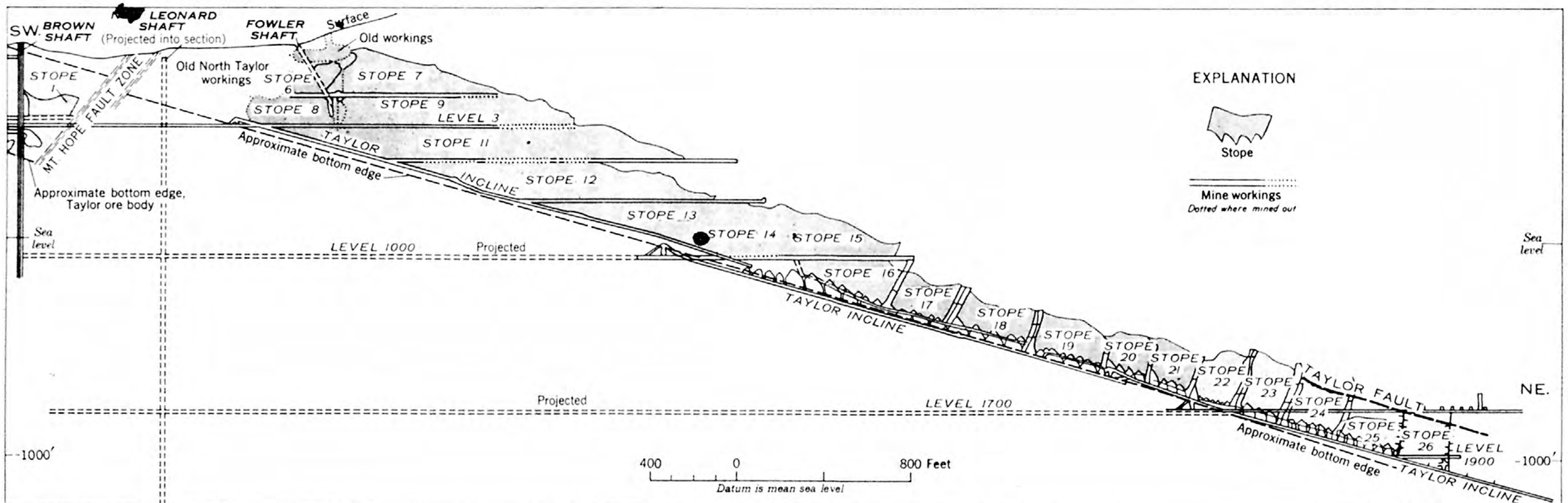
The host rock for the ore is coarse-grained hornblende skarn, locally pyroxene-rich, that contains thin biotite sköls and local irregular bunches of granite pegmatite. Locally the pegmatite contains nests and stringers of magnetite, but the magnetite is not sufficiently abundant to constitute ore. The distribution of the magnetite is spotty because of the extreme pinching and swelling of the skarn. The wall rock, which is principally alaskite, is not replaced by the magnetite. Narrow stringers of massive magnetite, known to the miners as "leaders", extend for some distance to the southwest and replace the oligoclase-quartz-biotite gneiss below the bottomrock of the deposit (pl. 5).

The conspicuous shoot structure in the Carlton deposit is caused by the extreme pinching and swelling of the skarn host rock. The structure is complex and cannot be shown adequately at the scale of the mine map (pl. 5). The structure was further complicated by the intimate injection of alaskite and pegmatite subsequent to the formation of the skarn. The pod-like shoots and the pinches plunge northeast. Two principal shoots were mapped in the North Carlton deposit; both were opened by stopes, but because the ore shoots are small they could not be mined at a profit. The ore is more variable in grade than the ore in the Taylor deposit; it is mostly of medium grade.

The Carlton deposit was not of economic importance in 1950, because of its small size, extreme irregularity, and low grade.

Mount Pleasant ore body

The Mount Pleasant ore body has not been mined in the Mount Hope mine but probably extends onto the property from the Richard mine a short distance below the 1,700-foot level. The deposit could be explored for and mined from the 2,100-foot level.



From Warren Foundry and Pipe Corp.

Geology by P. K. Sims, 1949

FIGURE 14.—Vertical longitudinal projection of Taylor ore body, Mount Hope mine.

GNEISS DEPOSITS

Teabo ore body

The Teabo ore body was mined on Mount Teabo in the now abandoned Teabo mine (pl. 1 and fig. 22; Bayley, 1910, p. 406). It was worked through a series of shallow shafts to a maximum depth of about 800 feet. Because of its northeast rake the deposit was encountered on the 1,000-foot level at Mount Hope mine and subsequently has been mined on the 1,700-foot level. In 1950 the deposit was being developed on the 2,100-foot level, southwest of the New Leonard shaft (fig. 15). The Teabo ore body ranks as second in production at Mount Hope mine, and it should continue to be an important source of ore for many years.

The Teabo ore body is the uppermost shoot in a large deposit that includes the Richard ore body. The Teabo and Richard generally are separated by a pinch, but in places an ore shoot known as the Allen lies between these two ore bodies (pl. 6 and figs. 16 and 22). The Allen deposit was mined in the Allen mine (Bayley, 1910, p. 403). The Teabo is separated from the overlying Elizabeth deposit, which lies in the same plane, by barren oligoclase-quartz-biotite gneiss. On the 1,700-foot level the toprock of the Teabo is 850 feet vertically below the bottomrock of the Elizabeth; this interval increases as depth increases because the Teabo rakes more steeply than the Elizabeth, and on the 2,100-foot level the Teabo is slightly more than 1,000 feet below the Elizabeth.

The host rock for the ore in the Teabo deposit is oligoclase-quartz-biotite gneiss. The wall rock is generally oligoclase-quartz-biotite gneiss, but at places lenses of amphibolite, biotitic amphibolite, and augen gneiss constitute the walls. The augen gneiss, a distinctive rock that consists of green oligoclase metacrysts in a matrix of biotitic amphibolite or biotite schist, is found locally on either the hanging wall or the footwall. It is thought to be similar to the gneiss along the hanging wall of the Allen deposit in the Allen mine, described by Bayley (1910, p. 404). Biotite sköls, not more than 2 feet thick, occur at places on both walls of the ore.

The ore in the Teabo deposit is characteristically finely granular, massive, blocky magnetite that contains only small amounts of gangue minerals. Apatite is the most abundant gangue mineral and forms crude laminae parallel to the ore walls. The ore contains an average of about 55 percent Fe and 0.70 to 1.00 percent P. Locally the magnetite occurs as inch-thin laminae or as disseminations in biotite schist or biotitic amphibolite. This type of ore is abundant in the pinch that separates the Teabo from the underlying Richard deposit. (See pl. 6.) It also occurs in places along one or both walls of the deposit.

The Teabo ore body strikes N. 40°–45° E., dips on the average 55° SE., and plunges about 20° NE. It is tabular in shape. It has a breadth of 225 to 300 feet and a stope length of 500 feet or more (fig. 16). It ranges in thickness from less than 5 feet to more than 35 feet; the average, where mined, is about 12 feet. Thicknesses of approximately 35 feet were observed in the upper part of stope 3, about 30 feet below the top rock, and near the top of stope 7. Plate 6 shows a geologic map and sections of the Teabo on the 1,000-foot and 1,700-foot levels, and figure 15 shows a geologic map of the Teabo on the 2,100-foot level.

As can be seen in plate 6, the Teabo on the 1,000-foot level is a relatively simple tabular body. On the 1,700-foot level, though, the deposit is more complex. In stopes 6, 7, and 8 and in the main drift northeast of manway raise 7, the deposit consists of 2 tabular deposits, herein referred to as the hanging-wall and footwall ore bodies. The two bodies are separated by a lenticular body of amphibolite that has a maximum thickness of about 20 feet where mapped in the crosscuts from manway raise 6. Presumably the amphibolite pinches to a feather edge in all directions. In stopes 6, 7, and 8 the hanging-wall ore body is as much as 35 feet thick, whereas the footwall ore body is generally less than 8 feet thick.

The Teabo deposit is characterized by moderate pinching and swelling. The section through manway raises 6 and 6H–1 shows the typical structure of the deposit. Some of the pinches and swells are related to rolls or irregularities in the gneissic structure of the wall rocks, but many others reflect irregularities that cut across the gneissic structure in the wall rocks. These irregularities are marked by a fluting that tends to rake parallel to the linear elements in the wall rocks. Some of the flutings can be traced through more than one stope.

The Teabo ore body is separated from the Richard ore body in most places by a marked pinch that has a breadth of 350 to 400 feet. This pinch is conspicuous in manway raise 3 (pl. 6). In the main drift on the 1,700-foot level, though, there is no marked pinch between the Teabo and Richard deposits. Instead, between the top rock of the Richard, as shown in plate 6, and the bottom rock of the Teabo there is a deposit that has a stope length of about 725 feet and a width of 5 feet or more; this deposit is thought to be equivalent to the Allen deposit. Development work on the Allen shoot on this level has indicated the presence of some ore of minable width and grade (Allan James, written communication). Mining is complicated in this ground by numerous longitudinal faults (pl. 6).

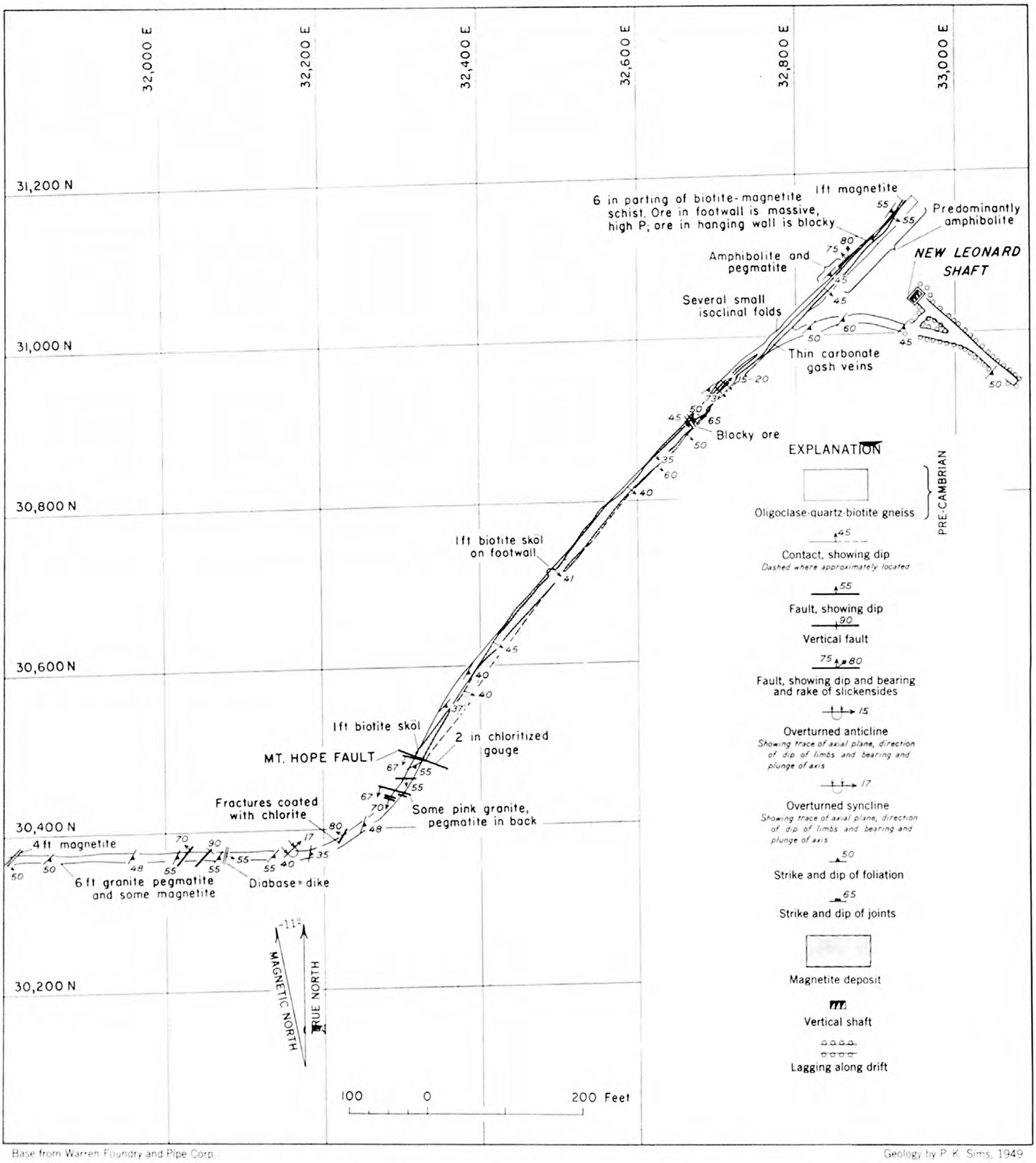


FIGURE 15.—Geologic map of the Teabo ore body on the 2,100-foot level, Mount Hope mine.

Several high-angle reverse faults have been encountered in the workings on the Teabo ore body, but for the most part they have not been traced individually from one stope to another. They are longitudinal breaks that strike at a small angle to the strike of the deposit.

Richard ore body

The Richard ore body, which has been mined throughout the Richard and the Baker mines, was encountered on the 1,700-foot level at Mount Hope mine and was being mined in stopes R–3, R–4, and R–5 (pl. 6 and fig. 16) in 1950. The deposit is described in detail

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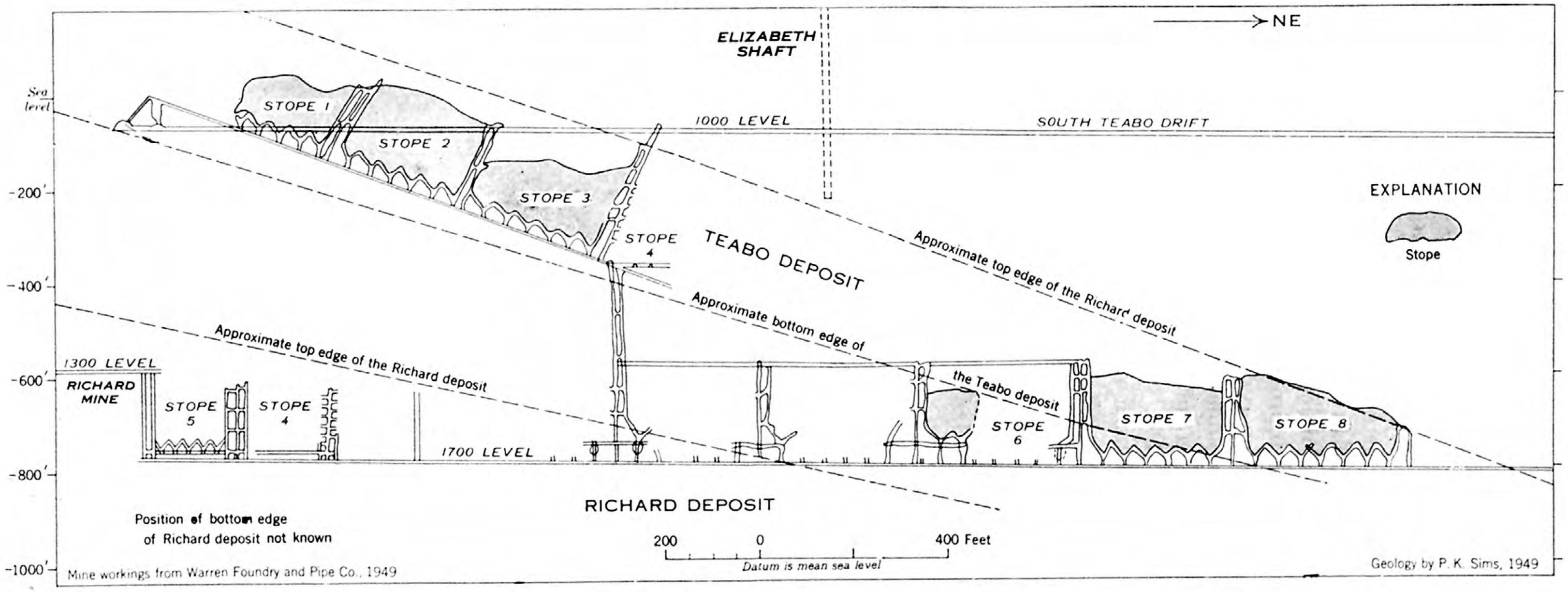


FIGURE 16.—Vertical longitudinal projection of the Teabo and Richard ore bodies, Mount Hope mine.

with the Richard mine and is only briefly discussed here.

In the Mount Hope mine, on the 1,700-foot level, the Richard ore body strikes N. 42° E. and dips an average of 45° SE. Where developed, it averages about 15 feet in thickness, but locally it is as much as 25 feet thick. As can be seen in plate 6, there is no marked break between the Richard and Teabo deposits on the 1,700-foot level, but the commercial toprock of the Richard is about 70 feet northeast of manway raise 4. In stopes R-3, R-4, and R-5, mining terminates at the longitudinal fault that was encountered at or near the top of manway raises R-3, R-4, and R-5. This fault is equivalent to fault "F" at the Richard mine (pl. 7). The Richard ore body is for the most part conformable with the gneissic structure in the wall rocks, but in places it cuts sharply across it. This can be seen in the 1,700-foot level at several places (pl. 6).

The ore in the Richard deposit is massive magnetite that in part is blocky and in part is "shot ore." The "shot ore" is moderately friable and more coarsely granular than the blocky ore. Locally the ore contains considerable biotite, which represents unreplaced remnants of biotite schist, and biotitic amphibolite. The wall rock is predominantly oligoclase-quartz-biotite gneiss and minor amphibolite and augen gneiss.

Elizabeth ore body

The Elizabeth ore body cropped out on Mount Teabo where it was mined from the Elizabeth adit (fig. 18) and a series of shafts, the deepest of which was the Painter shaft. Below the adit level the deposit was worked from the Elizabeth shaft (fig. 18; Bayley, 1910, p. 412) and from the South Elizabeth incline on the south side of the Mount Hope fault. On the north side of the fault the deposit was mined on the 1,000-foot and 1,700-foot levels and from the North Elizabeth incline, which extends from the 1,000-foot level to below the 1,700-foot level.

The structural relation of the Elizabeth to the other ore bodies at the Mount Hope mine can be seen by reference to plate 4. The Elizabeth is below the Leonard ore body and it is thought to lie essentially along and parallel to the axial plane of the Mount Hope syncline. On the south side of the Mount Hope fault the Elizabeth ore body is about 250 feet vertically below the Leonard ore body; on the north side of the fault the interval is only about 150 feet (figs. 17 and 19). The convergence as depth increases is caused by the differences in the rake of the two ore bodies. The plunge of the Elizabeth ore body is about 15° NE., whereas the plunge of the Leonard is about 17° NE.

The Elizabeth ore body strikes N. 45° E. and dips steeply southeast (pl. 5). It has a stpeo length of about 950 feet, a breadth of 225 to 275 feet, and an

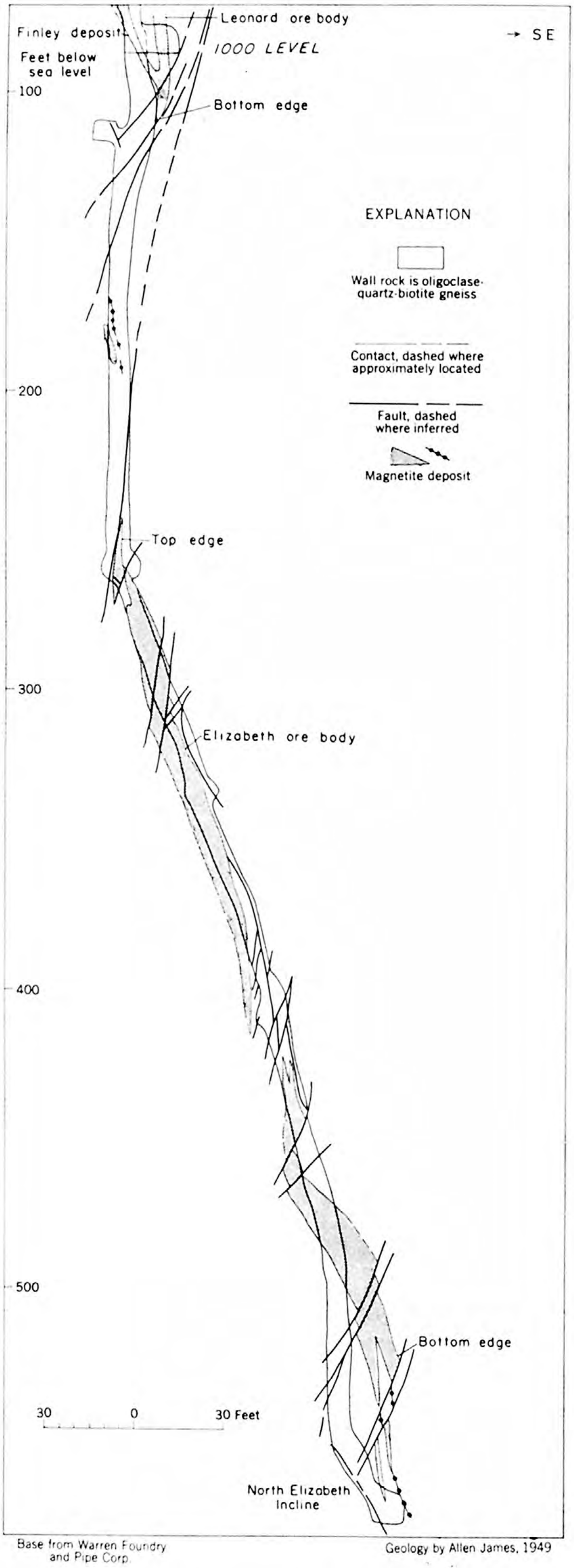


FIGURE 17.—Section through manway raise 75, Mount Hope mine.

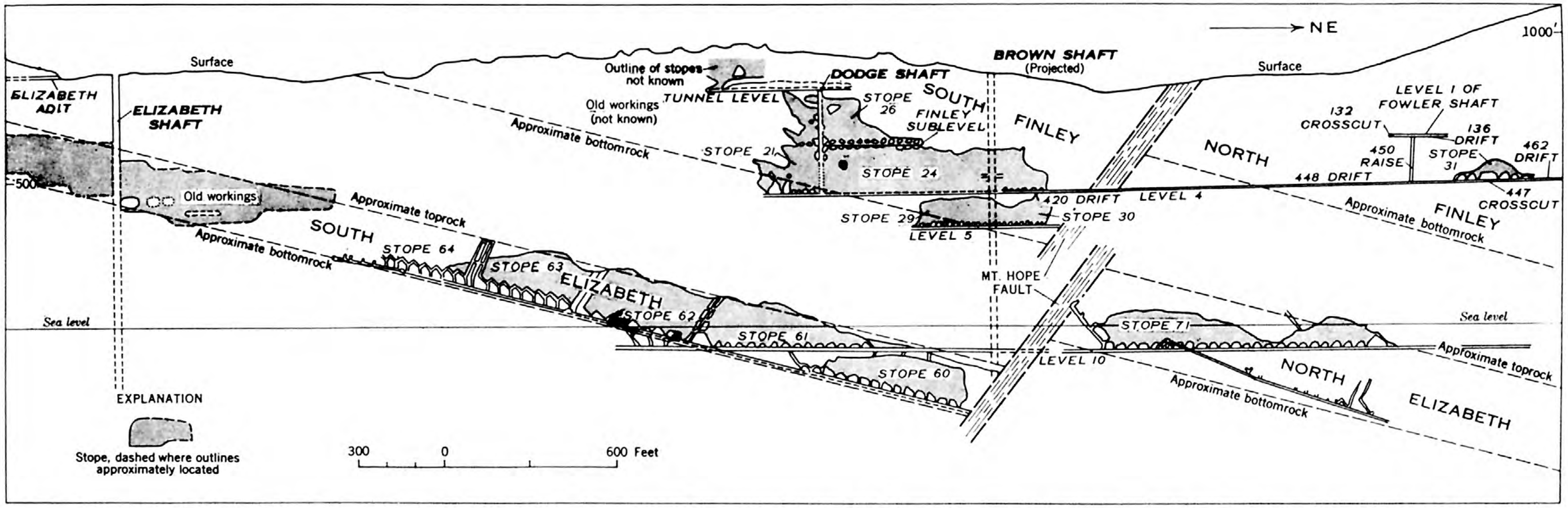


FIGURE 18.—Vertical longitudinal projection of Finley and Elizabeth deposits, Mount Hope mine. See fig. 19 for workings to northeast.

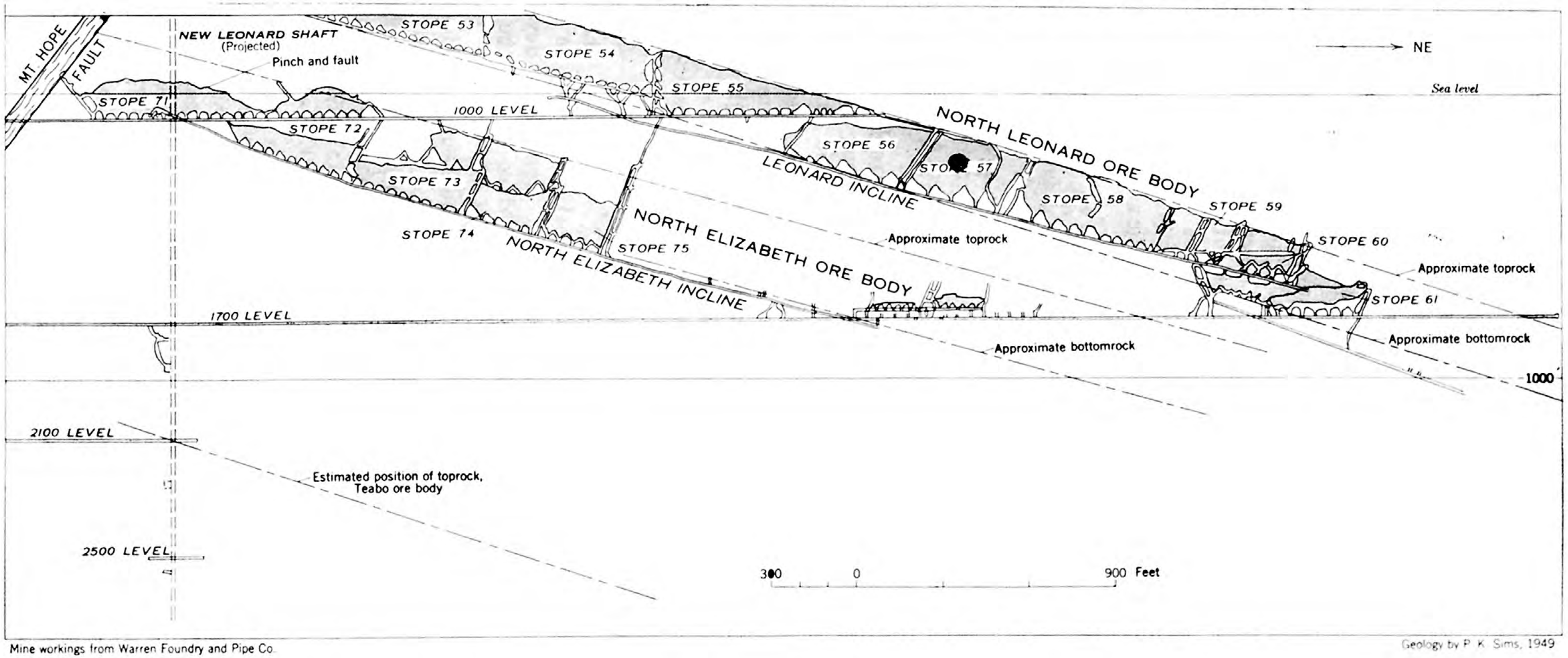


FIGURE 19.—Vertical longitudinal projection of North Elizabeth and North Leonard ore bodies, Mount Hope mine.

average thickness of about 7 feet. The maximum thickness is about 20 feet. In Elizabeth stope 79B the deposit is 18.5 feet wide and has a tenor of 37 percent Fe. It consists of 9.4 feet of massive ore that contains 50 percent Fe; 3.5 feet of 27 percent Fe on the footwall; and 5.5 feet of 21 percent Fe in the hanging wall. The deposit contains several pinches. The most prominent one is the marked pinch about equidistant between the bottom rock and toprock, which on the north side of the Mount Hope fault separates the deposit into two ore shoots (pl. 5). As can be seen in plate 5, several nearly parallel faults cut through the deposit at this pinch. On the 1,000-foot level, in the South Elizabeth ore body, small pinches occur locally, and these coincide with swells in the biotitic amphibolite that at places forms the wall rock.

In most places in the mine conspicuous faults occur along one or both walls of the deposit. The faults are steeply dipping and are nearly parallel to the dip of the deposit. They seldom occur along the ore contacts, but instead are in the hanging wall, or, less commonly, the footwall, a few feet from the ore and consequently cause considerable dilution during mining.

The massive magnetite for the most part replaces oligoclase-quartz-biotite gneiss. In places along the walls of the ore body it partly replaces biotitic amphibolite, recrystallized hornblende amphibolite, and biotite sköls, and forms low-grade disseminated ore that averages less than 30 percent Fe, as in Elizabeth stope 79B. The massive ore is generally blocky, and it contains laminae of apatite granules. The chemical analyses of a selected and an average sample from the Elizabeth deposit are given in table 12.

Leonard ore body

The Leonard ore body is in oligoclase-quartz-biotite gneiss. It cropped out on Mount Hope Hill and was mined continuously from the surface to its intersection with the Mount Hope fault (pl. 3). The principal workings were connected with the Leonard shaft, which now is caved and abandoned. On the north side of the fault the ore body was mined on the 400-foot level and from three different inclines that were driven along the bottom rock. (See pl. 2.) In 1950 it was being mined from the incline on the 1,700-foot level.

The Leonard ore body is on the southeast limb of the Mount Hope syncline and as shown in plate 3 and figure 20 is joined to the Finley deposit in the axial area of the syncline. The ore body strikes N. 45° E., dips steeply northwest to vertical, and plunges an average of 17° NE. It has a stope length of about 800 feet, a breadth of about 250 feet, and an average thickness of about 10 feet. The deposit ranges from about 4 to 25 feet in thickness; the greatest thickness is slightly above the middle of the deposit. The form of the deposit on the 1,000-foot level is shown in figure 20, and to judge from observations elsewhere in the mine and from maps of the old workings, now inaccessible, this form characterizes the deposit throughout the mine. The ore, where observed, is essentially parallel to the gneissic structure of the wall rocks.

A few steeply dipping longitudinal faults are encountered along one or both walls of the deposit, but these usually do not cause much difficulty in mining.

The ore in the Leonard deposit replaces oligoclase-quartz-biotite gneiss. The gneiss forms the walls of the deposit except locally where lenticular biotitic hornblende skarn or biotite sköls form the walls. The ore is mostly massive blocky magnetite that contains a few percent of apatite as scattered granules and rudely parallel laminae. In places somewhat coarser grained ore contains a few percent of relict granules of hornblende. The chemical analyses of a selected and an average sample of the Leonard ore are listed in table 12.

Finley deposit

The Finley deposit was mined at the surface on both Mount Hope and Hickory Hills prior to 1868. The most extensive operations were southwest of the Mount Hope fault where the deposit was opened along a distance of 2,400 feet (pl. 3 and fig. 18). On Hickory Hill openings on the vein extend for 1,000 feet. In addition to the near-surface workings, the deposit was mined from the 4th and 5th levels southwest of the Mount Hope fault between 1912 and 1916, (fig. 18), and in 1913 the Finley ore body supplied 74 percent of the ore taken from the Mount Hope mine. A small stope was opened on the 4th level on the north side of the Mount Hope fault in 1917, but the deposit proved to be too narrow for profitable exploitation and its development was suspended. No further mining of the Finley deposit has been done since that time.

The Finley deposit is on the northwest limb of the Mount Hope syncline; it joins with the Leonard ore body in the axial area of the syncline (pl. 3). The junction of the two deposits can be seen in the North Leonard drift on the 1,000-foot level, 350 feet southwest of crosscut 1019 (fig. 20) and was reported to have been encountered on the 4th level just northeast of the Mount Hope fault.

The deposit is a thin tabular body that trends about N. 30° E. and has an average dip of about 65° southeast. Rolls and mullion structures along the walls of some opencuts on the north side of the Mount Hope fault plunge 18° to 22° NE., and these probably indicate the rake of the deposit (pl. 3). The deposit ranges in thickness from less than a foot to about 10 feet; it probably averages 6 feet or less. Moderate pinches and swells are common and in a single opencut the vein

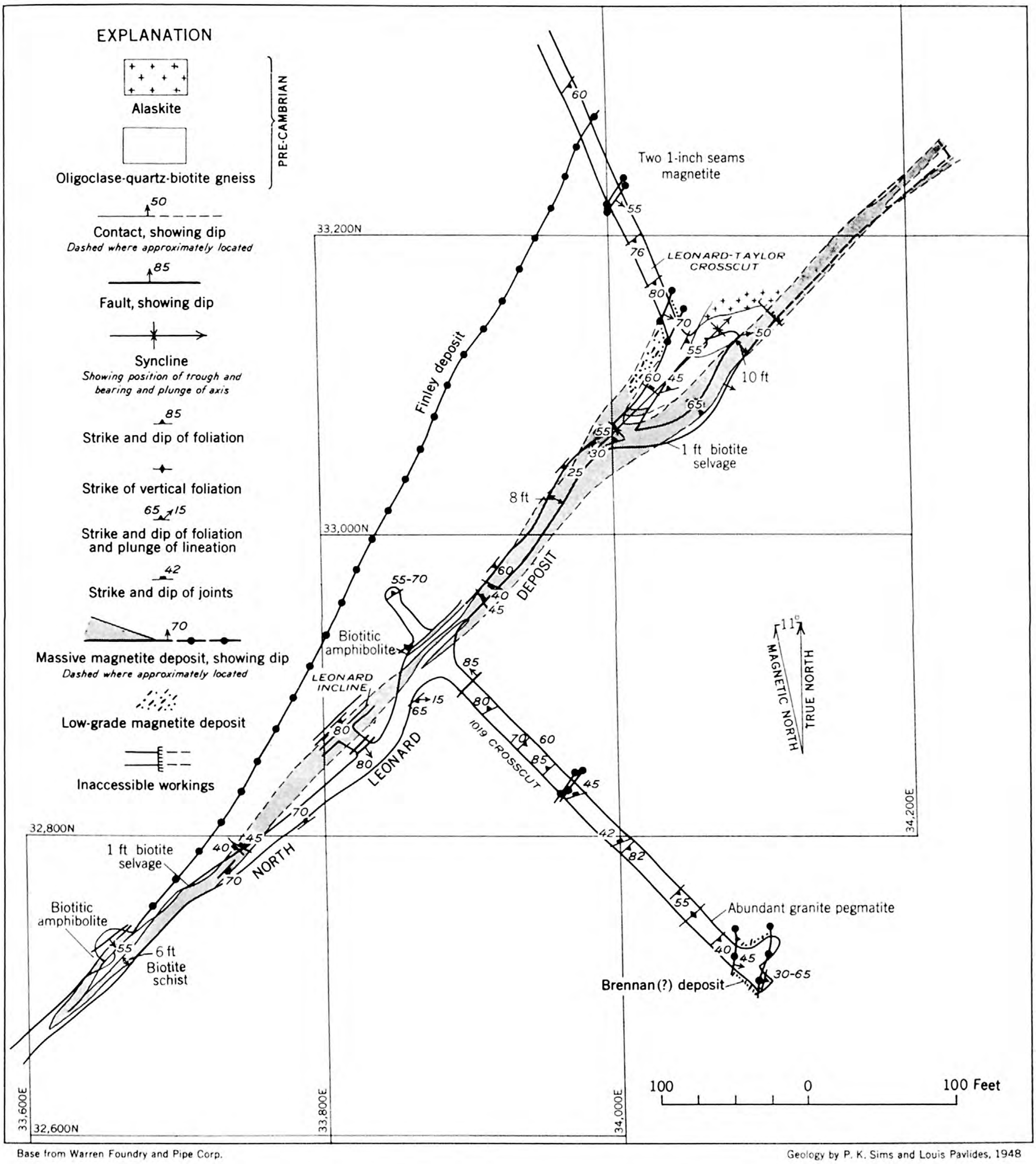


FIGURE 20.—Geologic map of the North Leonard and Finley deposits, 1,000-foot level, Mount Hope mine.

may be seen to range from 2 feet to 8 feet in width. Stope maps show that the deposit, where mined south of the Mount Hope fault, averaged about 8.5 feet in width.

The magnetite for the most part forms massive layers in oligoclase-quartz-biotite gneiss, or more rarely in microantiperthite granite. In part it forms thin streaks that alternate with country rock containing disseminated magnetite. The thicker parts of the deposit are characterized by blocky magnetite containing scattered granules of apatite. The analysis of an average ore specimen from an old Finley stope on the south side of the Mount Hope fault indicated an Fe content of 52.92 percent, a P content of 0.584 percent, and a TiO_2 content of 0.80 percent. The ore in the old stopes contained 35 to 37 percent Fe. In places, in the face of the most northeasterly opencut on the north side of the Mount Hope fault, a little pyrite cuts the magnetite. In thin sections it can be seen that the host rock is in part cataclastically deformed (pl. 16*A*). The feldspar is granulated and shows mortar structure; the quartz is typically sutured and recrystallized.

The Finley deposit is generally too thin for profitable exploitation under present economic conditions. Some shoots, probably of relatively small dimensions, may constitute ore in the future.

Brennan deposit

The Brennan (or Brannin) deposit was opened prior to 1868 on Mount Hope Hill (pl. 3) where it was exploited along a distance of about 700 feet by 4 or 5 shafts sunk to depths of 35 to 40 feet (Bayley, 1910, p. 410). Later the deposit was intersected in the Side Hill adit, 150 feet from the portal (fig. 13). The deposit proved to be exceedingly variable in width. In some places it measured 17 feet across; in others, as in the adit, it was less than 4 feet thick (Bayley, 1910, p. 410). On the north side of the Mount Hope fault the Brennan deposit was explored on the 4th level (drift 456) (pl. 2) and on the 10th level in crosscut 1019 (fig. 20). Observations in this crosscut indicate that the deposit is an irregular mineralized zone about 25 feet wide that consists of stringers and disseminations of magnetite that replace oligoclase-quartz-biotite gneiss. Biotitic amphibolite and granite pegmatite form the wall rocks.

The deposit was too low in grade and too variable in thickness to be of commercial importance in 1950.

Hawkins deposit

The Hawkins deposit was first encountered in the Side Hill adit, 200 feet northwest of the Finley deposit (fig. 13). Later it was mined to shallow depth along a distance of 450 feet on Hickory Hill (pl. 3). The deposit is a remarkably persistent mineralized zone that is encountered in nearly all crosscuts and drill holes that penetrate the rocks on the northwest limb of the Mount Hope syncline. It is a thin magnetite deposit seldom exceeding 5 feet in thickness, that replaces oligoclase-quartz-biotite gneiss near its contact with alaskite. The magnetite forms streaks and disseminations and more rarely distinct layers as much as 5 feet thick. It is too thin and too low in grade to be of commercial importance.

The Hawkins deposit occupies the same zone relative to the Elizabeth and Teabo-Richard deposits as the Middle "vein" at the Richard mine, and probably is equivalent to it.

Spencer deposit

The Spencer deposit is on Hickory Hill, half a mile northeast of the New Leonard shaft (pl. 3). It is northeast of, and essentially in the same plane as, the Leonard deposit. The deposit has been prospected for a distance of 1,000 feet. The workings consist of several shallow pits and a short inclined shaft that connects with some underground workings, the extent of which are not known. All the workings have caved and are now inaccessible. The deposit has not been developed in the main mine workings at the Mount Hope mine. Production from the deposit has been negligible.

The Warren Foundry and Pipe Corp. cored three diamond-drill holes in 1937 to test the Spencer deposit beneath the abandoned mine workings, and the locations of these holes are shown in plate 3. A cross section through holes R21 and R22 is given in figure 21.

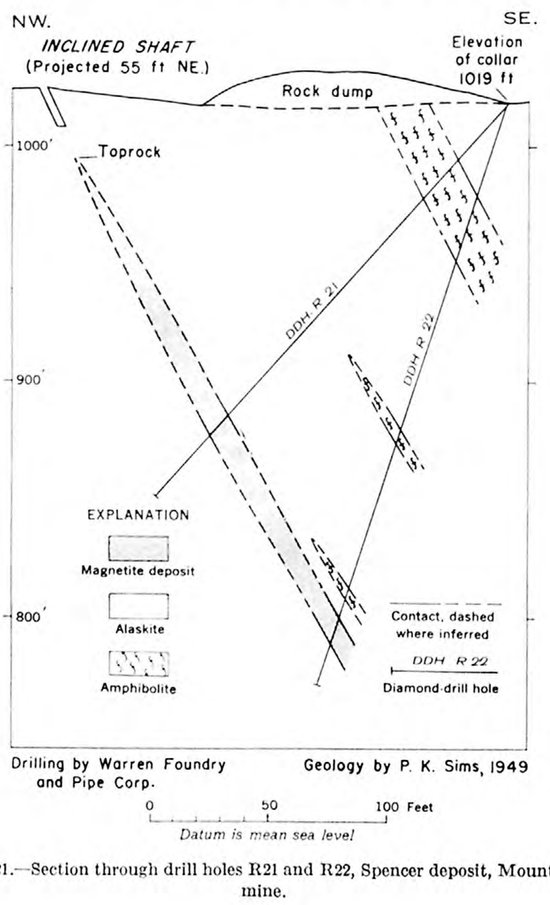


FIGURE 21.—Section through drill holes R21 and R22, Spencer deposit, Mount Hope mine.

The deposit trends N. 45° E. near the Spencer shaft, but swings to about N. 15° E. to the south (pl. 3). The dip is uniformly 60° SE. The host rock is principally oligoclase-quartz gneiss—a facies of oligoclase-quartz-biotite gneiss—although locally it is microantiperthite granite. The deposit is as much as 20 feet wide, but generally is much thinner. The magnetite forms thin massive layers from a fraction of an inch to 2 feet wide that are parallel to the foliation of the host rock. The intervening gneiss may contain small but variable amounts of disseminated magnetite; in places it is nearly barren. The ore walls are not sharply defined, but are gradational. The hanging-wall rock is for the most part pyroxene amphibolite; the footwall is microantiperthite granite.

In thin sections it can be seen that the magnetite preferentially replaces plagioclase along grain boundaries. At an advanced stage of replacement it may completely replace the plagioclase or may form rims around it. Apatite is an abundant accessory mineral in some seams of massive magnetite, and it constitutes as much as 10 percent of the ore. Analyses indicate that the phosphorus content averages about 1 percent.

OTHER DEPOSITS

Gold Diggings deposit

The Gold Diggings deposit is on Hickory Hill, half a mile north-northeast of the Brown shaft and 1,100 feet northwest of the Taylor ore body (pl. 3). It occupies the same position relative to the main Mount Hope deposits as does the Mount Hope Back vein of Bayley (1910, p. 408), which is about one-fourth of a mile northwest of the Taylor deposit on Mount Hope Hill (pl. 1), and presumably is the equivalent of the Mount Hope Back vein on the north side of the Mount Hope fault. The deposit has been prospected along a distance of 600 feet. The workings consist of a cribbed shaft reported to be 50 feet deep, but which is now caved to a depth of 15 feet, and a series of small prospect pits. It is evident from the small dumps that the deposit was only opened to shallow depths. In 1919, the Empire Steel and Iron Co. cored four diamond-drill holes to test the deposit, and the locations of these holes are shown in plate 3. Drilling indicated that the deposit is thin, generally 3 feet or less in thickness, and low in grade. Reconnaissance dip-needle data indicate the presence of a weak positive anomaly over the central part of the prospected belt. The length of the anomaly (+20 contour) is 250 feet; the maximum intensity is +57.

The deposit occurs within a folded belt of oligoclase-quartz-biotite gneiss. At the surface it trends N. 40° E. and dips 40° to 80° SE. Small rolls and mullion structures on the walls of the main opencut plunge 25° NE. parallel to the fold axes.

The magnetite replaces black medium- to coarse-grained gneissic amphibolite. The hornblende in the amphibolite is replaced by apatite, biotite, and magnetite, and in many places apatite forms 30 percent or more of the rock. Quartz, a minor accessory, forms interstitial grains between the hornblende crystals. Analyses of the ore contained as much as 55 percent Fe and 2.0 percent P. In thin sections it can be seen that the amphibolite is cataclastically deformed. Apatite, magnetite, and biotite were introduced into the rock along the granulated and crushed zones. The apatite in part shows undulatory extinction, suggesting that it too may be deformed. Magnetite is confined to the granulated zones, where it forms irregular veinlets.

To judge from the material on the dumps, the deposit is too thin to be minable. In addition, the high-apatite content of the deposit is prohibitive to its exploitation as an iron ore.

Prospects

A prospect consisting of several small shallow pits is 850 feet southeast of the Gold Diggings shaft (pl. 3). Reconnaissance dip-needle data indicate that the workings are overlain by a small positive magnetic anomaly whose length within the +20 contour is about 110 feet. The maximum intensity is +65. To judge from the rock dumps, the host rock is medium-grained albite-oligoclase granite. Pegmatite evidently is intimately associated with the granite. The magnetite forms disseminated grains and less commonly thin massive layers in the granite, and small nests and irregular veinlets in the pegmatite. The magnetite is partly slickensided, and along these surfaces it is mylonitized. The deposit is a local concentration of magnetite that is too small for commercial exploitation. It is thought to be equivalent to the Hilltop deposit at the Richard mine.

On Mount Hope Hill (pl. 3) a narrow positive magnetic anomaly lies about 400 feet northwest of the opencuts on the Taylor ore body. This anomaly is apparently in the same zone as the small deposit described above from Hickory Hill, and to judge from the rock dumps, the host rock and character of the ore are similar.

TEABO MINE

The Teabo mine, which is northeast of the Allen mine, has been abandoned since 1907 (Bayley, 1910, p. 406). The Teabo mine worked the Teabo ore body through several shafts, the deepest of which is the Teabo No. 5 shaft. (See pl. 1 and fig. 22.) The positions of shafts 3 and 5 and the approximate extent of the mine workings are shown in figure 22. The mine workings at Teabo mine are described by Bayley (1910,

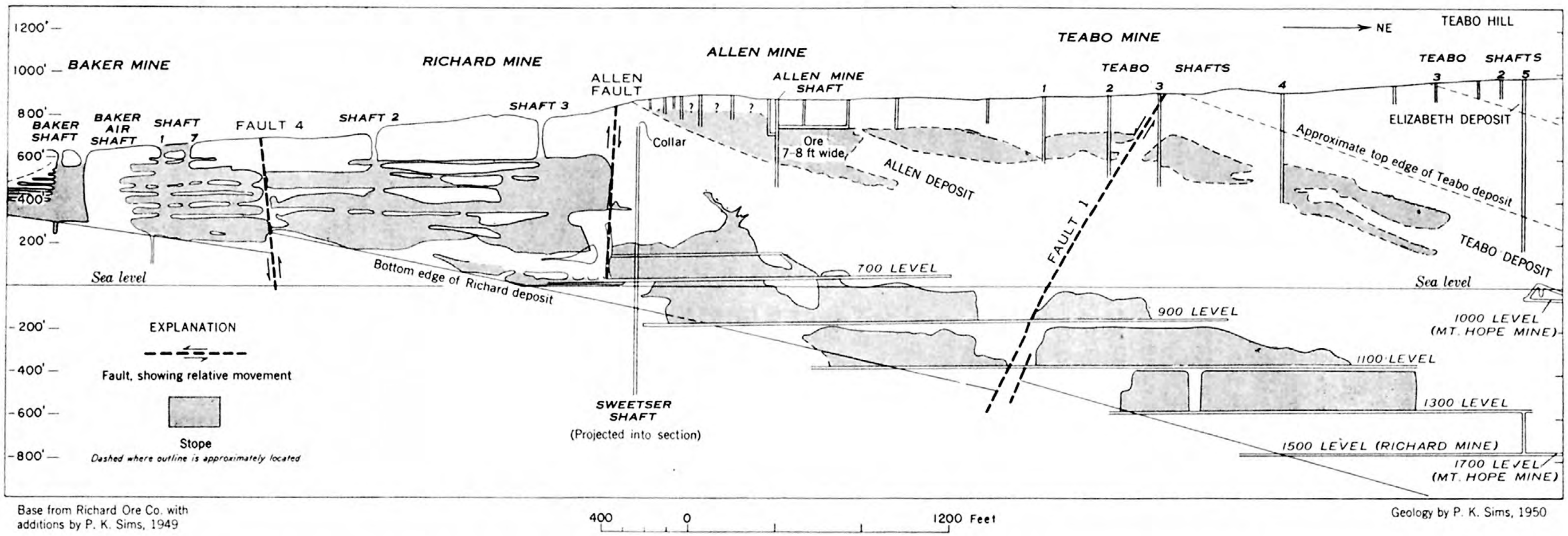


FIGURE 22.—Vertical longitudinal projection of the Richard, Allen, and Teabo magnetite deposits, Baker, Richard, Allen, and Teabo mines.

p. 406–407); the geology and structure of the Teabo ore body are discussed under the Mount Hope mine.

ALLEN MINE (17)

The Allen mine, in Rockaway Township, immediately northeast of the Richard mine, has been abandoned since 1884. It is now owned by the Richard Ore Co. The mine was worked before 1855 and continuously from this date until 1882, when mining was stopped. In 1883 and 1884 some exploration work was done, but nothing new was found and the mine was abandoned. The extensive mine workings consist of several shallow shafts (fig. 22) and an adit 630 feet long that was driven S. 44° E. 600 feet to the Allen deposit. (See fig. 23.) All the mine workings are now inaccessible, and the following description of the deposit is based upon data given by Bayley (1910, p. 403–405), old maps of the mine, and observations of the mine dumps by the writer.

At the surface the Allen deposit is separated from the Richard deposit by the Allen fault (fig. 24). It is known from the underground workings, though, that the Allen deposit is an ore shoot situated between the Richard and Teabo ore bodies. As yet this shoot has not been mined from the main workings at the Richard mine, but it has been developed at the Mount Hope mine, on the 1,700-foot level (fig. 16), and possibly it can be mined profitably at places. It is probable, though, that the Allen deposit is generally too thin and too irregular to be mined under existing economic conditions.

At the surface, the Allen deposit trends about N. 45° E. It is reported to dip 65° SE. where it was intersected by the Allen adit (Bayley, 1910, p. 403). The mine map (fig. 22) suggests that the deposit consists of 2 shoots which rake about 14° NE., but the shoot structure is less evident where the deposit has been intersected in the Mount Hope mine. The deposit definitely is irregular and Bayley (1910, p. 404–405) indicates that in the Allen mine it ranges from less than 2 feet to 23 feet in thickness.

The ore in the Allen deposit replaces oligoclase-quartz-biotite gneiss. According to Bayley (1910, p. 404) the hanging wall of the deposit in the northeast workings consists of "a curious conglomerate rock composed of nodules of greenish-white feldspar imbedded in a schistose matrix of magnetite, hornblende, and biotite." This rock is similar to the augen gneiss observed by the writer at places along the walls of both the Richard and Teabo deposits.

The ore cannot be distinguished megascopically from that in the Teabo and Richard deposits. Magnetite breccia, consisting of angular masses of magnetite cemented by white siderite, which is similar to the magnetite breccia locally observed by the present writer in the Richard deposit, has been described (Bayley, 1910, p. 404) from the deposit. A sample of the ore (Pumpelly, 1886, p. 171), which probably is representative, indicates an Fe content of 56.99 percent and a P content of 0.593 percent.

RICHARD MINE (18)

The Richard mine, owned by Colorado Fuel and Iron Corp., is 2 miles north of Dover, in Rockaway Township. The mine is immediately southwest of the Mount Hope mine and northeast of the Baker mine. The mine has been operated nearly continuously since 1856 and has yielded (through 1950) 5,560,657 long tons of iron ore (table 15). The production, the second largest in the State, has come from two ore bodies, the Mount Pleasant (or North) "vein" and the Richard (or South) "vein"; the Richard "vein" has supplied about three-fourths of the tonnage.

TABLE 15.—*Iron-ore production in long tons, from Richard mine, to December 31, 1950*

[Shipping ore: Includes both lump and concentrate. Data published with permission of The Colorado Fuel and Iron Corp.]

Year	*Crude ore hoisted*	*Shipping ore*	*Year*	*Crude ore hoisted*	*Shipping ore*	*Year*	*Crude ore hoisted*	*Shipping ore*
1856–1904	----------	[1] 2, 212, 838	1920	(4)	----------	1937	116, 818	79, 789
1904 [2]	----------	88, 398	21	----------	266	38	53, 769	35, 002
5	----------	98, 589	22	----------	9, 667	39	4, 737	3, 184
6	----------	100, 632	23	----------	61, 462	40 [5]	121, 501	87, 822
7	----------	75, 892	24	----------	64, 928	41	----------	122, 311
8	----------	84, 683	25	----------	68, 444	42	264, 240	188, 744
9	----------	92, 604	26	----------	68, 217	43	207, 056	151, 020
1910	----------	112, 810	27	----------	86, 995	44	134, 312	106, 060
11	----------	104, 560	28	111, 495	81, 655	45	160, 203	124, 237
12	----------	77, 198	29	92, 545	63, 993	46	168, 667	127, 940
13	----------	46, 939	1930	107, 298	73, 836	47	210, 298	149, 363
14 [3]	----------	25, 000	31	----------	39, 313	48	215, 831	153, 201
15	----------	65, 642	32	(4)	----------	49	----------	135, 166
16	----------	55, 362	33	(4)	----------	1950	----------	164, 334
17	----------	53, 150	34	(4)	----------			
18	----------	5, 245	35	(4)	----------			
19	(4)	----------	36	5, 508	14, 166	Total	----------	5, 560, 657

[1] Production to February 28, 1904 (Bayley, 1910, p. 402).
[2] Production 1904–39 from M. E. Johnson, State Geologist, New Jersey.
[3] Shut down about July 1, 1914. Production estimated by Sims.
[4] Inactive.
[5] Production 1940–50 from Richard Ore Co.

HISTORY OF OWNERSHIP AND DEVELOPMENT

The Richard mine property was originally included in the Mount Hope tract, located and purchased by Samuel Gardner in 1749 (Roche, 1923). In 1792 the property was sold to Jacob Faesch. In 1803, the year that ore was first found on the Richard property, Jacob Faesch gave 28 acres of land in the tract to his son, Richard. This property then became known as the Richard mine, and it was operated by Richard Faesch until 1809, when it was sold. From 1809 to 1856 the mine was operated by various owners. In 1856 the property was purchased by the Thomas Iron Co., who operated it until 1923, when it was sold to the Philadelphia and Reading Coal and Iron Co. When the Thomas Iron Co. acquired the property all the mining was being done on the northwest (Mount Pleasant) "vein." Mining from this deposit continued for several years, but the deposit was temporarily abandoned and the southeast (Richard) "vein" was opened. In 1893 a crosscut was driven near the No. 1 shaft that connected the two ore bodies, and since that date both deposits have been mined.

Previous to 1901 there were three inclined shafts or slopes on the Richard ore body, sunk on the footwall—No. 1 (length 533 feet), No. 2 (length 630 feet), and No. 3 (length 738 feet)—and two on the Mount Pleasant ore body, sunk on the footwall—No. 4 (length 932 feet) and No. 6 (length 600 feet) (Bayley, 1910, p. 402). The locations of the shaft collars are shown on figure 23. In 1901, shaft 5 was completed. It was a three-compartment shaft inclined 52° southeast that was sunk between the Mount Pleasant and Richard deposits. Two crosscuts were driven to intersect the ore bodies at a depth of 570 feet. The inclined shaft has a length of 868 feet, equivalent to a vertical depth of 685 feet. This was the principal hoisting shaft until the Sweetser shaft was completed. The Sweetser shaft, a four-compartment vertical shaft situated at the base of the hill, about 500 feet southeast of the "outcrop" of the Richard "vein", was begun in 1917 and by 1920 had been sunk to a depth of about 1,034 feet, about 100 feet below the 900-foot level. In 1930 the shaft was completed to a depth of 1,244 feet, 100 feet below the 1,100-foot level (fig. 28).

In 1941, E. and G. Brooke Iron Co. purchased the mine from the Philadelphia and Reading Coal and Iron Co., and since that time the mine has been a consistent large source of iron ore. The Colorado Fuel and Iron Corp. obtained the property in January 1952.

Prior to World War II, probably in 1938, a dip-needle survey of the Richard mine property was made by the Jones and Laughlin Steel Corp. In 1942 a magnetic survey with a Hotchkiss Superdip was made by Sherwin F. Kelly, Geophysical Services, Inc., for Richard Ore Co. (fig. 23). The magnetic survey indicated a new strong magnetic anomaly near the crest of the hill, about 1,050 feet northwest of the Sweetser shaft, and in 1942 this deposit, named the Hilltop deposit, was core drilled by Richard Ore Co. According to the company the drilling indicated that the deposit is low in grade.

MINE WORKINGS

The principal workings at Richard mine are shown on figures 24 and 25. Figure 24 shows the workings on the Richard (or South) ore body northeast of shaft 2. The workings on this deposit in the southwest part of the mine are given by Bayley (1910, pl. 9). Figure 25 shows the workings on the Mount Pleasant (or North) ore body northeast of shaft 5. The location and extent of the old workings southwest of shaft 5 are only partly known, but a generalized plan map and longitudinal projection of these workings are shown on plate 9.

The accessible mine workings on both the Mount Pleasant and the Richard deposits are connected to the Sweetser shaft. The abandoned workings on the upper levels were reached through the several inclined shafts.

The Sweetser shaft, the only hoisting shaft, connects with the 700-, 900-, and 1,100-foot levels. It intersects the Richard ore body at the 800-foot intermediate level and the Mount Pleasant deposit a short distance above the 1,100-foot level. (See fig. 26.) The workings on both ore bodies are connected at each level by one or more crosscuts about 300 feet in length, as shown on figures 24 and 25. A 25-degree incline that trends about N. 65° E. extends from the 1,100-foot level to the 1,300- and 1,500-foot levels. In 1949 a raise was driven from the 1,700-foot level of Mount Hope mine to connect with the drift S 1300 E of the Richard mine, and in 1951 the drift S 1500 E at Richard mine was driven across the property line to connect with the 1,700-foot level of Mount Hope mine.

In 1949 the principal mining was being done on the 1,100- and 1,300-foot levels; the 1,300-foot drift on the Mount Pleasant deposit was being driven to the southwest to develop the Baker (or New) shoot; and the 1,500-foot level was being developed. The development on the Richard and Mount Pleasant deposits to May 1951 is shown, respectively, on figures 24 and 25.

In 1949 the operators obtained a lease on the Baker mine property so that they could mine the lower part of the Mount Pleasant deposit.

MINING METHODS

Shrinkage stoping, without timbering or filling is used at Richard mine. During development, drifts are driven along the footwall of each ore body. The drifts on the Mount Pleasant ore body follow along the ore stringer or "leaders" between the ore shoots. All stope chutes and raise chutes are driven on 25-foot centers.

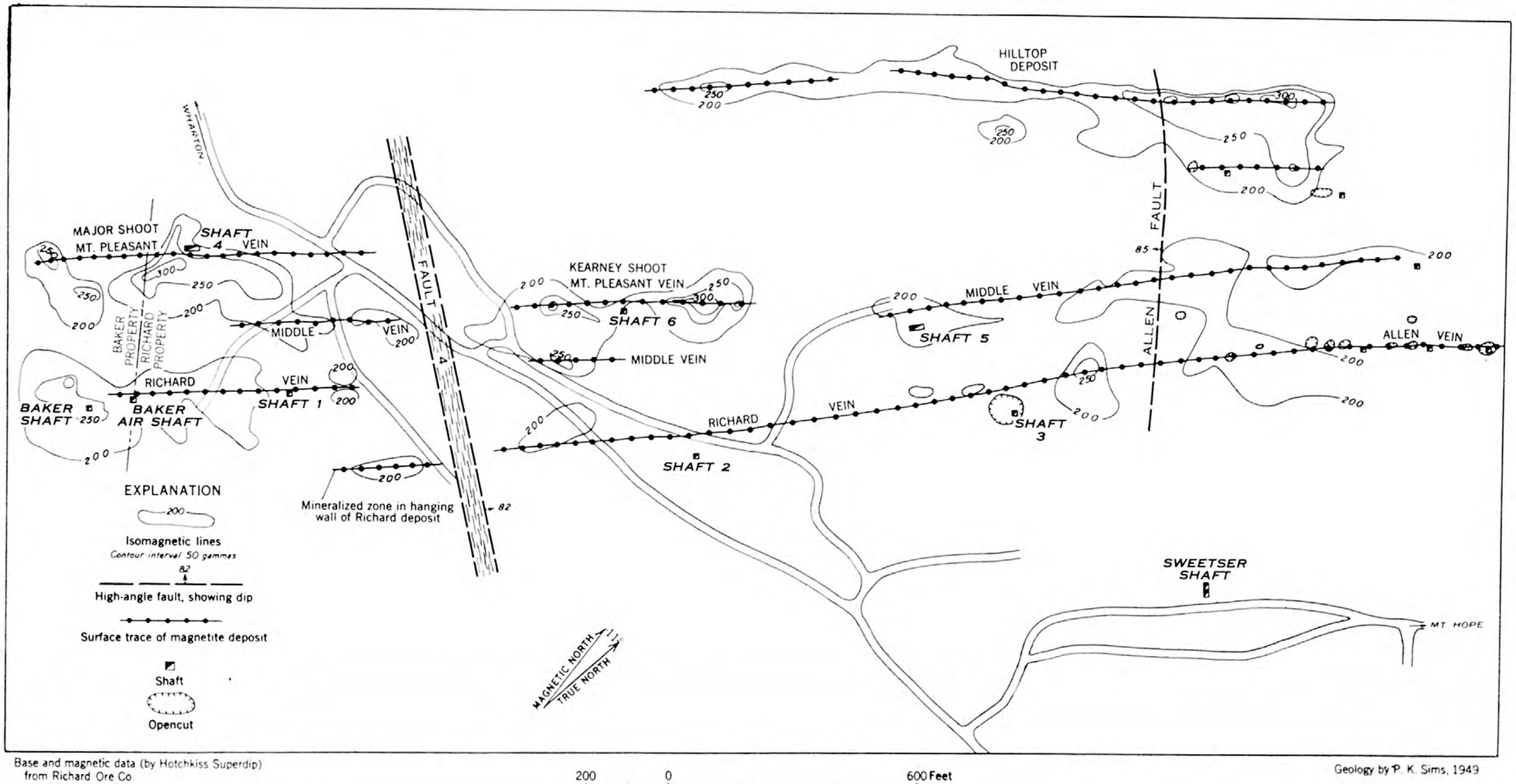


FIGURE 23.—Magnetic map of Baker and Richard mines.

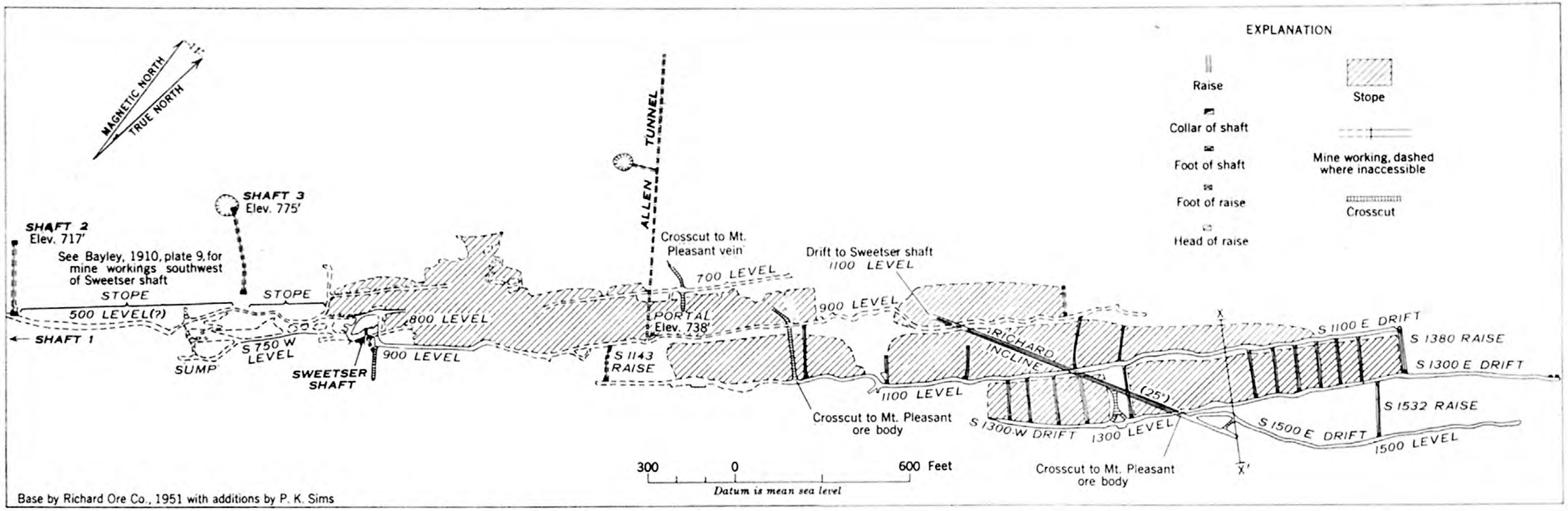


FIGURE 24.—Map of workings on Richard (South) ore body, northeast of shaft 2, Richard mine. Section X-X' shown on figure 28.

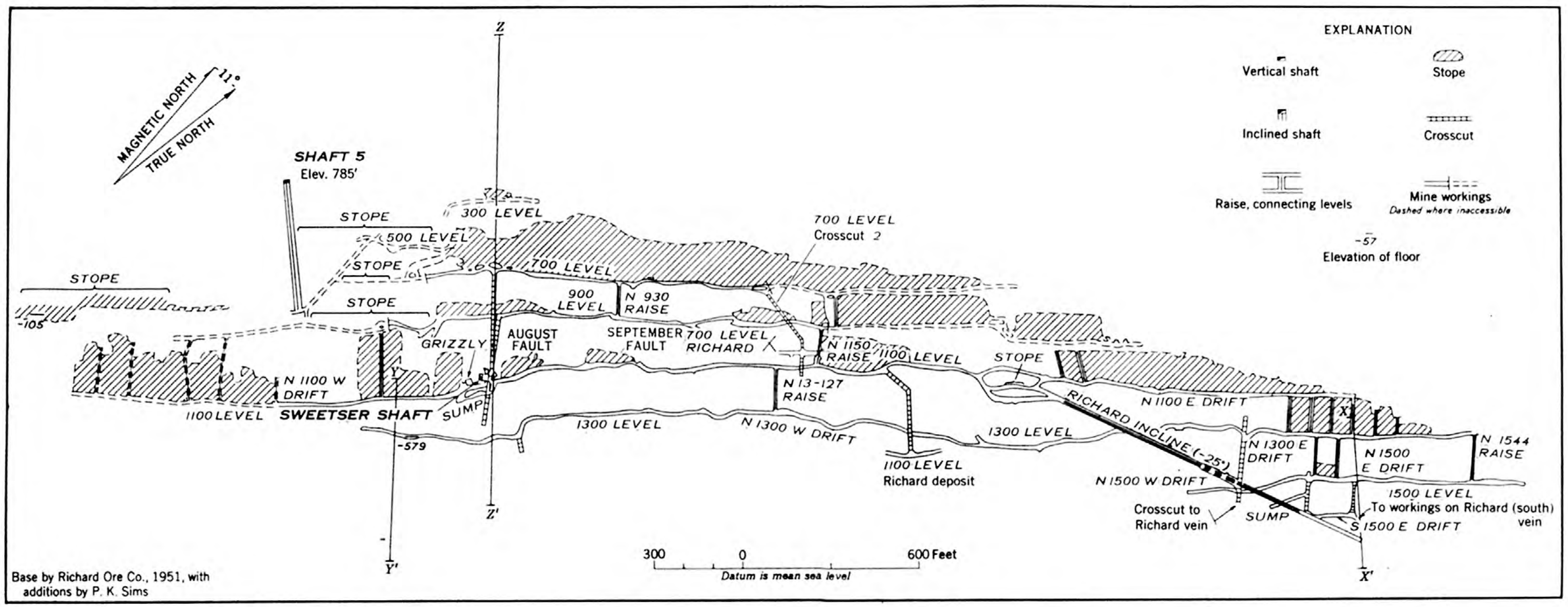


FIGURE 25.—Map of workings on Mount Pleasant (North) ore body, northeast of shaft 5, Richard mine. Section X-X' shown on figure 28; section Y-Y' shown on figure 27.

The raise interval in both the Richard and Mount Pleasant deposits is 75 feet within the ore body. The raise pillars are removed after all stoping operations are completed. The raises are driven from level to level along the footwall of the ore bodies.

After all mining operations in a drift have been completed and the ore removed from the stopes, the chute pillars and the roof of the drift are removed. During this operation the drilling is done from the drift. The broken material is then loaded into mine cars with mucking machines. During the regular mining stoping operation, however, all broken ore is loaded into the cars by gravity feed, except in those stopes near the bottom rock of the Richard deposit where the ore body dips less than 45°. Here it is necessary to use scrapers to move the ore to the ore pockets.

ORE BENEFICIATION

The ore at the Richard mine is treated by a magnetic concentrator that produces both lump ore and fine concentrate. The lump ore contains on the average 61 percent Fe and 0.8 percent P. The fine concentrate averages 66 percent Fe and 0.25 percent P. In 1949 the concentration ratio of the hoisted ore was 1.4 to 1. The ore from both the Richard and Mount Pleasant ore bodies are beneficiated together, and records are not kept of the grade of each.

GEOLOGY

The geology of the Richard mine is similar to that at Mount Hope mine, described previously. There are no natural exposures of the bedrock on the Richard property, for the surface is covered by a thin mantle of unconsolidated material principally of glacial origin, but the magnetite deposits are known at the surface from opencuts and shafts and from systematic magnetic surveys (fig. 23).

ROCKS

Oligoclase-quartz-biotite gneiss constitutes the bulk of the rocks (pls. 7, 8; figs. 26–29). It forms a layer more than 1,500 feet thick that encloses both the Richard and Middle deposits (fig. 26). The gneiss is a greenish-gray medium-grained rock that generally has a pronounced layering. It consists chiefly of oligoclase and quartz, with variable amounts of biotite. In places microantiperthite is the predominant feldspar in the gneiss. The biotite tends to be concentrated into thin laminae, but it is in general uniformly distributed throughout some layers. Magnetite is a common accessory mineral in the gneiss, and is the most abundant mafic mineral in some parts of the gneiss. In some places a few thin amphibolite layers and lenses are intercalated with the gneiss.

A few layers of augen gneiss from 1 to 4 feet thick form "horses" within the Richard ore body. (See pl. 7.) The augen are composed of microantiperthite, and they occur in a fine-grained granular aggregate of oligoclase, quartz, magnetite, and biotite. The augen gneiss grades into biotite schist by loss of its augen structure. A biotite selvage (sköl) occurs in places on either wall of the Richard ore body.

Throughout most of the mine workings a zone of amphibolite and pyroxene gneiss occurs between the oligoclase-quartz-biotite gneiss and the Mount Pleasant ore body. The combined thickness of the amphibolite and pyroxene gneiss generally is about 50 feet on the upper levels but is somewhat greater on the 1,500-foot level.

Alaskite forms the footwall, and in most places also the hanging wall, of the Mount Pleasant deposit. The alaskite is a pink to red, locally gray, medium-grained granite that consists essentially of microperthite and quartz. Near the contacts with pyroxene gneiss the granite is contaminated, and it contains oligoclase as the dominant feldspar and also variable amounts of hornblende, pyroxene, and sphene that have been derived from the adjacent pyroxene gneiss. Granite pegmatite of alaskitic composition locally is abundant near the Mount Pleasant deposit. It occurs as distinct, irregular bodies several feet in width or as dikes that have been injected into ore-bearing skarn.

Hornblende skarn is the host rock for the magnetite in the Mount Pleasant ore body. The skarn is a black coarse-grained rock that consists predominantly of hornblende, with subordinate pyroxene and biotite. In many places the skarn is injected and shredded by granite pegmatite. Modified skarn is abundant in the Baker shoot of the Mount Pleasant deposit.

STRUCTURE

FOLDS

The rocks in the Richard mine have a prevailing trend of N. 40°–45° E. and an average dip between 45° and 60° SE. The uniform southeast dip could be interpreted as a homocline, but from data obtained in the Mount Hope mine the writer believes that the deposits in Richard mine are situated on the northwest limb of the Mount Hope syncline. The principal evidence in Richard mine for a syncline is the marked flattening of dip in the rocks in the ground below the bottom rock of the Richard deposit on the 900-foot level. (See fig. 29.) According to this interpretation this ground is in the axial region of the syncline. An alternative interpretation is that the flattening represents a local roll.

In general, the dip of the ore bodies and the country rocks is steeper in the upper part of each ore deposit and gentler near the bottom. This is shown in figure 26. The Richard ore body dips 50 to 55° SE. but near

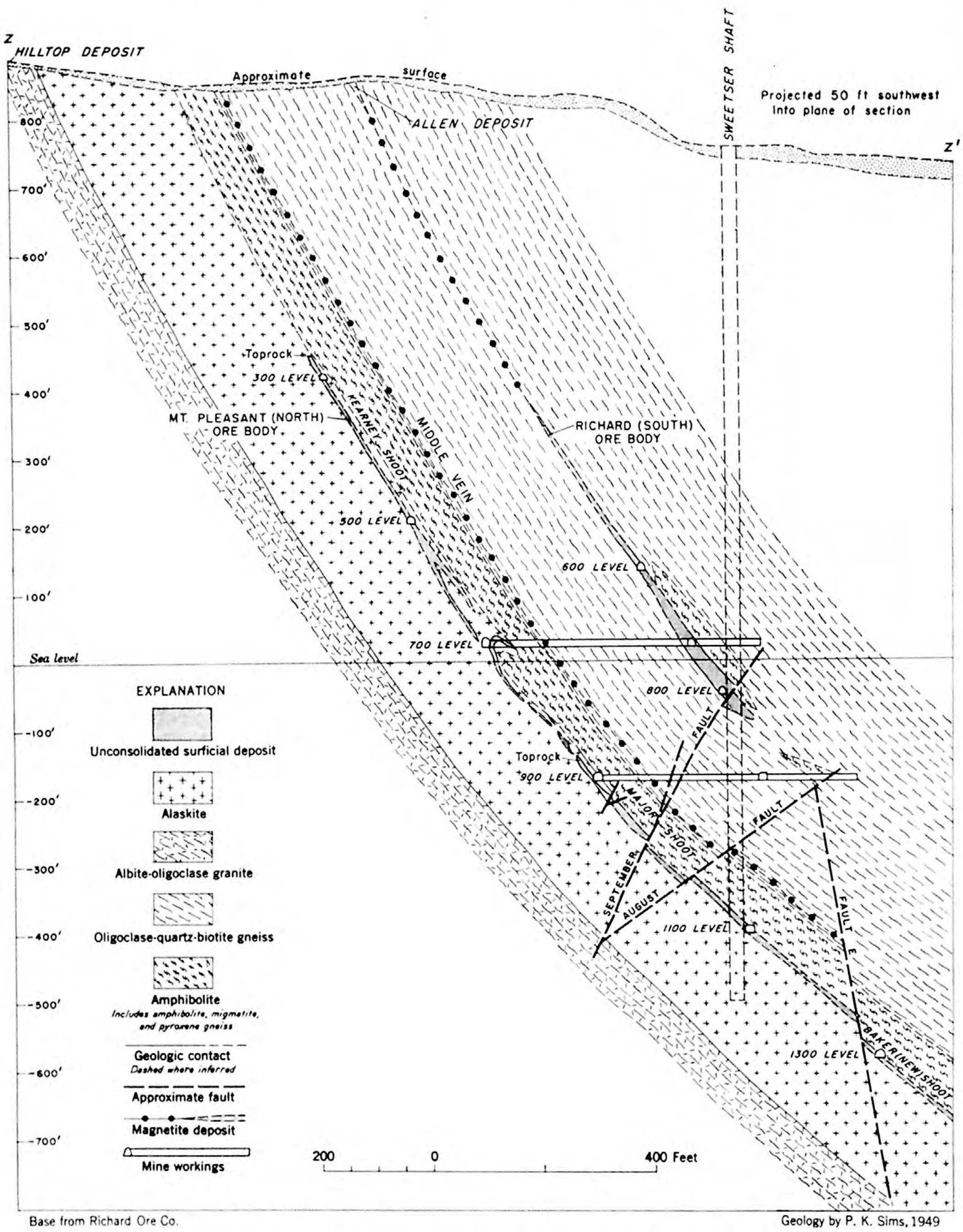


FIGURE 26.—Section through ore bodies at Richard mine, showing relation of ore to wall rocks and faults. Line of section along Z–Z′ shown on figure 25.

its bottom rock it flattens to about 20° locally. (See pl. 7.) Similarly, the Kearney and Major shoots of the Mount Pleasant deposit dip 50° or greater southeast, but the Baker shoot generally has a flatter dip, as shown in plate 8. At places in the mine small drag folds, only a few feet in width, plunge northeastward. A fold of this type was mapped on the 700-foot level and is shown in plate 8. The folding took place before the deposition of the magnetite in the Mount Pleasant deposit, because the magnetite replaces the folded host rock. Several other folds of a smaller amplitude were mapped. A small fold that can be classed as a roll was mapped on the drift N 1700 W. (See pl. 8.) This fold or roll is reflected more by a conspicuous flattening of the Mount Pleasant ore body in the axial area than by an abrupt steepening.

A few isoclinal folds are known in the oligoclase-quartz-biotite gneiss. This type of fold is difficult to recognize and can only be determined when the flexure of the fold is exposed. A fold of this type that was mapped at the top of raise S 1380 E is shown in figure 7. Here the magnetite layer (Richard deposit) cuts across the foliation of the country rock and essentially parallels the axial plane of the anticline.

FAULTS

Transverse and longitudinal or oblique faults constitute a major mining problem in the Richard mine. Little is known concerning the age relations of these types of faults, as the intersections have not been seen in the mine.

Three transverse faults are known at the Richard mine: No. 4, a steeply-dipping fracture whose surface trace is 525 feet southwest of the Richard mine shaft 2 (pl. 1; figs. 22 and 23); No. 1, whose surface trace is near the Teabo mine shaft 3 (pl. 1 and fig. 22); and the Allen fault, whose surface trace is 335 feet northeast of the Richard mine shaft 3 (pl. 1; fig. 23). Each of these faults has been encountered in the underground workings. The No. 4 fault and most of the Allen fault are not accessible at present, but the No. 1 fault was mapped by the present writer on the 900-, 1,100-, and 1,300-foot levels.

Several longitudinal and oblique faults have been intersected in the mine workings. These faults, however, have not been recognized at the surface and are not shown on plate 1. These faults dip 40° NW. to vertical, strike east-northeast and show reverse movements. Unlike the transverse faults, which generally are marked by several feet of broken ground, the breaks along these faults are relatively sharp. Vertical displacements range from less than a foot to about 80 feet on individual faults, but generally are less than 20 feet. Several of the faults are quite continuous, and because they trend nearly parallel to the ore bodies are encountered in many stopes on a single deposit, as can be seen by reference to plates 7 and 8.

The September fault is an oblique fracture which shows reverse movement and which trends about N. 55° E. and dips 60°–75° NW., where it is known on the 900-, 1,100-, and 1,300-foot levels. (See pls. 7 and 8; figs. 26 and 29.) As can be seen in the section through raise 13–127 on the Mount Pleasant ore body (pl. 8, section *Y–Y′*) the fault has an apparent displacement of about 30 feet and a throw of 25 feet. The horizontal separation parallel to the trace of the fault, where it intersects the Mount Pleasant deposit, is 20 to 25 feet. The September fault is probably equivalent to fault C mapped in drift S 1300 W and possibly also is equivalent to fault D mapped in drift S 1500 E. The fault intersects both the Mount Pleasand and the Richard ore bodies. The September fault cuts the Richard ore body near its bottomrock, and mining has terminated at the fault on the 900- and 1,100-foot levels. If fault C, mapped in drift S 1300 W is equivalent to the September fault, as the writer believes, the fault also effectively forms the bottom of the Richard deposit on the 1,300-foot level. In 1951, Richard Ore Co. was driving a raise along the bottomrock of the deposit at the southwest end of the drift S 1300 W to mine the ore segment cut off by fault C. (See fig. 25, section *X–X′*).

The September fault has been traced through the workings on the Mount Pleasant deposit from the 900-foot level to the 1,300-foot level (pl. 8). It probably was intersected also on the upper levels, southwest of shaft 5. On the 1,100- and 1,300-foot levels the fault cuts through the Mount Pleasant deposit at the pinch between the Major and Kearney ore shoots, and thus did not present many problems in mining. On the 900-foot level, however, the fault cut through the Major ore shoot.

The August fault is an oblique fault which shows normal movement and which strikes N. 70° E. to east and dips 35° to 45° N. on the 900- and 1,100-foot levels. It probably merges with the September fault below the 1,100-foot level. (See pl. 8 and fig. 26.) On the 1,100-foot level, the August fault intersects the Mount Pleasant deposit 300 feet northeast of the Sweetser shaft, and here has a horizontal separation parallel to trace of the fault of about 40 feet and an overlap of about 18 feet. The throw of the fault at this locality is probably about 15 feet. The August fault does not intersect the Richard ore body in the mine workings that are now accessible.

Several longitudinal and oblique faults in the Richard mine that are less well known were mapped and assigned letter names during the present survey.

In 1950 a longitudinal fault, called fault E, was intersected in drift S 1300 W. (See fig. 27.) This fault, which has not been cut elsewhere in the Richard mine, strikes nearly parallel to the Mount Pleasant deposit and dips about 79° NW., according to M. T. Hoster (1951, oral communication). As can be seen on figure 27, the fault at this locality has a throw of 85 feet.

Several longitudinal and oblique faults that cause problems in mining have been intersected in the workings on the Richard ore body.

Fault A is an oblique fault with reverse movement that strikes N. 70°–75° E. and dips 65°–75° NW. It has been intersected in drift S 1300 E and in the raises between the 1,300- and 1,100-foot levels. (See pl. 7.) The fault in places consists of more than one break, and in raise S 1380 E the aggregate throw on the fault is 30 feet. According to A. Getz of Richard Ore Co. (oral communication), the vertical displacement decreases to the southwest, and the fault disappears entirely

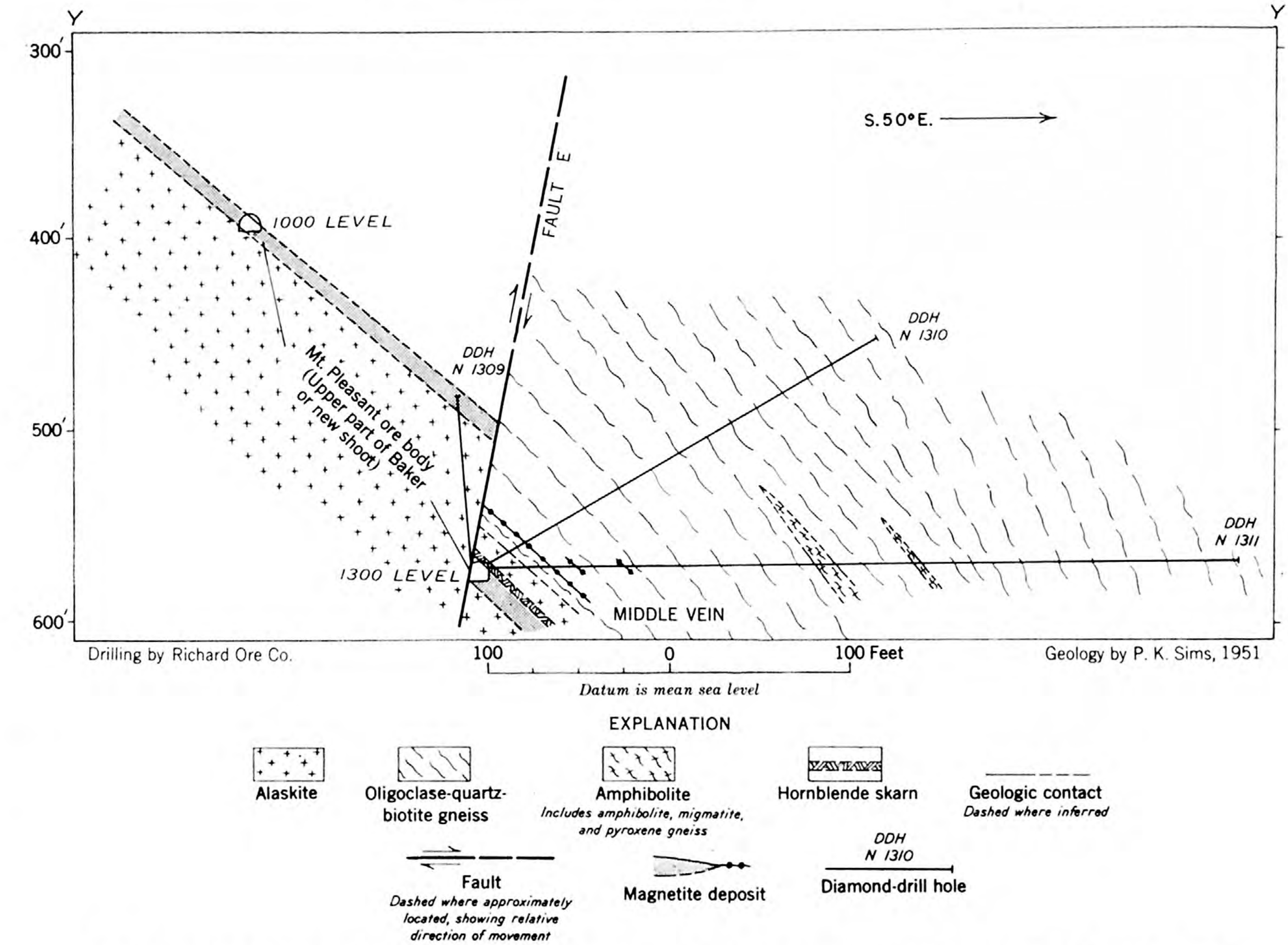


FIGURE 27.—Section showing displacement of Mount Pleasant ore body by fault E, Richard mine. Line of section along $Y-Y'$ shown on figure 25.

a short distance northeast of raise S 1302 E (pl. 7). In drift S 1300 E, northeast of fault A, several faults are present, but little is known of their displacements. In the northeast end of drift S 1300 E, a reverse fault, called fault F, has a throw of about 30 feet where it was cut in the raise from the 1,700-foot level at Mount Hope mine. The fault strikes about N. 45° E. and dips 87° NW. It has been traced through several stopes on the Richard ore body on the 1,700-foot level at Mount Hope mine.

Two prominent longitudinal faults have been mapped in drift S 1300 W (pl. 7). Fault C is a reverse fault that strikes about N. 65° E. and dips about 80° NW. As can be seen in sections *X–X'*, *Y–Y'*, and *Z–Z'* (pl. 7), it cuts off the Richard ore body near its bottomrock. The throw of the fault is not known, but is estimated to be more than 60 feet. It seems to connect with fault B in the vicinity of the crosscut on the 1,300-foot level. The fault is thought to correlate with the September fault, which was encountered on the upper levels.

A reverse fault, fault D, was intersected on the 1,500-foot level (pl. 7). At this locality the fault has a throw of about 100 feet, to judge from its displacement of the Richard ore body. (See fig. 28.) The throw is so large that Richard Ore Co. probably will not be able to mine the ore in the ground above the 1,500-foot level between the base of the incline on the 1,500-foot level and raise S 1532 E. (See figs. 24 and 28.) Fault D may correlate with fault C, but there is no definite evidence to assure this correlation. If the two faults are equivalent, it is apparent that the displacement on the fault increases to the northeast.

Several other longitudinal and oblique faults with minor displacements have been mapped in the Richard mine (pls. 7 and 8), but so far as known, none of these cause problems in mining.

MAGNETITE DEPOSITS

Three magnetite deposits are known in the Richard mine. From northwest to southeast these are the Mount Pleasant (or North) deposit, the Middle deposit, and the Richard (or South) deposit. The Allen deposit,

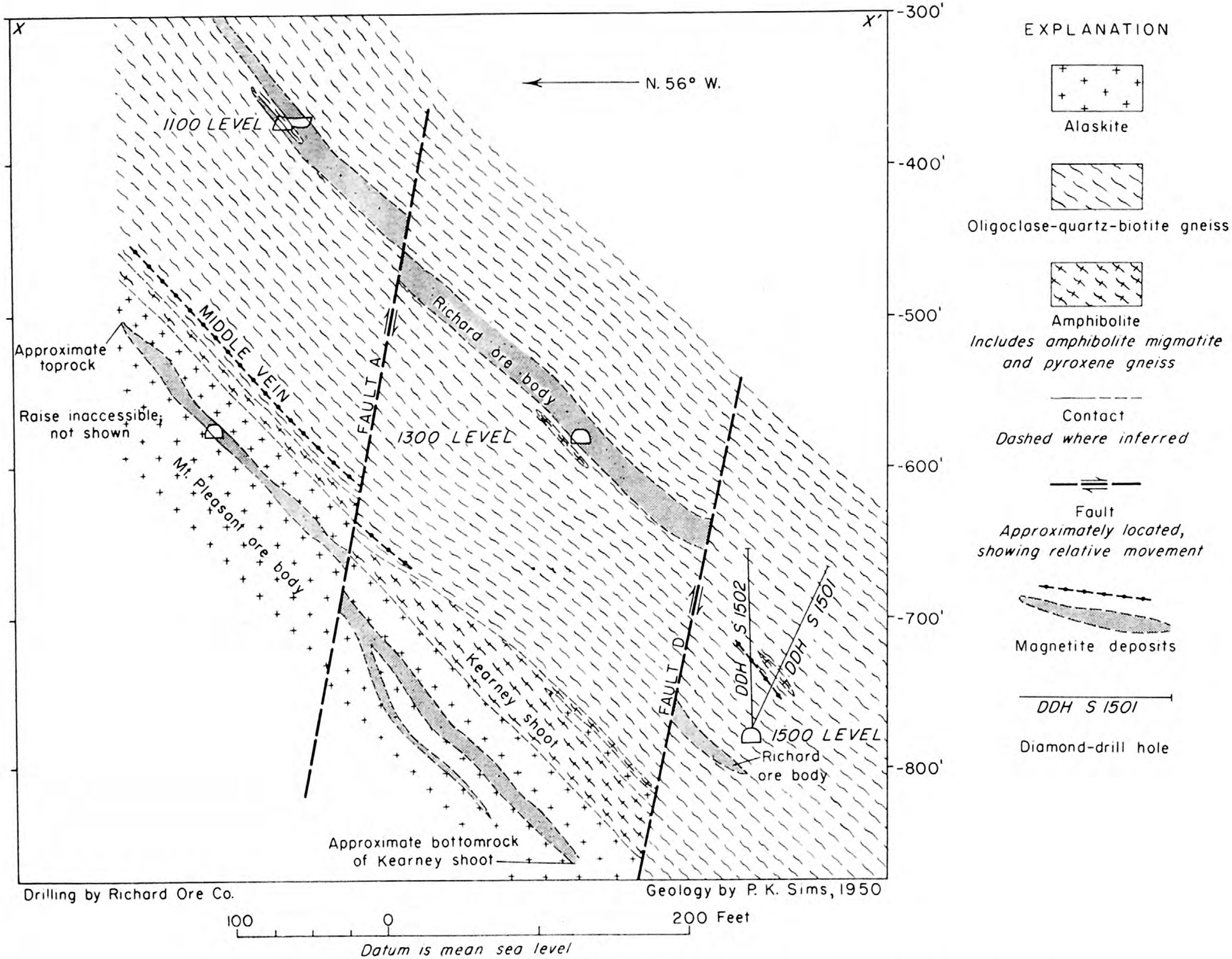


FIGURE 28.—Section showing offset of ore bodies by faults, Richard mine. Line of section along X–X' shown on plates 7 and 8 and figure 25.

an ore shoot in the lower part of the Teabo ore body, which was mined in the abandoned Allen mine, also is on the Richard property but has not been mined in the Richard mine (fig. 22). Another deposit, the Hilltop, is about 400 feet northwest of the Mount Pleasant deposit but has not been intersected in the Richard mine workings (fig. 24). In the hole drilled by the Pittsburgh Coal and Coke Co. in 1946 (fig. 23), a deposit of low-grade magnetite was intersected between depths of 624 and 636 feet. This mineralized zone is about 450 feet southeast of the Mount Pleasant deposit and may be equivalent to a deposit intersected by the long hanging-wall crosscut driven on the 5th level from shaft 4, on the southwest side of fault 4 (pl. 9). This deposit has not been mined in Richard mine.

RICHARD (OR SOUTH) ORE BODY

The Richard (or South) ore body (fig. 22), has contributed about three-fourths of the ore recovered from the Richard mine. It is a tabular body that has an outcrop length of about 2,600 feet. The Richard ore body is an ore shoot within a large tabular deposit that includes the Allen and Teabo deposits. It is separated from the overlying Teabo by a pinch that in most places is too thin to mine profitably under present economic conditions. The bottomrock of the ore body does not come to the surface; it is covered by a thick deposit of sand and gravel (M. T. Hoster, oral communication). The toprock, which is marked by a pinch in the deposit, is near Teabo No. 3 shaft and about 300 feet to the northeast the deposit widens to form the Allen shoot of the Teabo ore body (fig. 22).

The Richard ore body strikes about N. 35° E. on the 1,100- and 1,300-foot levels at Richard mine, dips 20° to 55° SE. and plunges 10°–15° NE. (pl. 7). In general, the upper part of the deposit dips 45°–50° SE. more steeply than the lower part. Near the bottomrock the deposit flattens and in the lower part of the stopes on the 1,300-foot level, the footwall has a dip of about 20°. Little information has been gathered concerning the plunge of the bottomrock of the deposit, because the lower part of the ore body, where exposed, is cut up by faults. The thickness, where mined, ranges from 5 feet to about 30 feet; the greatest thickness is near the bottomrock (pl. 7).

The Richard ore body terminates abruptly at its bottomrock. To judge from the exposure on the 900-foot level (fig. 29), the bottomrock is marked by an abrupt flattening of the footwall, and the ore pinches out entirely. The toprock, on the other hand, is marked by a pinch in the deposit to a thickness below the economic limit of mining. As can be seen in plate 7, it thins to about 4 feet near the northeast end of the 1,100-foot level. According to A. Getz (oral communication), the deposit also thins to 4 feet or less in the top of the stopes above the 1,100-foot level.

The operators have explored the ground beneath the bottomrock of the Richard ore body for a new deposit in the plane of the Richard, but the exploration has not been successful. In 1950 two diamond-drill holes were cored from the drift N 1300 W to explore for a possible extension of the Richard ore body about 500 feet vertically below the bottomrock. (See fig. 27.) Both holes failed to intersect ore. The company has not fully tested the Teabo deposit above the Richard deposit.

The Richard ore deposit is a replacement body in oligoclase-quartz-biotite gneiss. The ore in most of the deposit consists of coarsely-granular and somewhat crumbly massive magnetite. In many places the ore has a blocky structure formed by intersecting joint sets. It has a laminated structure where several percent of mafic minerals occur in the ore. In places, the ore contains a few percent of hornblende and pyroxene in discrete grains that commonly have a preferred orientation. Apatite is a ubiquitous gangue mineral that constitutes more than 1 percent of the ore; where most abundant the white granules of apatite form laminae parallel to the walls of the deposit.

The contacts of the ore against the wall rocks generally are sharp and there is an abrupt change from massive ore to essentially barren country rock. The contacts are marked in many places by biotite selvages or sköls, a few inches to as much as 2 feet thick. The sköls commonly contain some disseminated magnetite.

In a few places, a parting or "horse" of rock occurs from 3 to 7 feet above the footwall contact of the Richard deposit. The parting consists either of augen gneiss or of biotite magnetite-bearing schist and is less than 4 feet thick. In the upper part of the deposit, however, as in stope S 1380 E, biotite schist constitutes several percent of the deposit. The biotite schist, which contains about 30 percent Fe, forms laminae as much as 5 feet thick that are interlayered with massive magnetite. Locally, granite pegmatite occurs as irregular masses in the ore. Thin quartz and carbonate veins cut the magnetite in a few places.

Polished sections of the ore indicate that it is composed essentially of magnetite. Chemical analyses of the ore are given in table 12. The ore contains more than 1 percent TiO_2, primarily as ilmenite; about 1.5 percent P, as apatite; and small amounts of MnO and V_2O_3. The Mn and V probably are contained in the crystal lattice of the magnetite.

MOUNT PLEASANT (OR NORTH) ORE BODY

The Mount Pleasant (or North) ore body (pl. 8) is about 250 feet northwest of the Richard deposit and nearly parallel to it. The Mount Pleasant probably has been the principal source of ore in the Dover district, and it has been mined in the Hubbard, North River, Harvey, Hurd, Orchard, Washington Forge, West Mount Pleasant, Mount Pleasant, and Baker mines, in addition to the Richard mine. The deposit extends into the Mount Hope mine from the Richard, but it has not yet been worked at Mount Hope mine. As can be seen in plate 9, the bottomrock of the deposit crops out a short distance southwest of the Harvey mine; the toprock is 600 feet northeast of shaft 6 at the Richard mine.

Plate 8 shows a composite geologic map and sections of the Mount Pleasant deposit in the accessible workings at the Richard mine. The relation of the deposit to the Richard ore body is shown on figures 26 and 28. In Richard mine, the Mount Pleasant deposit trends N. 40°–45° E., dips on the average 40°–60° SE., and plunges about 20° NE. In general, the dips are near 60° in the upper part of the deposit and near 40° in the lower part of it. In some places small folds in the host rock are reflected by relatively flat dips in the deposit, as in drift N 1300 W, near raise 13–127 W. In the crosscut on the 700-foot level (pl. 8), it can be seen that the ore occurs in a fold that plunges northeast. The deposit generally is conformable to the foliation in the wall rocks, but locally it cuts across the gneissic structure at a small angle, as shown in plate 20.

The Mount Pleasant deposit is a tabular ore body, which in the Richard mine has a well-developed shoot structure. The aggregate breadth is estimated to be at least 1,900 feet, as shown in plate 9. This estimate is based on the best known data, but because of the lack of knowledge concerning the vertical displacement

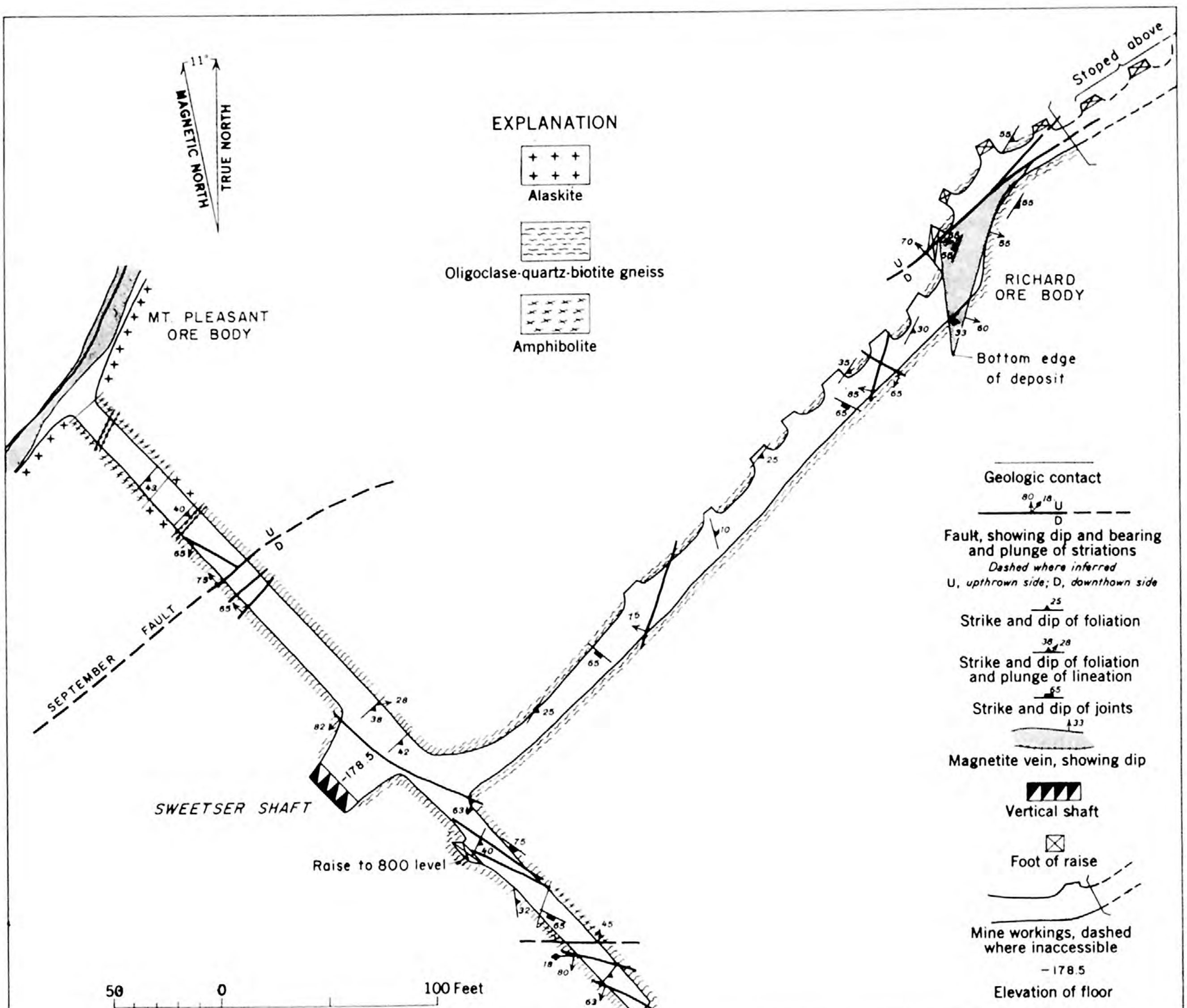


FIGURE 29.—Geologic map of the Richard (South) ore body on the 900-foot level, Richard mine.

of the Rockaway River fault and the lack of information in the area southwest of the Mount Pleasant mine, the estimate cannot be considered more than a probability.

In the Richard mine, the Mount Pleasant deposit consists of 3 ore shoots that from top to bottom are named the Kearney, Major, and Baker (or New) (pl. 9). In general, the structure of the shoots is similar. They pinch and swell and in places are split into two or more discrete magnetite bodies or seams. There are some differences, however, in the ore of each shoot.

The uppermost shoot, the Kearney, is separated from the underlying Major shoot by a well-defined pinch that on the 1,100- and 1,300-foot levels is about 600 feet in length. The pinch has been recognized throughout the mine, as can be seen in plates 8 and 9. The pinch is marked by a decrease in width of the ore and by the absence of skarn. The skarn pinches out entirely in this interval, and the magnetite forms one or more seams of massive ore that replace alaskite. (See pl. 8.) The pinch separating the Major from the Baker ore shoot is less well defined, generally smaller, and more irregular. On the 1,100-foot level, in the vicinity of the Sweetser shaft, the pinch is marked by a decrease in the thickness of the massive magnetite from about 4 feet to about 1 foot. There is no break in the skarn, however; instead it continues from one shoot into the other.

The toprock of the Mount Pleasant deposit, like the pinch between the Kearney and Major shoots, is marked by a pinch in the thickness of the ore and by the absence of skarn, as can be seen in drifts N 1100 E and N 1300 E (pl. 8). The pinch in the ore is gradual on the 1,100-foot level but is sharp on the 1,300-foot level. The bottomrock of the Mount Pleasant deposit has not been observed, but it is inferred that it is similar to the toprock.

The Kearney ore shoot has yielded the bulk of the ore from the Mount Pleasant vein in the Richard mine. The shoot has a breadth of from 500 to 550 feet (pl. 9), and an average width of about 8 feet. The ore is chiefly medium to finely granular, massive magnetite that contains several percent of apatite. Much of the ore has a blocky structure. Locally the ore is layered and contains laminae of granular pyroxene or hornblende.

The upper part of the Major ore shoot consists principally of massive blocky ore similar to that found in the Kearney shoot. Some of the ore is crumbly and is known to the miners as "shot ore." The lower part of the shoot, however, is much different, and it is made up of a footwall layer, generally from 3 to 5 feet thick, of massive (blocky) magnetite and a hanging-wall layer of lean ore. The lean ore occurs in a biotitic hornblende skarn that generally has a good layering and which is in part modified by pegmatite that has been intimately injected along the foliation planes of the skarn. The pegmatite is in places slightly replaced by the magnetite.

The Baker (or New) ore shoot was the principal source of ore from the Mount Pleasant vein in the workings from shaft 4. (See pl. 9.) The mining operations here indicate that the shoot had a breadth of about 600 feet. The only workings on the shoot accessible during the mapping were on the 1,100-foot level, southwest of the Sweetser shaft. Since then, however, the shoot has been opened on the 1,300-foot level. The Baker shoot is from 6 to 12 feet thick and is very similar to the lower part of the Major shoot. It is made up of a footwall layer of massive magnetite from 3 to 12 feet thick where observed, and a hanging-wall layer of lean ore. The lean ore is in modified skarn that differs from that in the Major shoot only in being more highly veined in a lit-par-lit manner by granite and pegmatite.

The ore in the Mount Pleasant deposit is principally massive. It is mostly blocky and contains a percent or more of apatite, which occurs as white granules. Some of the ore consists of irregular masses and nests and stringers of magnetite in skarn. This ore is lower in grade than the massive ore. Chemical analyses of ore from the Mount Pleasant deposit are given in table 12.

MIDDLE "VEIN"

The Middle "vein," also known as the Spring "vein," is a remarkably persistent mineralized zone that is about 75 feet southeast of the Mount Pleasant deposit. It occurs throughout most of the mine, and is thought by the writer to be equivalent to the Hawkins deposit at the Mount Hope mine, and to the deposit that is 66 feet southeast of the Mount Pleasant deposit in the Mount Pleasant mine (Bayley, 1910, p. 396).

The deposit is thin, ranging from 1 to about 4 feet in thickness, and is low in grade. It consists of magnetite stringers and local massive bodies as much as 18 inches thick. The deposit occurs in oligoclase-quartz-biotite gneiss, a short distance from the contact of the gneiss with amphibolite. (See pls. 7, 8; figs. 26, 28.) The gangue minerals are chiefly unreplaced fragments of the host rock—oligoclase, quartz, and biotite—but in addition apatite, calcite, and pumpellyite were observed locally in the ore. Pumpellyite and calcite fill cracks and pits in the magnetite, and locally replace the plagioclase for a short distance from the "vein." It can be seen under the microscope that the magnetite is in a cataclastic zone in the gneiss.

HILLTOP DEPOSIT

The Hilltop deposit is about 400 feet northwest of the Mount Pleasant ore body and 1,050 feet northwest of the Sweetser shaft (fig. 23). The deposit has been prospected by several opencuts, but it has not been mined underground. The extent of the deposit was determined in 1942 by a magnetic survey by Sherwin Kelly Geophysical Services, Inc. As can be seen on figure 23, the deposit is marked by a magnetic anomaly about 1,500 feet in length, as measured within the +200 contour. The maximum intensity is slightly more than +300. The anomaly consists of 2 parallel anomalies, about 100 feet apart, that merge at the northeast end into a single anomaly about 300 feet wide.

In 1942 Richard Ore Co. cored 4 diamond-drill holes to test the Hilltop deposit. The drilling indicated that the deposit is large, but low in grade. As the cores were destroyed, the writer was not able to examine the ore and the wall rocks. To judge from the rock dumps of the opencuts on the southeast mineralized belt, the magnetite forms disseminated granules and small veinlets scattered through the albite-oligoclase granite host rock. The magnetite is accompanied by sparse biotite, calcite, apatite, and pumpellyite.

BAKER MINE (19)

The Baker mine, in Rockaway Township, adjoins the Richard mine on the southwest. The property is owned by Henry O. Baker and family.

The mine was opened in 1866 and was abandoned in 1906 (Bayley, 1910, p. 398). Its abandonment resulted from a cave-in caused by robbing pillars (Bayley, 1910, p. 399), but apparently most of the minable ore was extracted before the mine was closed. The aggregate production from the mine is estimated to be 400,000 tons; about 150,000 tons of the ore was mined between 1873 and 1877.

The mine was opened on two ore deposits about 300 feet apart—the Mount Pleasant (northwest) and the Richard (southeast). The main, or Baker, shaft (fig. 22), was sunk on the Richard deposit, and it extended to the bottom rock of the ore body, a vertical distance of about 325 feet. The extent of the known mine workings on the Richard deposit is shown on figure 22. The deposit was not worked to the surface southwest of the Baker shaft, because it has been eroded here by a deep glacial channel, now filled with unconsolidated sand and gravel. The extent of the workings on the Mount Pleasant deposit is not known, but presumably the deposit was worked out along the complete length of the Baker property. The extent of the mine workings in 1872 is shown by Bayley (1910, p. 399; fig. 23). According to Bayley (1910, p. 398) the Mount Pleasant ore body was 7 feet thick, whereas the Richard deposit was 23 feet thick in the Baker mine. The northeast continuation of both deposits has been worked in the Richard mine.

DOLAN MINE (20)

The Dolan, or Doland, mine is 1,200 feet northwest of the Baker mine, on the north side of Mount Hope road. The deposit is within the same ore zone as, and northeast of, the Huff mine. The mine was worked only on a small scale and the production in 1884 was about 1,000 tons. The workings are now almost completely overgrown; for a description of them the reader is referred to Bayley (1910, p. 369).

Two deposits 42 feet apart were mined. The deposits were 6 to 8 feet wide and dipped 60° SE. To judge from the rock dumps, the magnetite forms massive layers parallel to the foliation of the host rock and disseminated grains. The host rock is oligoclase-quartz gneiss, probably a facies of oligoclase-quartz-biotite gneiss.

MOUNT PLEASANT MINE (21)

The Mount Pleasant mine in Rockaway Township, is midway between the Baker (19) and Washington Forge (23) mines. The principal shaft, now caved, is a short distance north of Union Turnpike, between Dover and Berkshire Valley. All the mine workings are now inaccessible.

The mine was opened on the Mount Pleasant ore body in 1786 and was worked extensively until its abandonment in 1896. The aggregate production from the mine is estimated to be 400,000 tons. At the time of its closing the mine was about 2,300 feet long and at least 700 feet (vertically) deep. The full extent of the mine workings is not known, but the outline of the workings shown in plate 9 probably is nearly correct up to June 1880. Most of the ore came from the northeast end of the mine; in 1880, however, the southwest part of the property was explored; a drift was started at a depth of about 600 feet and driven southwestward 800 feet, where a transverse fault that displaced the Mount Pleasant deposit 70 feet to the left was encountered. (See fig. 30.) The drift was continued southwestward along the strike of the vein for a distance of 500 feet, and back stopes were carried upward for 300 feet (Jenkins, 1897, p. 328). Since the ore in this part of the mine could be extracted more cheaply through the Orchard mine shaft, work in this part of the mine was discontinued, and the mine was abandoned in 1896.

The geology of the mine is little known, because the mine is inaccessible and because there are no surface exposures. By analogy, however, it can be inferred that the geology is similar to that of the Richard mine. Several faults have been described (Bayley, 1910, p. 396–397). Transverse faults that strike in general eastward and that dip steeply northward offset the

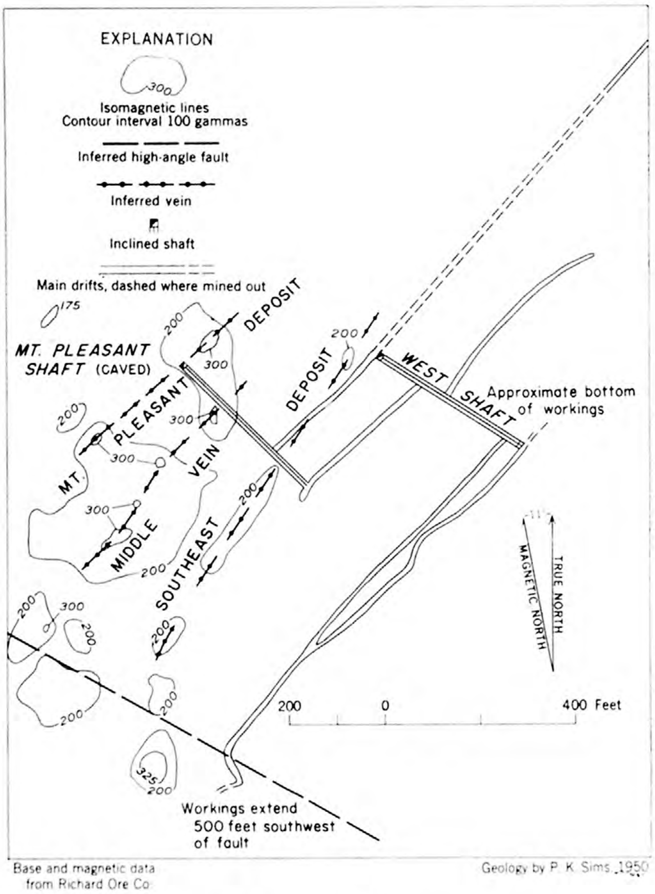


FIGURE 30.—Magnetic map of Mount Pleasant mine.

Mount Pleasant deposit. A transverse fault in the southwest part of the mine with a horizontal displacement of about 70 feet is shown in plate 9 and figure 30. In addition, several longitudinal faults that dip northwestward and that show reverse movements offset the deposit and tend to emphasize its shoot structure. One reverse fault was reported to have a throw of 35 feet (Bayley, 1910, p. 396).

Four essentially parallel magnetite deposits are reported from the Mt. Pleasant property (Bayley, 1910, p. 395–396)—the Northwestern, possibly equivalent to the Huff or Dolan deposits; the Mt. Pleasant, referred to in published reports as the Main deposit, and incorrectly referred to as the Teabo; a deposit 66 feet southeast of the Mt. Pleasant; and a deposit about 350 feet southeast of the Mt. Pleasant deposit. (See fig. 30.) The Mt. Pleasant (Main) deposit, which was the principal one mined, averaged about 6 feet in width. It dips 57° SE. (average) and trends N. 43° E. Five "ore shoots," whose average height was 60 feet, were mined (Bayley, 1910, p. 396); the shoots presumably belong to the Baker (or New) ore shoot, as shown in plate 9. The ore taken from the northeast part of the mine is believed to be equivalent to that mined from the lower part of the No. 4 shaft in the Richard mine.

An analysis of 10 carloads of ore mined in 1880 from the northeast stopes gave (Pumpelly, 1886, p. 171): 64.85 percent Fe; 0.185 percent P. The ore from the southwest stopes was of similar grade but contained more than average amounts of P. An analysis of ore from the southwest stopes in 1867 gave: 67.0 percent Fe; 1.6 percent P (Bayley, 1910, p. 398).

Little is known concerning the other deposits on the Mount Pleasant property. The deposit described as being 66 feet southeast of the Mount Pleasant ore body probably is equivalent to the Middle "vein" at the Richard mine; its probable position at the surface is indicated on figure 30. The deposit that is 350 feet southeast of the Mount Pleasant deposit, shown as the southeast deposit in figure 30, is in approximately the same position relative to the Mount Pleasant as the Richard deposit at Richard mine; there is no evidence that the two deposits are correlatives, although it is possible that the lower part of the Richard may extend onto the Mount Pleasant property. To judge from published descriptions, it can reasonably be assumed that neither of the deposits reported to be southeast of the Mount Pleasant (or Main) "vein" was extensively mined.

The magnetic map (fig. 30) indicates that one, or perhaps two, small deposits lie between 200 and 350 feet northwest of the Mount Pleasant deposit.

BULL FROG MINE (22)

The Bull Frog mine is about 500 feet southwest of the Mount Pleasant mine shaft, on the opposite side of Union Turnpike. The Bull Frog mine is probably the Meadow mine described by Bayley (1910, p. 394). The mine worked the southwest part of the Mount Pleasant deposit at the Mount Pleasant mine (pl. 9). The extent and depth of the workings are not known, but to judge from the material at the mine dumps (1948) they are moderately large. The ore on the dumps resembles closely that of the Mount Pleasant deposit at Richard mine. The magnetite occurs as massive seams and layers that replace pyroxenic hornblende skarn, and to a minor extent, alaskite.

MEADOW MINE

[Not located]

The Meadow mine (Bayley, 1910, p. 394) is probably the Bull Frog mine (22), described above. The mine is estimated to have produced 75,000 tons of iron ore. According to Bayley (1910, p. 394) the mine was opened prior to 1884, and in that year the shaft was 400 feet deep and the drifts 300 feet long. It probably was first worked as an independent mine in 1883, and it was operated continuously until 1886, when it was abandoned. In 1886 the mine was 450 feet long. The deposit, almost certainly the Mount Pleasant, averaged 4 feet in thickness, and dipped 57° to 60° SE. The deposit contained neither toprock nor bottomrock.

WASHINGTON FORGE MINE (23)

The Washington Forge mine is on the north side of Rockaway River, in the town of Wharton. The mine workings are inaccessible, and the surface openings have been filled in with dirt and waste. The mine production is estimated to be 50,000 tons of iron ore.

The mine was opened in 1868 by 2 shafts 20 feet apart, and was worked intermittently until 1875, when it was closed because of excess mine water. It was reopened in 1879 after the drainage tunnel to the Orchard mine was completed, and was worked until 1881, when it was abandoned. At the time of its closing the mine had been developed through a length of about 250 feet and to an average depth of 200 feet. The approximate extent of the mine workings is shown on plate 9.

The only information on the mine is given in published reports by the New Jersey Geological Survey, especially Bayley (1910, p. 394). The mine worked the Mount Pleasant deposit, and according to Bayley the deposit, where opened, was about 10 feet wide. The Washington Forge mine is separated from the Orchard mine by the Rockaway River fault. (See pl. 9.) The displacement of the ore body by the fault is not known exactly. Bayley (1910, p. 393) estimates that the horizontal displacement on the fault is about 150 feet; the present writer estimates a horizontal displacement of almost 400 feet and a vertical displacement of 375 feet.

WEST MOUNT PLEASANT MINE (24)

The West Mount Pleasant mine is about 170 feet northeast of the Washington Forge mine (Bayley, 1910, p. 394), and is also on the Mount Pleasant deposit. The mine workings consisted principally of an inclined shaft, 300 feet deep, that was sunk to work the northeast continuation of the ore in the Washington Forge mine. The shaft, which has been filled, was inaccessible in 1948.

HUFF MINE (25)

The Huff (or Hoff) mine is on the east slope of the hill northwest of Washington Forge pond. The main shaft (fig. 32) is about 50 yards west of the Wharton-Spicertown road. The mine was worked intermittently from the time of its opening prior to 1855 until it was abandoned about 1911. Between 1855 and 1868 it was worked to a depth of 150 feet and along a length of approximately 600 feet, yielding about 50,000 tons of ore. By 1880 it had produced 78,000 tons of iron ore. The mine was in operation for short periods during the 1880's; it was abandoned in 1886, at which time the mine was 200 feet deep and presumably had reached bottomrock. It was reopened in 1905 by the Hoff Mining and Realty Improvement Co. of Rockaway. The shaft was sunk a few feet deeper and the ore was found again. The supposed bottomrock was only a pinch in the ore. The mine was operated on a small scale until it was closed. During the period immediately preceding its closing about 12,000 tons of ore was hoisted annually.

The principal workings that were accessible in 1911 are shown on figure 31. The shaft is inclined 45° SE. and connects with the first and second levels. An inclined bucket slide connects with the third level. A dip-needle map of part of the surface is shown on figure 32. The maximum attraction lies over the East vein. Reconnaissance dip-needle traverses indicate that this belt of positive attraction is about 1,200 feet long.

There are two nearly continuous series of pits at the surface. The interval between the line of pits is about 150 feet near the southwest end, but it is only about 75 feet near the shaft. The pits probably represent the surface workings on the two main deposits, the West and East veins. The main shaft is on the East vein. The East vein dips 63° SE. at the surface. Grooves on the walls plunge 19° NE. The West vein dips about 70° SE. The open stopes indicate that the deposits are narrow and rarely exceed 8 feet in width. The host rock for the ore is oligoclase-quartz-biotite gneiss. The gneiss also forms the wall rocks and usually contains several percent of disseminated magnetite. The magnetite occurs as thin laminae, from a fraction of an inch to about 1 foot in width, which alternate with layers of gneiss that contain some disseminated magnetite.

According to Bayley (1910, p. 369) the ore forms a series of shoots that dip about 60° SE. and rake 35° NE. In the mine workings two deposits from 10 to 14 feet apart were worked. The West (footwall) "vein" averaged 9 feet in width; the East "vein," 6 feet. The rock layer separating the two deposits was noted to thin with depth. The ore mined in 1886 averaged 45 percent Fe. An analysis of a carefully selected sample taken from the bottom of the mine in 1880 gave: 54.19 percent Fe, 1.33 percent P, and a trace of S (Cook, 1880, p. 106).

The Huff deposits are about 1,000 feet northwest of the Mount Pleasant ore body. The Dolan and Scrub Oaks deposits are similarly situated in relation to the main deposits in the Wharton ore zone, but there is no evidence of a continuous linear mineralized belt between the Huff and these deposits.

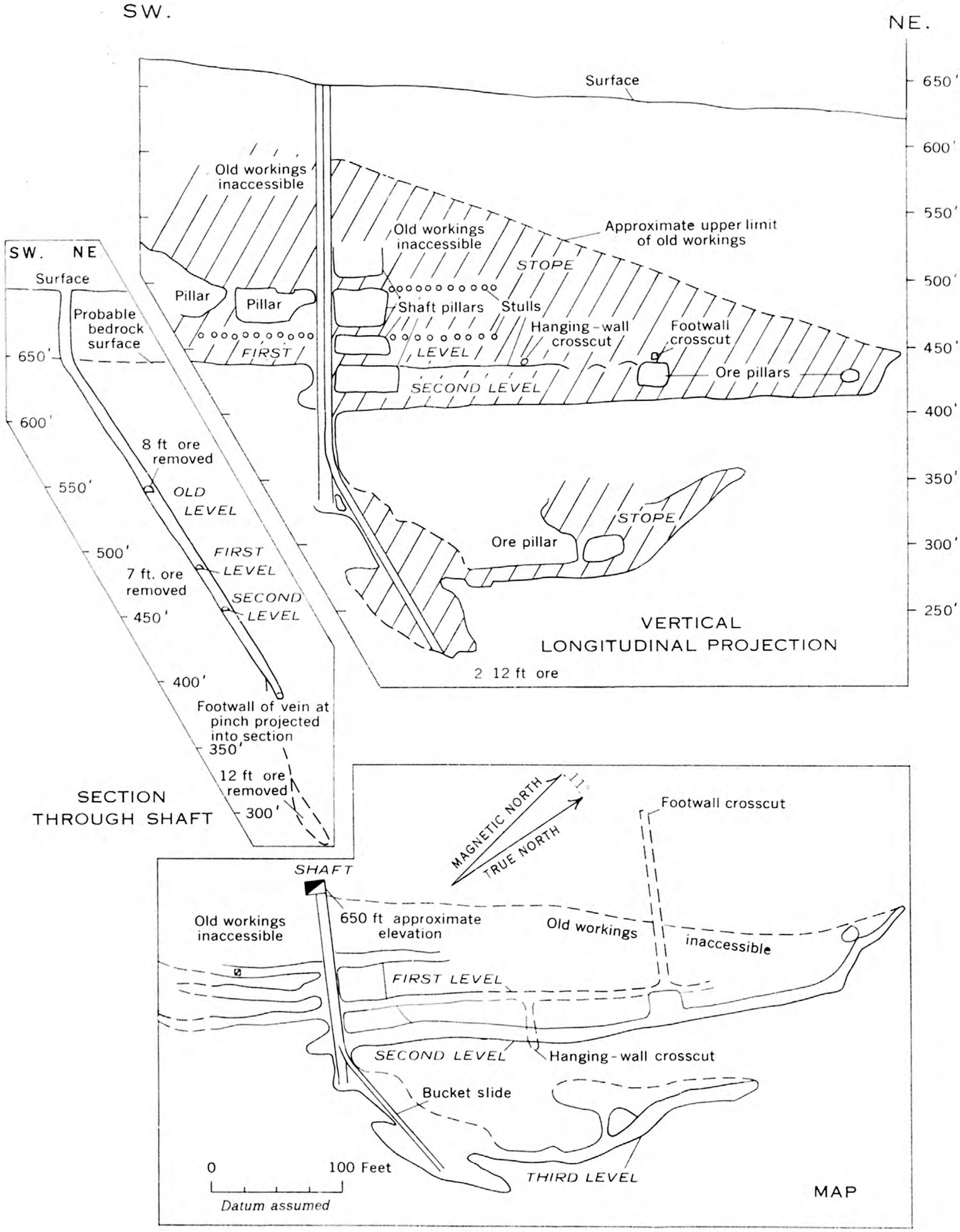


FIGURE 31.—Map and sections of Huff mine.

FIGURE 32.—Dip-needle map of Huff mine.

JOHNSON HILL MINE

[Not located]

The Johnson Hill mine, said to be on the southeast slope of the hill west of Wharton (Bayley, 1910, p. 368), was not located by the writer. Some of the shallow prospect pits on the southwest extension of the Huff deposits, however, may be on the Johnson Hill property.

According to Bayley (1910, p. 368), "there were reported to be some remarkable faults crossing the vein, but they have not been described because of lack of definite information concerning their character." It is possible that these faults are related to the Rockaway River fault (pl. 1) which is inferred to cross the line of projection of the Huff deposits near the tracks of the Delaware Lackawanna and Western Railroad.

ORCHARD MINE (26)

The Orchard mine is in the town of Wharton, between the Washington Forge and Hurd mines. The Orchard shaft, which was inaccessible in 1947, is 200 feet southeast of Washington Forge Pond. The mine is estimated to have yielded about 375,000 tons of iron ore. The mine was opened about 1850 (Bayley, 1910, p. 392) and was worked nearly continuously until 1874, when an influx of water caused the operators to suspend operations. After completion of a drainage adit at Hurd mine, the Orchard mine was reopened in 1879, and it remained in operation until closing in 1884. The mine was reopened in 1886 and was worked steadily until 1893. It was then closed until 1907 when a new deposit that had been worked in the Hurd mine—the Sterling—was found to extend onto the Orchard property; this deposit was worked until 1910, when the mine was permanently abandoned

The mine workings are shown in plate 9. The ore was hoisted through the Orchard shaft which is inclined 57° SE. and which has a vertical depth of about 850 feet. The deposit was worked from 13 levels, the longest of which was about 1,200 feet and to a vertical depth of at least 700 feet.

Little is known of the geology of the deposit; presumably, however, the country rock is similar to that in the northwest part of the Richard mine. A large transverse fault—the Rockaway River—cut off the ore body at the northeast end of the mine, and the mine workings, except on the 10th level, (see pl. 9) terminate against the fault. The fault displaced the Mount Pleasant ore body about 400 feet to the right; the deposit was worked on the northeast side of the fault in the Washington Forge mine. According to Bayley (1910, p. 393) there were no other faults in the mine.

The principal workings at the Orchard mine were on the Mount Pleasant deposit (pl. 9). According to Bayley (1910, p. 392–393) a deposit beneath the Mount Pleasant, which the present writer interprets to be the Sterling, also was worked. Exploration in the hanging wall of the Mount Pleasant deposit by an 800-foot crosscut failed to find other ore bodies but did intersect a thin seam of magnetite (Bayley, 1910, p. 392). The Mount Pleasant ore body in Orchard mine strikes about N. 40° E. and dips 48° to 57° SE.; it is reported to plunge 30° NE. (Bayley, 1910, p. 393), but to judge from the mine workings it plunges about 14° NE. The deposit, where mined, averaged 5 feet in thickness and contained a well-developed shoot structure (Bayley, 1910, p. 393). The ore contained 55 to 60 percent Fe and about 1.5 percent P; a sample obtained from the cars in 1880 gave: 55 percent Fe and 1.722 percent P (Pumpelly, 1886, p. 170).

The Sterling deposit is described under the Hurd (27) and Sterling (30) mines. If the mine openings shown in plate 9 represent the workings in the Orchard mine at the time of its closing, considerable ore remains beneath the mine workings.

HURD MINE (27)

The Hurd mine is 1,850 feet southwest of the Orchard mine, in the town of Wharton. The mine ranks as one of the largest mines in the Dover district, and together with the Harvey mine, it has yielded an estimated 635,000 tons of iron. It should not be confused with the Hurd mine at Hurdtown, at the northeast end of Lake Hopatcong.

The Hurd mine was opened before 1868, for in that year it had been worked along a distance of 100 feet and to a depth of 70 feet (Cook, 1868, p. 578). The mine was closed shortly thereafter, and was reopened in 1872. In 1874 the mine was closed again because of the influx of a great quantity of water, but it was reopened in 1879 after completion of a drainage adit (Bayley, 1910, p. 391). The mine was worked until 1883 when it again was shut down, but it was reopened by 1886. In spite of the periods of idleness, the mine produced nearly 450,000 tons between 1867 and 1886. From 1886 until it was finally abandoned, sometime between 1910 and 1920, the mine was worked intermittently. In 1897 a deposit, the Sterling, was found beneath the workings on the Hurd (Mount Pleasant) deposit, and this deposit was worked until the mine was abandoned. In 1904 Joseph Wharton acquired the mine to supply ore for the furnace at Wharton.

The Hurd mine is separated from the workings opened from the New Sterling shaft (pl. 9) by the North River fault. The fault has a horizontal displacement of about 130 feet to the left (Bayley, 1910, p. 389) and an estimated vertical displacement of about 40 feet. Other faults have not been described from the mine.

Two ore deposits—the Hurd (Mount Pleasant) and the Sterling—were worked in the Hurd mine. According to Bayley (1910, p. 392) another deposit, 15 feet wide, was discovered in 1905, but the position of this deposit relative to the Hurd and Sterling is not known. Possibly this deposit is represented by the mine workings in the bottom of the Hurd mine, below the bottom of the Sterling deposit, as shown in plate 9. This conclusion is based entirely upon the fact that the Sterling deposit on the southwest side of the North River fault has a maximum mining height of only about 150 feet, and there is no reason to believe that it would be nearly twice that in the Hurd mine. The deposit worked in the bottom of Hurd mine may be the Corwin, as shown in plate 9.

The Hurd deposit is the southwest (lower) part of the Mount Pleasant deposit. The bottomrock of the deposit is believed to crop out about 1,350 feet southwest of the New Sterling shaft; it plunges about 14° NE. (pl. 9). The deposit in Hurd mine was reported to average less than 9 feet in thickness; it dipped about 52° SE. (Bayley, 1910, p. 392). A sample of the ore from 50 tons in the cars in 1880 assayed 57.11 percent Fe and 1.618 percent P (Pumpelly, 1886, p. 170). The Sterling deposit, where being mined in 1901, was 2.5

to 6 feet thick, had a breadth of 65 feet, and plunged about 19° NE.

HARVEY MINE (28)

The Harvey mine is 300 feet southwest of the Hurd mine, on the northeast slope of the hill. The mine worked the Mount Pleasant ore body (pl. 9). The Harvey mine was opened, worked, and abandoned before 1855 (Bayley, 1910, p. 390); evidently it was subsequently reopened for in 1868 (Cook, 1868, p. 578) it was reported to be 400 feet long and 300 feet deep. Shortly afterwards the mine opened into the Hurd mine, and the Harvey mine lost its identity.

Large mine dumps are still present at the base of the hill, near the mine, and to judge from them the deposit worked is similar to the Mount Pleasant deposit at Richard mine. The magnetite replaces coarse-grained pyroxenic hornblende skarn. Evidently the wall rocks are principally alaskite with subordinate amphibolite and amphibolite migmatite.

NEW STERLING SHAFT (29)

The New Sterling shaft is 750 feet southwest of the Hurd mine and 1,900 feet northeast of shaft 13 at the Sterling mine. The New Sterling shaft was opened in 1890 to mine the ore from the northeast part of the Sterling deposit and was worked until 1900, after which it was operated in conjunction with the Hurd mine. The shaft, inclined 45° to the southeast, encountered the Sterling deposit (pl. 9) at a vertical depth of about 390 feet. The shaft was continued to a vertical depth of slightly more than 800 feet. The Sterling deposit ranged from 3 to 18 feet in thickness.

STERLING MINE (30)

The Sterling, or Stirling, mine comprises a group of openings on the hill southwest of the Hurd mine. The principal hoisting shaft was shaft 13. (See pl. 9.) It is estimated that the mine has produced 250,000 tons of iron ore, three-fifths of which was mined before 1868. The Sterling is one of the oldest mines in the district; according to C. T. Jackson it was first worked in 1640 (Bayley, 1910, p. 388). At any rate, the mine was operated long before 1855, and by 1868 it had yielded about 150,000 tons of iron ore. It was worked almost continuously from 1855 to its closing in 1885.

The Sterling mine, which is the best known of the Irondale group of mines, worked the Sterling deposit from its outcrop, just southeast of the Erb fault, for a distance of more than 2,000 feet and to a vertical depth of about 500 feet. The northeast continuation of the Sterling deposit was worked from the New Sterling shaft, the Hubbard mine, and the North River mine, as well as from the Hurd mine. The Sterling deposit is southwest of, and in the same plane as, the Mount Pleasant deposit. It is separated from the Mount Pleasant deposit at the surface by about 500 feet of barren ground. (See pl. 9.)

The Sterling deposit strikes about N. 40° E., dips 30° to 45° SE., and plunges an average of 14° NE. According to Bayley (1910, p. 388) the plunge locally ranges from 10° to 18° NE. The deposit had an average thickness of 7 feet and a mining height of between 90 and 150 feet. The host rock, to judge from the material at the mine dumps near shaft 13, is a green medium-grained oligoclase-quartz-biotite gneiss. A few specimens show magnetite replacing pyroxenic hornblende skarn. The magnetite is massive, generally crumbly, and rich in apatite. An analysis from the cars in 1880 gave 58.80 percent Fe, and 1.342 percent P. (Pumpelly, 1886, p. 170.)

HUBBARD AND NORTH RIVER MINES

The Hubbard and North River mines were a few hundred feet northeast of the Sterling mine. (See pl. 9.) Both mines worked the same deposit, presumably the Mount Pleasant. The Hubbard mine worked the southwestern part of the deposit for a distance of about 600 feet and to a maximum depth of 200 feet (Bayley, 1910, p. 389). The total production is estimated at 75,000 tons. The North River mine was about 300 feet northeast of the Hubbard; it worked the Mount Pleasant deposit from the southwest boundary of the property northeastward to the North River fault. The production from the North River mine was about 20,000 tons (Bayley, 1910, p. 389).

Little is known concerning the extent of the mine workings or the nature of the deposit. From the sparse information available the present writer believes that both mines worked the southwest part of the Mount Pleasant deposit, from the outcrop of its bottomrock to the North River fault. The surface openings of the two mines are shown in plate 9. Bayley (1910, p. 390) refers to the deposit as the North River shoot, and he indicates (Bayley, 1910, p. 388) that it lies above the Sterling deposit. The ore deposit in the two mines ranged from 1 to 14 feet in thickness, and dipped 30° to 45° SE. Surface openings and reconnaissance dip-needle data indicate that the deposit trends about N. 42° E. The footwall at the Hubbard mine was reported to be coarse granite, probably alaskite.

PROSPECT (31)

This prospect, which is 4,000 feet northeast of shaft 1 at the Scrub Oaks mine at the west edge of Wharton, is on a minor shoot in the same ore zone as the Scrub Oaks deposit. The workings consist of two groups of shallow pits that are separated from one another by the North

River fault. A narrow zone of weak magnetic attraction overlies the pits.

J. D. KING MINE (32)

The J. D. King mine is on the west slope, near the northeast end of the ridge west of Wharton. The mine is on a deposit that lies about 500 feet northwest of the Scrub Oaks ore body.

The mine was opened before 1869. In 1871 further exploratory work was done, but since the deposit was small, mining operations were soon suspended.

The surface openings consist of several small pits from 5 to 15 feet deep. The vein was prospected along a distance of about 700 feet.

Specimens from the dumps indicate that the ore is low to medium in grade. The magnetite forms narrow stringers and veinlets that replace plagioclase-quartz-pyroxene gneiss. The wall rocks are not exposed. In some specimens several percent of pyrrhotite is closely associated with magnetite.

SCRUB OAKS MINE (33)

Scrub Oaks mine, owned by Alan Wood Steel Co. of Conshohocken, Pa., is 2 miles west of Dover, on the west slope of the hill overlooking the valley in which Succasunna and Kenvil are situated. The mine formerly was known as the Replogle or Dell mine.

PRODUCTION

Scrub Oaks mine yielded through 1950 a total of 3,713,932 long tons of shipping ore to rank as the fourth largest iron-producing mine in the Dover district. Since 1939 the production has averaged more than 200,000 tons annually, to exceed that of any other mine in the State. All the ore is beneficiated to a high-grade concentrate of Bessemer grade that averages about 67 percent Fe. The ratio of concentration for the ore hoisted in 1950 was 2.91:1. The production of crude ore hoisted and fine concentrate is given in table 16.

TABLE 16.—*Iron-ore production, in net long tons, from Scrub Oaks mine to December 31, 1950*

[Published by permission of Alan Wood Steel Co.]

Year	*Crude ore*	*Concentrates*
1856–1905	----------	[1] 58, 500
1905–17	(2)	----------
1918 [3]	8, 653	5, 860
1919 [3]	69, 198	22, 407
1920 [3]	176, 096	55, 539
1921 [3]	----------	2, 522
1922 [3]	2, 345	22, 437
1923–29 [4]	(2)	----------
1930	30, 541	13, 596
1931	127, 703	60, 635
1932–33	(2)	----------
1934	203, 647	94, 418
1935	193, 811	81, 020
1936	431, 725	162, 095
1937	670, 059	264, 304
1938	112, 519	42, 649
1939	780, 712	274, 945
1940	903, 418	328, 147
1941	894, 608	336, 405
1942	921, 060	292, 973
1943	859, 366	272, 543
1944	673, 960	231, 552
1945	536, 195	192, 773
1946	449, 604	161, 878
1947	567, 488	188, 486
1948	542, 690	184, 028
1949	597, 031	206, 444
1950	629, 504	216, 276
Total	10, 481, 933	3, 713, 932

[1] Estimate by Bayley (1910, p. 365).
[2] Inactive.
[3] Data from Warren Foundry & Pipe Corp. (1918–22).
[4] Data from Alan Wood Steel Co. (1923–50).

HISTORY OF OWNERSHIP AND DEVELOPMENT

The Scrub Oaks property was opened in 1856 (Roche and Crockett, 1933a, p. 161). Between 1856 and 1868 a series of shafts were sunk on the deposit along a distance of 1,000 feet, and the ore body was worked in one place to a depth of 200 feet (Cook, 1868, p. 596); the ore was found to be too low in grade, however, for use in the furnace. Later the mine was reopened and worked a few months from a shallow pit and an adit, during which time 1,680 tons of ore was raised. Again in the summer of 1881 the mine was worked, and it yielded 820 tons. The mine was idle until 1899 when negotiations were begun for the erection of a concentrating plant, but these were unsuccessful. In 1905 it was decided to sink a new shaft in the hope of finding a large body of ore, but the shaft sinking soon was abandoned and the property remained idle until World War I.

The Wharton Steel Co., who had acquired the property in 1907, opened it in 1917 as a source of Bessemer ore for its furnaces at Wharton. They conducted a dip-needle survey of the surface followed by an extensive surface diamond-drilling program which disclosed a large deposit of medium-grade ore. After this discovery two inclined shafts (shafts 1 and 2) were sunk on the ore body and a mill was erected. In 1920, shaft 2 was deepened to level 2, and in the following year shaft 1 was sunk to the same level. The upper levels of the mine were worked until 1923, when the Wharton furnaces were closed.

Alan Wood Steel Co. acquired the Scrub Oaks property in 1929, and since that time the mine has been nearly continuously active except for a shutdown during 1932 and 1933. The ore is shipped to the Swedeland furnaces of Alan Wood Steel Co. (Roche and Crockett, 1933a, p. 161).

Shaft 1, the hoisting shaft, was sunk to level 3 in 1930, to level 4 in 1937, to level 5 in 1942, and to level 6 in 1947. In 1951 it was being deepened to level 8. According to W. P. Schenck (oral communication), some trouble with rock bursts was encountered during shaft sinking below level 7.

In 1949 mining was being done on levels 5 and 6; stopes were opened along most of level 5, and level 6 was being developed. (See fig. 33.) In 1951 mining was nearly completed on level 5 and was in progress on level 6. During 1950 and the early part of 1951, sublevel 6 was driven 1,635 feet southwest of shaft 1 to explore for a deposit that is southwest of the Scrub Oaks ore body and essentially in the same plane. Diamond-drill exploration from the sublevel indicated that the toprock of the deposit, named by Alan Wood Steel Co. as Scrub Oaks No. 2 ore body, is at the elevation of level 6, about 1,400 feet southwest of shaft 1.

MINE WORKINGS

The principal mine workings at Scrub Oaks mine are shown on figure 33. The plan map is simplified and shows only the main haulage levels and the principal manway raises and shafts; most sublevels as well as the stope outlines are omitted. The vertical longitudinal projection shows the approximate outlines of the stopes. The mine workings consist principally of an inclined shaft (No. 1 or Ross shaft) and 6 working levels 250 feet vertically apart. The shaft is a 4-compartment opening, inclined 55° SE., that is sunk in the country rock 100 feet in the footwall of the ore. The shaft is connected to the main haulage levels, in the footwall of the ore body, by crosscuts. Sublevels that are about 25 feet above the tramming levels, are driven along the footwall contact of the ore.

EXTRACTION AND CONCENTRATION OF ORE

The mining method in use at Scrub Oaks mine is shrinkage stoping, without timbering or filling (Roche and Crockett, 1933a). This method is ideal, as the wall rocks are strong and stand well. The stopes on the lower levels are about 300 feet long and are separated by 40-foot pillars that are removed after the stopes are completed. Manway raises are driven in the footwall from level to level in the center of each pillar.

Because of the presence of hematite in the ore, beneficiation requires a dual treatment. The ore is first passed over wet magnetic separators, to recover the magnetic portion, then is passed over gravity separation machines to recover the nonmagnetic ore. The concentrate is sintered at the furnace and is used in the blast furnace. The milling process has been described in detail by Roche and Crockett (1933b, p. 241–244).

The grade of the crude ore hoisted in the Scrub Oaks deposit ranges from about 26 to 33 percent Fe. The ore is beneficiated to a fine concentrate of Bessemer grade that has an average tenor of 67 percent Fe.

A new complete analysis of the ore is given in table 12. The high-silica content is attributed principally to quartz and albite. The titanium oxide is present largely as rutile (TiO_2); ilmenite was not observed in the ore. The phosphorus is derived from apatite, and the CO_2 from calcite.

GEOLOGY

The magnetite deposits at Scrub Oaks mine—the Scrub Oaks and the Scrub Oaks No. 2—are 1,500 feet northwest of the Corwin and Sterling magnetite deposits, which are within the zone that contains most of the large producing mines in the Wharton ore belt (pl. 1). The Scrub Oaks deposits are in the same mineralized zone as the Baker (at the base of the hill), Huff, and Dolan mines.

The bedrock is largely covered and in most places it is mantled by 40 feet or more of unconsolidated debris. The geology described in the following pages is, therefore, based largely upon a study of the mine workings and drill cores.

ROCKS

The principal rocks exposed in Scrub Oaks mine are albite-oligoclase granite and microantiperthite granite. The distribution of these rocks, where known, is shown in plate 10 and figures 34 and 35.

The albite-oligoclase granite, the principal host of the ore, constitutes a sheet that is about 175 feet thick; it is enclosed by a sheetlike body of microantiperthite granite whose total thickness is unknown. The albite-oligoclase granite is a red, green, or gray fine- to medium-grained leucocratic rock that is composed principally of albite-oligoclase and quartz. Throughout most of the mine the granite is gray in color. In places particularly where it contains several percent of magnetite, the granite is greenish. Adjacent to the ore bodies, the granite characteristically is red. The red color is due to tiny inclusions(?) of hematite in the albite that tend to occur along the (010) direction. Observations in the mine indicate that the red granite extends as much as 150 feet from the ore in the footwall, the average being near 50 feet, and about 20 feet in the hanging wall. The albite-oligoclase granite has a fair to good foliation formed by subparallel tabular feldspars. Amphibolite layers, blocks, and lenses that are essentially conformable with the foliation are present here and there. A lineation produced by quartz pencils is visible locally.

The contacts of the albite-oligoclase granite with the enclosing microantiperthite granite appear gradational,

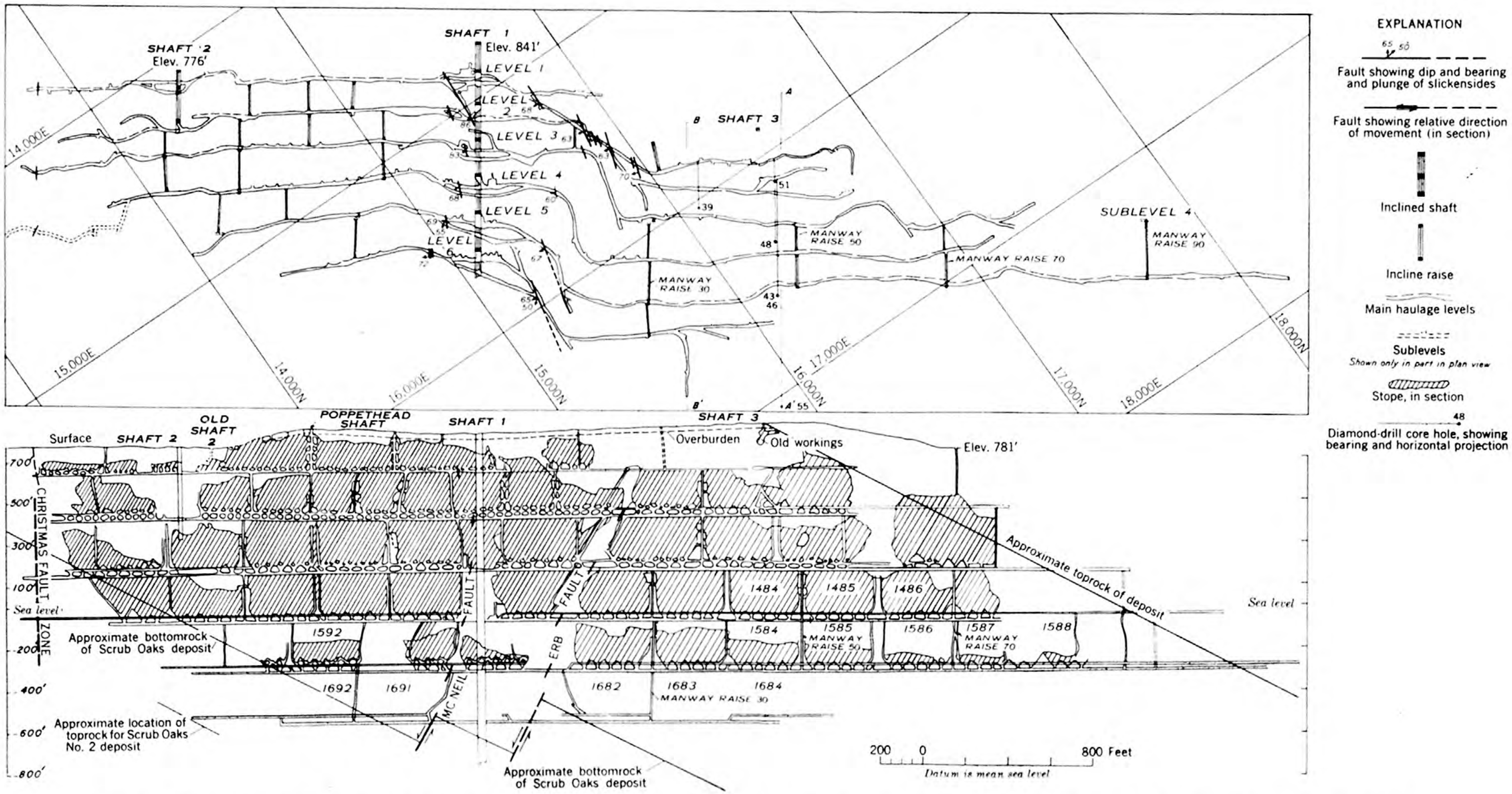


FIGURE 33.—Map and longitudinal projection of main workings at Scrub Oaks mine. Section X–X′ shown on figure 34; section Y–Y′ shown on figure 35. From Alan Wood Steel Co., 1949.

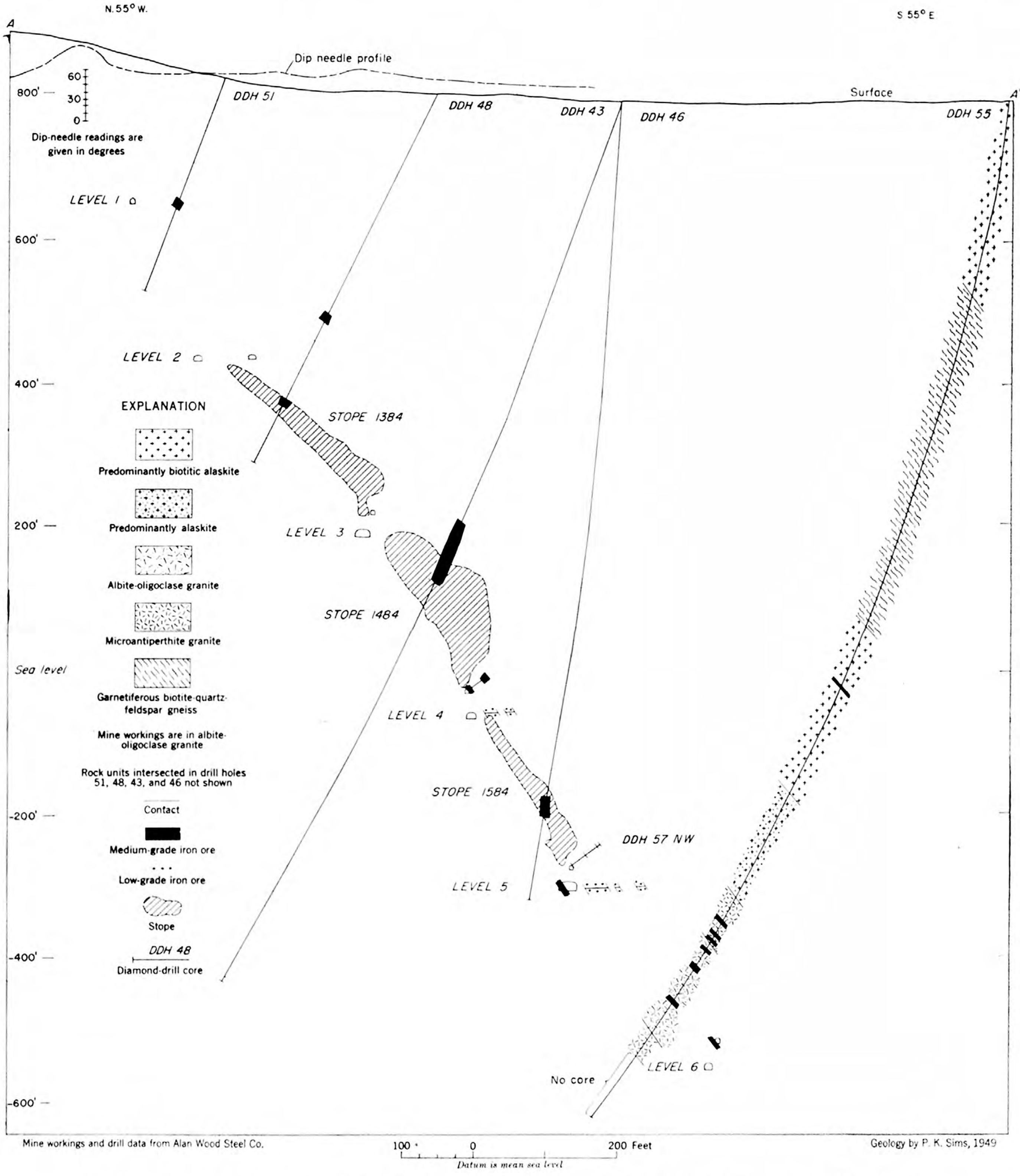


FIGURE 34.—Section through diamond-drill holes 55, 46, 43, 48, 51, and mine workings, Scrub Oaks mine. Line of section shown on figure 33.

and accordingly the contacts are not shown on all the mine illustrations. Generally, though, the contact can be recognized megascopically by a color change from the dominant red or gray of the albite-oligoclase granite to the dark greenish gray of the microantiperthite granite.

Pegmatite, whose composition ranges from granite to syenite, forms layers and streaks in the albite-oligoclase granite. Locally it constitutes bodies several feet wide. The pegmatite consists predominantly of albite and milky quartz, the proportions of which vary greatly, and these minerals give the rock a characteristic red and white streaked or blotchy appearance. In places, within the ore bodies, the pegmatite contains sufficient magnetite to constitute low-grade ore.

The microantiperthite granite is a greenish-gray to gray medium-grained rock that is composed principally of microantiperthite and quartz, with 5 percent or more of mafic minerals, principally clinopyroxene. Commonly the mafic minerals are partly altered to chlorite. In contrast to the albite-oligoclase granite, this granite has a well-developed foliation produced by a compositional layering and subparallel tabular minerals. In places the granite contains amphibolite layers and streaks a foot or more wide.

STRUCTURE

The foliation in the Scrub Oaks mine has an average strike of N. 33° E. and an average dip of 55° SE.; the lineation plunges about 28° N. 52° E. Throughout the mine the foliation is remarkably uniform and, so far as known, folds such as those observed in places in the other accessible mines are absent. The prevailing trend of the foliation is, however, locally interrupted by small rolls that are distinguished by a local change in strike to a more northerly direction and a flattening in the dip (pl. 10). Some of the rolls are sufficiently large to be reflected by conspicuous bends in the drifts. The rolls plunge essentially parallel to the lineation and, accordingly, they can be projected from level to level. An attempt has been made on figure 36 to plot the approximate axes of the prominent rolls that have been found in the northeast part of the mine.

The position of the Scrub Oaks mine in relation to folds of intermediate size is not known. It can be assumed, however, on the basis of the known structure in the Dover district, that the mine probably is situated on the limb of an isoclinal fold. This hypothesis, however, cannot be substantiated, as little is known of the structure in this part of the district.

Two post-ore transverse faults, the Erb and McNeil, offset the ore body and separate it into three minable segments. The vertical component of movement on the faults is only approximately known, and is estimated to be 270 feet for the Erb and 125 feet for the McNeil (fig. 33). Another transverse break, the Christmas fault, was encountered in mine workings at the southwest end of the mine, and no minable ore has been found south of it. The displacement of this fault is not known but probably is small.

MAGNETITE DEPOSITS

Two magnetite deposits—the Scrub Oaks and the Scrub Oaks No. 2—are known to be present in the Scrub Oaks mine. The Scrub Oaks ore body has yielded all the production to date. The Scrub Oaks No. 2 deposit was first encountered in 1950; the writer believes that this deposit correlates with the deposit that was mined at the Baker (at the base of the hill) mine.

The ore bodies are essentially comformable to the gneissic structure of the enclosing rocks—that is, their strike and dip are essentially parallel to the foliation and their plunge is nearly parallel to the plunge of the lineation.

The Scrub Oaks ore body for the most part is in albite-oligoclase granite, and its position within the granite sheet is moderately consistent. Throughout the mine the footwall contact of the ore body is 50 to 110 feet, generally about 60 feet, from the footwall contact of the albite-oligoclase granite with the microantiperthite granite; the hanging-wall contact of the ore on level 6 is about 40 feet from the hanging-wall contact of the albite-oligoclase granite with the microantiperthite granite (fig. 35; also Sims, 1953, pl. 28).

The Scrub Oaks ore body has an outcrop or stope length of about 5,500 feet. At the surface the bottomrock is 1,500 feet southwest of shaft 2 and the toprock is near shaft 3 (fig. 33). The breadth of the ore body is about 1,650 feet; the thickness ranges from slightly less than 10 feet to about 70 feet, the average being near 25 feet. The deposit, in broad outline, appears tabular. In detail, however, it is a poorly defined irregular body that consists of one or more layers or lenses of ore (ore shoots) separated by slightly mineralized rock (pl. 10 and fig. 36). Throughout most of the length of the deposit the ore constitutes a moderately well defined layer. In places, though, particularly near the toprock, the ore body is much less well defined and consists of several subparallel branching layers that may or may not be connected.

The generalized form of the Scrub Oaks deposit in the northeast part of the mine, on levels 3, 4, 5, and 6, is shown on figure 36. This composite map, which represents horizontal sections through the ore at the elevation of the main haulage drifts, was compiled from geologic maps of the main haulage levels and sublevels, from diamond-drill cores, and from stope profiles prepared by the company engineers. Data obtained from the sublevels and stope profiles were projected down the dip of the ore body to the main levels. The data from which this map was compiled were much more complete for levels 5 and 6; consequently, the pattern of the ore on these levels probably conforms reasonably well to the true shape of the ore body. A study of the ore on these levels indicates that some of the irregularities in the

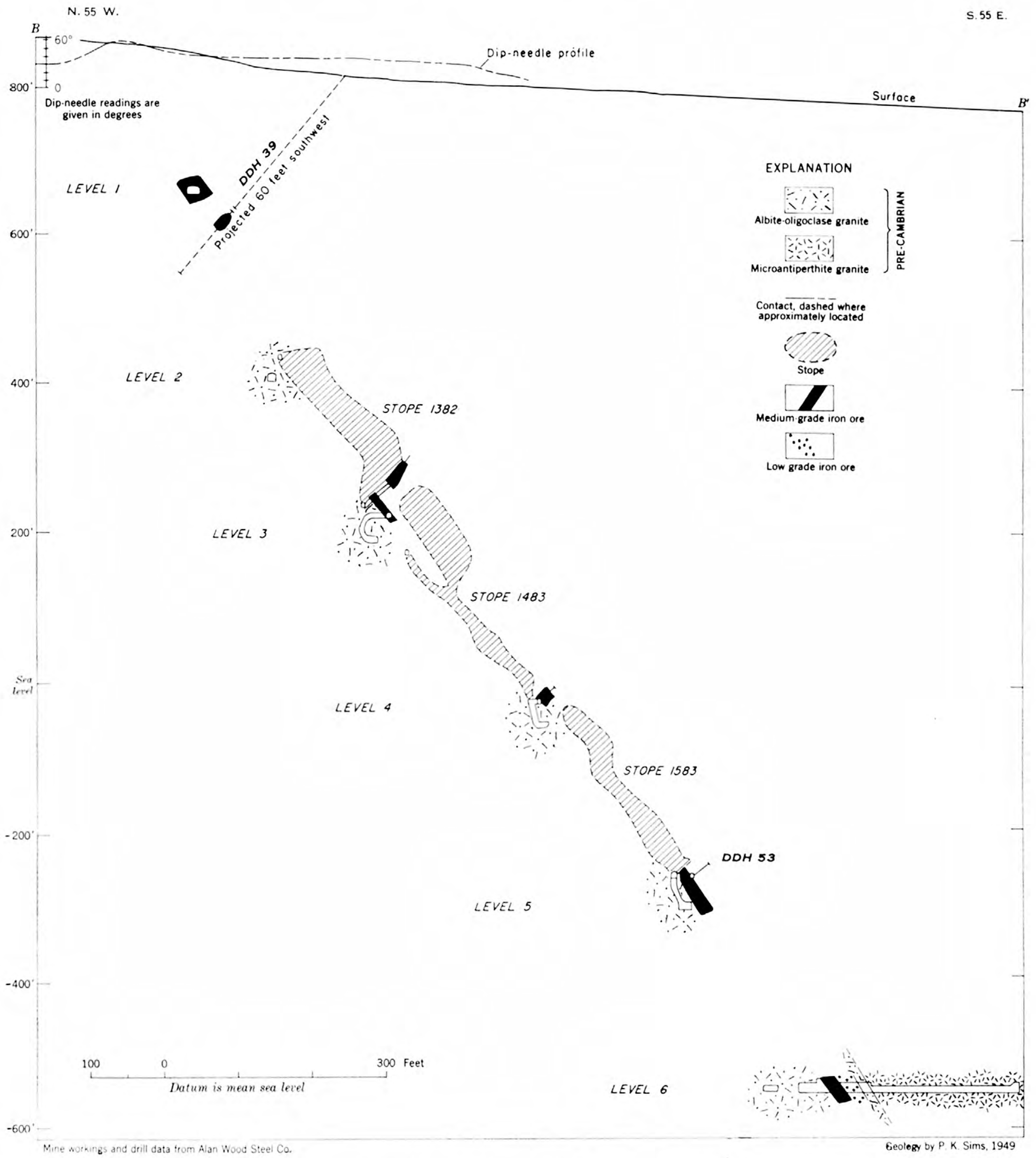


FIGURE 35.—Section through Scrub Oaks mine. Line of section Y–Y' shown on figure 33.

ore body are related to megascopic structures of the country rock, and that others probably are not. On level 6, it can be demonstrated that the wide part of the ore body shown northeast of the hanging-wall crosscut (fig. 36) reflects a flattening that occurs along the axis of a roll. Similar widths of ore, greater than normal, have been encountered on the levels above, and most, if not all, of these also can be related to rolls. A plot of the approximate axes of these rolls indicates that they plunge northeast nearly parallel to the linear

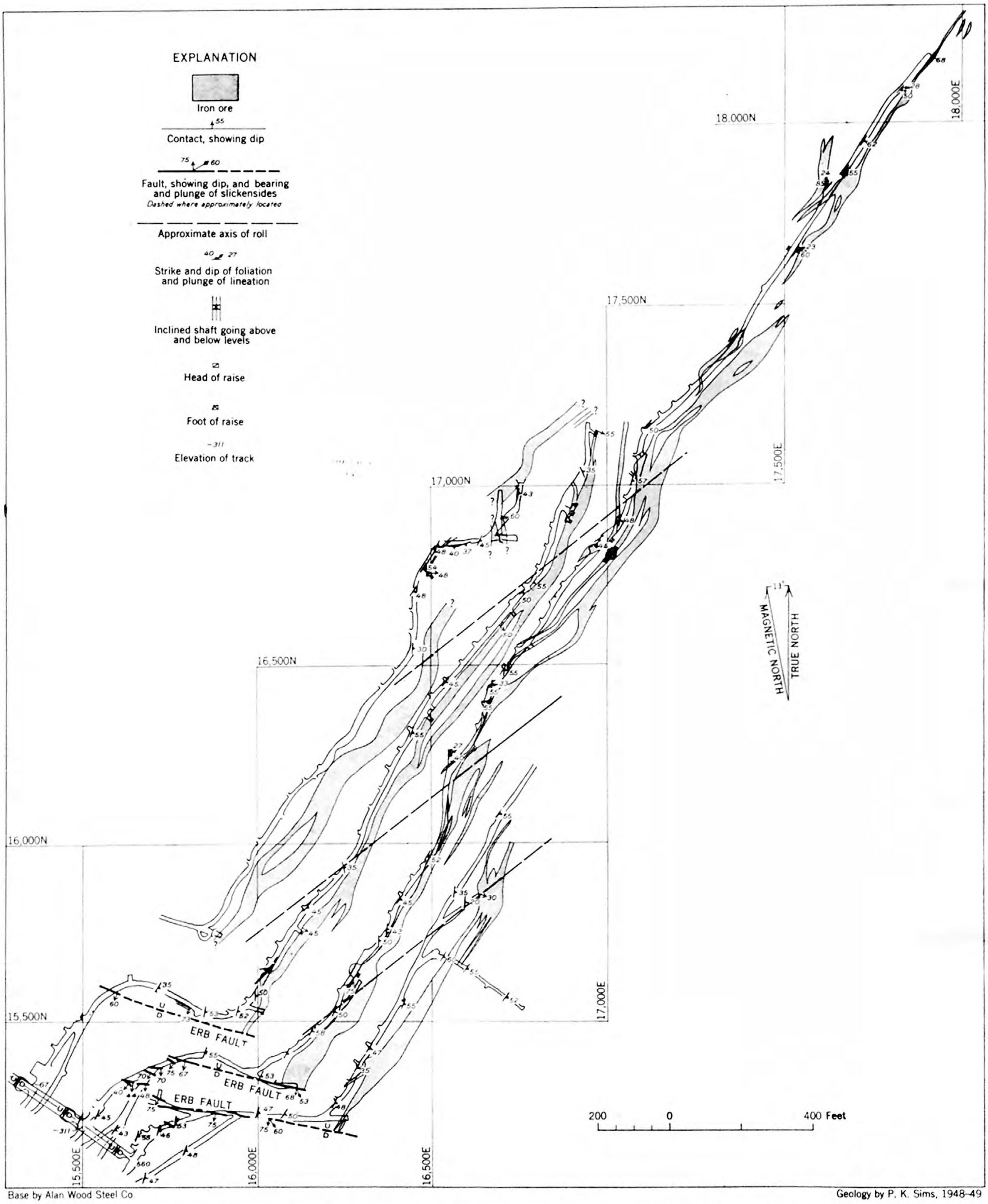


FIGURE 36.—Composite map showing northeast part of Scrub Oaks ore body on levels 3, 4, 5, and 6, Scrub Oaks mine.

structure in the wall rocks. Furthermore, it is evident that these structures can be projected from level to level, hence it is possible to anticipate their approximate position on each succeeding lower level. It is probable also that many of the other major irregularities in the ore body reflect gneissic structures in the host rock, as for example, the split in the ore body that occurs on levels 3, 4, and 5, between the second and third roll axes (fig. 36). This split, to judge from its position on each succeeding level, also roughly parallels the plunge of the roll axes. Many of the minor irregularities, however, such as the isolated lenses and the pinches, cannot clearly be related to known structures in the host rock and need further study.

The contacts between the individual ore shoots and the country rock are relatively sharp. The limits of the stope walls, however, because of the irregularities in the ore body, are not sharply defined; they are determined at places by assays and core drilling.

The bottomrock and toprock of the Scrub Oaks deposit also are not sharply defined, as they are in the massive ore bodies in the district; instead, they are marked by a decrease in grade below the economic mining limit and by splitting and pinching. The character of the ore body at the toprock of the deposit is shown on level 5 (pl. 10 and fig. 36). Near manway raise 90 the deposit pinches; northeast of the pinch it consists of several irregular branching lenses of ore, the largest of which, about 300 feet northeast of the manway raise (pl. 10) pinches abruptly to a narrow layer. There is also in this part of the deposit a marked diminution in grade of the ore below the present economic limit of mining. The character of the bottomrock of the deposit is shown on level 6 (Sims, 1953, pl. 28). The bottomrock (see fig. 33) of the deposit, in contrast to the toprock, is not marked by an abrupt pinch, together with splitting; instead, it is characterized principally by a marked decrease in grade. Southwest of the bottomrock the deposit has an average grade of only 7 to 15 percent Fe. Northeast of the Erb fault (fig. 33) the bottomrock was found in the southwest end of stope 1682. Drilling from the hanging-wall crosscut on level 6 substantiates this conclusion, for it failed to intersect ore-grade material vertically beneath the stope at the elevation of level 7. The drilling, however, did disclose a good thickness of ore northeast of the crosscut at the elevation of level 7.

The Scrub Oaks No. 2 deposit, where encountered on level 6, is about 850 feet southwest of the Scrub Oaks ore body and essentially in the same plane. The approximate position of the toprock of the deposit is shown on figure 33. The drill cores indicate that the deposit has a stope length of more than 400 feet and an average thickness of between 10 and 20 feet. Splits in the deposit, probably similar to those in the Scrub Oaks deposit, seem to be present.

The ore shoots in the deposits are in granulated and partly recrystallized zones in the albite-oligoclase granite that resulted from microbrecciation produced by cataclastic deformation. Granulation apparently was most intense along the roll axes, and as a result the ore here is slightly thickened. It is probable that some of the irregularities of the deposit that cannot be related to known megascopic structures are due to microbrecciation.

The ore in both the Scrub Oaks and the Scrub Oaks No. 2 deposits is principally in albite-oligoclase granite; locally it is in microantiperthite granite. The ore minerals—magnetite and hematite—are dispersed through the host rock quite irregularly and constitute disseminated ores. For the most part they occur as aggregates and veinlets; in places they form massive layers and streaks of medium-grade ore a few inches to a few feet thick. The ore consists principally of magnetite. Hematite constitutes about 15 percent of the ore; martite (hematite pseudomorphous after magnetite) probably forms a percent or two of the ore.

The ore typically is hard and siliceous, and it consists of fine to coarse granular magnetite with generally small but variable quantities of hematite. The relatively nonmagnetic ore generally is more massive and more coarsely granular than the typical ore. It can be distinguished megascopically from the magnetite ore by its steel-gray color, its reddish streak when powdered, and its slight magnetic attraction.

The nonmagnetic ore at Scrub Oaks mine has been referred to as martite, but there is little foundation for this statement. Martite occurs locally in the Scrub Oaks deposit, but it is thought to be quantitatively unimportant, probably constituting only a percent or two of the ore. It consists of aggregates of hematite that replace parts of individual grains of magnetite. Complete replacement of magnetite by martite was not observed in any of the specimens examined. Polished sections of the ore disclose that the magnetite is homogeneous; it contains no exsolved constituents.

Examination of available assay data, and of the mine workings, indicates that the hematite in the Scrub Oaks ore body is most abundant in stopes 1586 and 1587, where it probably forms more than 30 percent of the total soluble iron (pl. 10 and fig. 33). Abundant hematite was observed also on level 4, at the head of manway raise 70, and on level 5 below stope 1587. This hematite-rich ore shoot seems to be closely related to the axis of a prominent roll (fig. 36). Hematite occurs in two forms. Most of it forms distinct coarse granules that exhibit marked twinning. In part, though, it is found to be molded around magnetite and to form irregular narrow veinlets that embay and replace magnetite.

The gangue minerals, which constitute an integral part of the ore, are chiefly unreplaced remnants of the host rock—albite-oligoclase and quartz. Several other minerals are present, however, that are not found in the barren country rock. These were introduced by the ore-forming solutions and, with the exception of apatite, are later than the magnetite. They are, in approximate paragenetic order, apatite, rutile, tourmaline, calcite, muscovite, and pumpellyite.

CORWIN MINE (34)

The Corwin mine, in Mine Hill Township, is on the east slope of the hill west of Springs Brook and is 1,300 feet southeast of Scrub Oaks mine. Production from the mine is estimated at 150,000 tons. The Erb fault separates the Corwin mine from the Sterling mine (pl. 9).

The mine was worked extensively before 1868, and in that year the ore was removed from a deposit 3 to 10 feet thick along a distance of 1,700 feet and to a depth of 200 feet. The ore body dipped 45° SE. and raked 5° to 6° NE. (Bayley, 1910, p. 367). The deposit is offset by the McNeil fault, which separates it into the northeast and the southwest group of workings; the northeast workings are displaced about 80 feet to the right (pl. 9).

The host rock is oligoclase-quartz-biotite gneiss. To judge from the material on the dumps, the deposit consists of narrow layers of massive magnetite interleaved with gneiss containing disseminated magnetite. The ore that was mined was finely granular and crumbly "shot ore" and contained small granules of apatite and pyrite. The wall rock was biotite schist or schistose amphibolite (Cook, 1868, p. 575–576), and it contained some disseminated magnetite. An analysis of the ore gave 61.4 percent Fe (Cook, 1868, p. 576).

JACKSON HILL MINE (35)

The Jackson Hill mine is in Mine Hill Township, northeast of the Randall Hill mine and 1,800 feet southeast of the Corwin mine. The mine worked the northern part of the ore body mined in the Randall Hill mine. The mine workings are described briefly by Bayley (1910, p. 386–387). The geology of the deposit is described under the Randall Hill mine (36).

RANDALL HILL MINE (36)

The Randall Hill mine is in Mine Hill Township, on the west slope of the hill between Springs Brook and Highway 6 (pl. 1). The deposit lies east of, and trends nearly parallel to, the Irondale road. The mine is on the southeast part of the deposit on which the Jackson Hill deposit is situated, probably on a separate ore shoot. The mine was opened prior to 1855 and was worked intermittently until 1882, when it was abandoned because it had reached a depth whereby it was no longer possible to raise the ore profitably. The mine workings are described briefly by Bayley (1910, p. 385–386).

The deposit on which the Randall Hill and Jackson Hill mines are situated has a length of 2,200 feet. It trends N. 40° E. and dips 45° SE. It terminates at the northeast end against the McNeil fault and at the southwest end against the Christmas fault. Several parallel transverse faults of small displacement are reported to offset the ore in the Randall Hill mine (Bayley, 1910, p. 386).

The deposit was reported to be generally narrow; locally in the Randall Hill mine it consisted of three parallel veins the largest of which was 2 to 8 feet thick.

The host rock is microantiperthite granite. The magnetite forms inch-thin layers that conform to the gneissic structure and small grains that are sparsely disseminated through the rock layers separating the magnetite laminae.

PROSPECT (37)

This prospect in Mine Hill Township, is on M. I. T. Hill, on the west side of the road from Highway 6 to Scrub Oaks mine. The prospect is situated on a small deposit that trends N. 40° E. The workings consist of several shallow pits that have tested the vein along a distance of about 600 feet. A small exposure of pyroxenic microantiperthite granite lies northwest of the opencuts. The foliation of the granite strikes N. 40° E. and dips 55° SE. To judge from the material on the dumps the magnetite occurs as irregularly shaped inch-thin veinlets that replace microantiperthite granite. The wall rocks are not exposed. A reconnaissance dip-needle survey indicates that the deposit is too small to be of commercial importance.

BAKER MINE—AT BASE OF HILL (38)

The Baker mine (at the base of the hill) is the northwest Baker mine of the report by Cook (1868). The mine is in Mine Hill Township, on the west slope of the hill east of Kenvil, nearly 1 mile south-southwest of Scrub Oaks mine.

The mine is on a small shoot that lies southwest of, and in the same ore zone as, the Scrub Oaks deposit. To judge from the surface workings and a reconnaissance dip-needle survey, the shoot has a length of about 400 feet. The deposit is reported to be 7 to 8 feet wide at its southwest end and 4 feet at its northeast end. The tenor of the ore ranges between 35 and 40 percent Fe. The phosphorus content is low and the ore is reported to be of Bessemer grade. A sample taken from the ore cars in 1880 gave 32.02 percent Fe and 0.033 percent P (Pumpelly, 1886, p. 169).

According to Bayley (1910, p. 364) the average production during its prosperous years was about 14,500 tons. The total production probably did not exceed 150,000 tons.

Wharton Steel Co. drilled two diamond-drill holes (Nos. 15 and 16) that were collared about 50 feet north of State Highway 6 (pl. 1) to test for a northeast extension of the Baker deposit. Hole 15 penetrated 6 feet of low-grade ore averaging 26.7 percent Fe at a depth of 137 feet; hole 16 cut 7 feet of subore at 170 feet and 5 feet at 240 feet.

BAKER NO. 1 MINE (39)

Baker No. 1 mine is 1,200 feet east of the Baker mine (at the base of the hill), in Mine Hill Township. The workings are on both sides of Highway 6 (pl. 1). The original openings were on the north side of Highway 6, and the openings on the south side of the road were worked in the late 1880's (Bayley, 1910, p. 364). The approximate limits of the mine workings are shown in figure 37. The deposit trends N. 30° E. and dips 60° SE. The ore body on the north side of the road averaged 9 feet in width; the range is between 2 feet and 20 feet. On the south side of the road the deposit was 6 feet wide.

The host rock is oligoclase-quartz-pyroxene gneiss; the wall rock is microantiperthite granite. The magnetite occurs as massive streaks and layers from a fraction of an inch to about 1 foot in thickness that are interlaminated with essentially barren rock. The thicker layers of massive magnetite contain several percent of apatite that form rudely accordant laminae.

South of shaft 3 there are two series of surface cuts that trend parallel to the Baker No. 1 vein (pl. 1). The relation of these openings to the deposit mined from shafts 2 and 3 is not clear. They may represent either faulted segments of the Baker No. 1 ore body or two separate deposits.

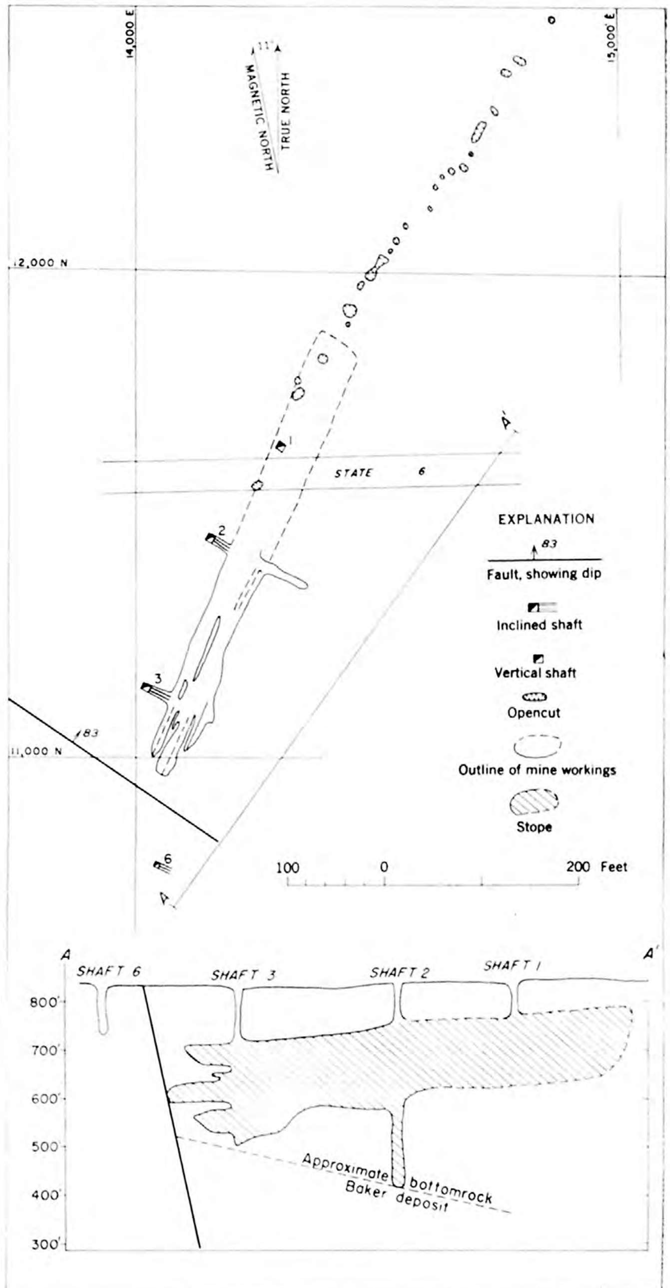


FIGURE 37.—Map and vertical longitudinal projection of workings at Baker No. 1 mine.

CANFIELD MINE (42)

The Canfield mine is in Mine Hill Township, on the east slope of the hill west of Canfield Avenue, 1,500 feet north of the Dickerson mine. The mine property, about 119 acres, is owned by Rutgers University. The mine was opened in 1870 by the Dickerson estate. In 1873, 6,000 tons of ore was produced from two deposits (Bayley, 1910, p. 363), but it was abandoned soon afterwards. In 1942 a magnetometer survey of the property was made by Keller (Keller, Fred, 1942, unpublished report in files of Rutgers University).

Two deposits about 200 feet apart were worked. The deposits trend northeastward, but on the basis of geophysical data they are inferred to connect to the southwest. The northwest deposit was opened by an inclined shaft from which considerable drifting was done. The southeast deposit was worked to shallow depths along a length of about 300 feet. The southeast deposit ranges from about 5 feet to 20 feet wide and consists of massive magnetite layers interleaved with country rock. The northwest deposit is 4 to 6 feet wide where mined and dips 40° SE. (Bayley, 1910, p. 363). The deposit consists principally of disseminated magnetite accompanied by narrow massive layers that replace red medium-grained granite whose feldspar is principally vein perthite. Quartz is abundant in some layers and scarce in others. The ore appears to be entirely low in grade; the P content is probably small. The magnetic survey indicates the presence of several other deposits on the property, but all appear to be small.

SPRING MINE

[Not located]

The Spring mine is said to be east of the Corwin mine in the valley of Springs Brooks (Bayley, 1910, p. 387), in Mine Hill Township. This mine probably worked the southeastern one of the three parallel veins west of Springs Brook (pl. 1), but since its location is not definitely known it is not shown on plate 1.

SULLIVAN MINE

[Not located]

The Sullivan mine was another of the Irondale group of mines (Bayley, 1910, p. 367) between the Erb and Spring mines. It was not located during this survey, but it may have worked the middle one of the three "veins" mentioned under Spring mine.

ERB MINE

[Not located]

The Erb mine worked that part of the Scrub Oaks ore body on the north side of the Erb fault. This part of the deposit is now being mined underground in Scrub Oaks mine.

DICKERSON MINE (45)

The Dickerson mine is in Mine Hill Township, near Canfield Avenue, about one mile south of State Highway 6. The mine is one of the oldest in the district. It was opened in 1713 and was worked intermittently until it was closed in 1890. A detailed history of the mine was written by F. A. Canfield (Bayley, 1910, p. 359–360). Production is estimated to be 1,016,000 tons; the largest output for any year was 48,000 tons.

The mine workings consist of two large opencuts, two shafts—the Singer (46) and the Dickerson (45)—and extensive underground openings. The mine workings are shown in figure 38. The mine workings have been described in numerous annual reports of the State Geologist, and are summarized by Bayley (1910, p. 359–361). Maps of the mine workings have not been published, though, and the descriptions are not entirely clear.

During the early development of the mine the two principal ore bodies—the Big Mine and the Cow Belly—were worked as separate mines. The Big Mine was worked from an inclined shaft 1,100 feet long that descended in a northeastly direction at an angle ranging from 48° to 38°. The vertical depth of the slope is about 700 feet. The Cow Belly deposit also was worked from a slope that was nearly as deep as the Big Mine slope. The two mine workings were connected by a horizontal drift. A minor deposit, the Side vein, was worked from the Big Mine workings. The drifts on the Side deposit trend generally northwestward and southeastward above a depth of 120 feet; at a depth of 120 feet they apparently trend northeastward (Cook, 1883, p. 100). In 1883 a vertical shaft—the Dickerson—was sunk because of the difficulty of raising the ore up the long slope in the Big Mine. The Dickerson shaft encountered the Side vein at a depth of 550 feet and the Big Mine deposit at 750 feet.

The geology of the mine is little known. To judge from the exposures along the walls of the opencuts the country rock is predominantly alaskite that contains local irregular masses of granite pegmatite and thin layers of biotitic amphibolite. The wall rocks at the northeast end of the opencut on the Big Mine deposit strike N. 40° to 55° E., dip 30° to 50° SE., and plunge 25° NE. (See fig. 38.) The structure at the southwest end of the opencut is obscure, possibly because of folding. The rocks at the southwest end of the open pit on the Cow Belly deposit strike N. 70° E., dip 60° SE. and plunge 25° NE.

A few transverse faults were reported in the mine (Bayley, 1910, p. 360). The largest known fault is shown on figure 38. This fault strikes about N. 70° W., dips steeply southwestward, and is reported to offset the ore bodies 35 feet to the east. The vertical displacement on the fault is not known.

Three ore bodies were mined at Dickerson mine: the Cow Belly, the Big Mine, and the Side. The Cow Belly was worked at the surface in the southwest pit shown on figure 38; the Big Mine was worked in the northeast pit. The Side vein lies in the hanging wall of the Big Mine ore body; it was not mined at the surface, but was found at a depth of about 250 feet (Bayley, 1910, p. 360). The Cow Belly deposit at the surface strikes about N. 70° E. and dips about 60° SE. The surface length of the deposit is not known but is estimated to be less than 200 feet. Near the bottom of the mine it merged with the Big Mine deposit. The Big Mine deposit strikes about N. 45° E. at the surface. It was reported to dip 55° to 60° SE. and to plunge about 45° NE. (Cook, 1883, p. 101). Toward the bottom of the mine the deposit had a stope length of 225 feet and a width of 18 feet; at the bottom of the shaft the deposit had a stope length of 400 feet. The increase in stope length resulted from the merging of the Cow Belly deposit with the Big Mine deposit (Bayley, 1910, p. 361).

The ore from all the deposits was reported to be "shot ore". The Side vein was highest in grade, as it was not mixed with rock; the Cow Belly deposit was

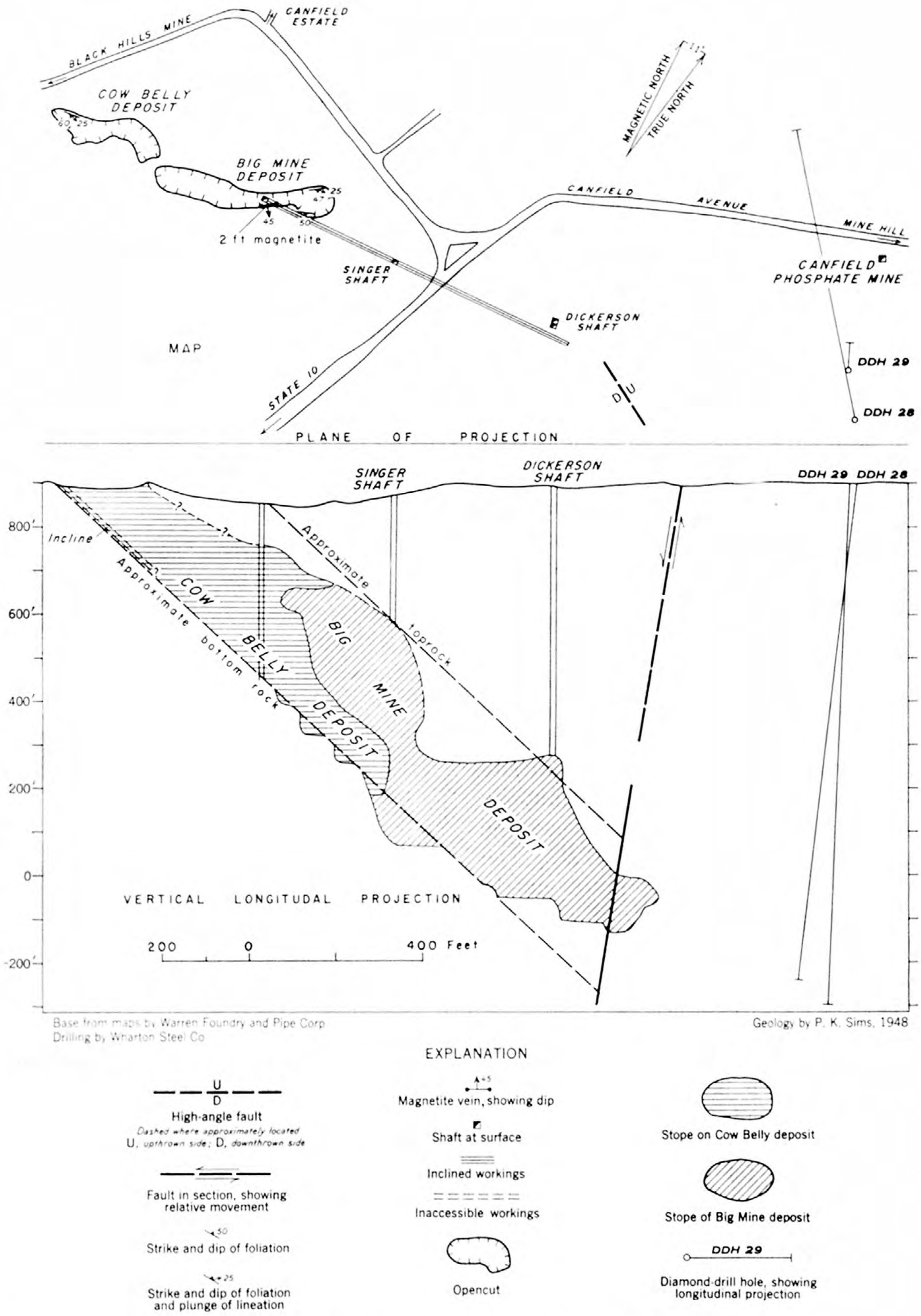


FIGURE 38.—Map and vertical longitudinal projection of Dickerson mine.

lowest in grade and generally high in P, in places containing as much as 2 percent P.

Analyses of ore from the Big Mine and Side deposits are as follows:

Analyses of iron ore from the Dickerson mine

[Analysis from Pumpelly (1886, p. 169)]

	Fe	P
1	61. 62	1. 186
2	65. 17	. 282
3	63. 63	. 178

1. Sample from sink in Main vein.
2. Sample from near bottom of Main vein.
3. Sample from Side vein.

CANFIELD'S PHOSPHATE SHAFT (47)

Canfield's phosphate shaft is one-fourth mile northeast of the Dickerson mine, on the east side of Canfield Avenue. The shaft is on a deposit that is unique to the district in that it contains about equal volumes of magnetite and apatite. The mine was opened in 1870 and was explored by two shafts. North of the main shaft (pl. 1) the deposit was reported to be offset by a transverse fault that displaced the ore body 35 feet to the left (Bayley, 1910, p. 381).

The deposit can be traced from the main shaft southwest nearly to the Singer shaft, a distance of about 1,000 feet. It trends N. 50° E., dips 65° SE, and is about 8 feet thick. The ore is a granular aggregate of magnetite and grayish apatite that forms alternating laminae parallel to the walls. Quartz, biotite, and xenotime constitute less than 5 percent of the ore (pl. 17*B*). The magnetite and apatite are present in approximately equal volumes. An analysis of average ore (Bayley, 1910, p. 381) gave:

SiO_2 and insolubles	11. 30	BaO	. 07
Magnetite	54. 01	P_2O_5	14. 91
CaO	17. 21		
MgO	1. 65	Total	99. 15

According to Bayley (1910, p. 381) experiments have been made in the separation of the apatite from the magnetite by the use of sulfuric acid in the hope that a method might be discovered for the production of a phosphate sufficiently cheap to make the ore a valuable source of commercial fertilizer, but the method has not been proved successful on a commercial scale.

BLACK HILLS MINE (48)

The Black Hills mine, in Mine Hill Township, is on the west slope and near the crest of the hill west of Canfield Avenue. It is 1,300 feet southwest of the Dickerson mine. The mine is owned by Warren Foundry and Pipe Corp. Production from the mine is estimated to be 4,000 tons.

The first openings were made in 1879, and the mine was worked intermittently until 1883. In 1880, the production was 2,195 tons of ore. In 1890 F. A. Canfield pumped out two shafts and examined the deposit, but shortly afterward abandoned the openings. In 1900 about 500 tons of ore was raised. In 1942 two diamond-drill holes (holes M9 and M10) were cored by Warren Foundry and Pipe Corp. to test the property, but none of the holes intersected ore. The mine workings consist of four small shafts, two opencuts—90 feet and 70 feet in length—and several small pits. The principal workings are shown in figure 39. Four deposits of similar character were opened, the largest of which (the Southeast) was worked along a length of 450 feet and to a depth of 100 feet. The deposits are nearly parallel and trend about N. 55° E. and dip about 80° SE.

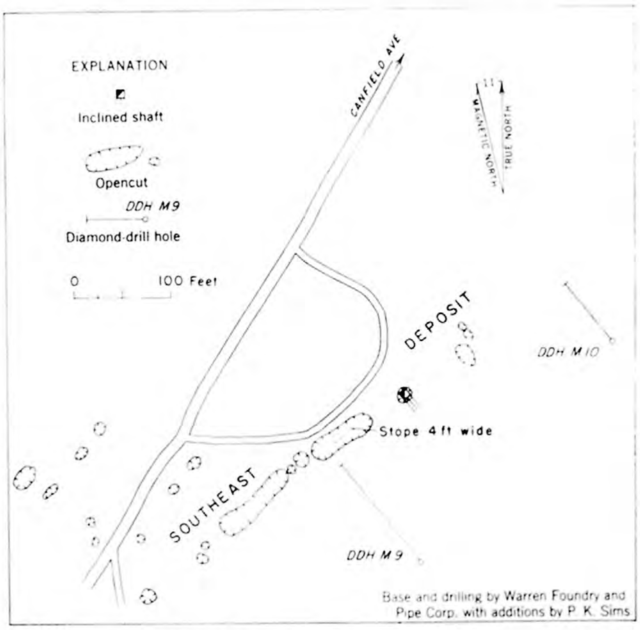


FIGURE 39.—Map of Black Hills mine.

The deposits are in albite-oligoclase granite gneiss; the magnetite occurs as disseminated grains and as irregular veinlets. Contacts with the albite-oligoclase granite gneiss wall rocks are gradational. The grade of the best ore mined was 45 percent Fe (Bayley, 1910, p. 358); most of it has a tenor ranging from 15 to 30 percent Fe. The ore contains several percent of quartz and albite as gangue minerals, but it is low in P, and hence suitable for the manufacture of Bessemer metal.

MILLEN MINE (49)

The Millen mine is in Mine Hill Township, 500 feet south of State Highway 6. The Byram mine adjoins it on the southwest. The mine was abandoned in 1883. The workings are now destroyed, and the reader, therefore, is referred to Bayley (1910, p. 384) for a description of the mine. Production from the mine is estimated at about 50,000 tons.

SOUTHEAST BAKER MINE
[Not located]

The Southeast Baker mine, said to be northeast of the Byram mine and southeast of the Millen mine (Bayley, 1910, p. 384) was not located.

BYRAM MINE (41)

The Byram mine, formerly one of the large producers in the State, is in Mine Hill Township, east of Canfield Avenue and 1,500 feet south of Highway 6. The mine workings are extensive (Bayley, 1910, p. 382) and reach to depths of 1,100 feet measured on the dip of 60°. The mine was abandoned in 1883 and is now entirely inaccessible. The total production is estimated to be about 600,000 tons. About 1855 the mine was yielding near 30,000 tons per year, and between 1870 and 1883 the total shipments of iron ore was 157,376 tons.

The surface openings indicate that the main ore body has an outcrop length of about 1,000 feet. The deposit trends N. 40° E., dips 50° SE., and was reported to be 3 to 8 feet thick (Bayley, 1910, p. 383). Two other deposits were explored to the northwest of the main vein, and a shaft was sunk on the deposit that is about 80 feet from the main vein (pl. 1). The deposit was intersected by at least 6 transverse faults, the displacements of which ranged from 1.5 feet to 14 feet. In all the faults the displacement was to the left.

To judge from the material on the dumps, the deposits consist of massive granular and crumbly magnetite ("shot ore") that replaces oligoclase-quartz-biotite gneiss. The magnetite forms layers an inch to several feet in width that are parallel to the gneissic structure in the country rock. The massive ore is in part block and contains abundant apatite that occurs both as scattered granules and as laminae. Analysis of cobbed ore indicate that the grade of the ore ranges from 28 to 40 percent Fe. Selected ore samples show an Fe content of 57 to 59 percent and a P content of from 0.245 to 2.11 percent (Pumpelly, 1886, p. 168; Bayley, 1910, p. 384).

BROTHERTON MINE (43)

The Brotherton mine is in Mine Hill Township, south of the road between Mine Hill and Mount Fern (pl. 1). It is southwest of the Byram mine. The mine was opened before 1855 and was abandoned in 1901 (Bayley, 1910, p. 380). It worked a deposit that was 2 to 5 feet wide for a length of 600 feet and to a depth of 200 feet. Examination of the surface pits and small dumps indicates that the deposit consists of massive magnetite layers and seams that are interleaved with country rock impregnated by disseminated magnetite. The host rock is mocroantiperthite-quartz gneiss, probably a facies of oligoclase-quartz-biotite gneiss. The deposit worked in the Brotherton mine is the northeastern part of that mined in the Evers mine, and there is a nearly unbroken series of small pits that may be followed from one mine to the other.

The ore was high grade. An analysis of cobbed ore ready for shipment in 1880 gave: 50.98 percent Fe; 0.214 percent P; and a trace of TiO_2 (Pumpelly, 1886, p. 167).

EVERS MINE (44)

The Evers mine is on the southern part of the deposit worked in the Brotherton mine. It is 250 feet east of the McFarland mine.

The deposit averaged only 1.5 feet in thickness but it was mined before 1868 for a length of 300 to 400 feet and to a depth of 230 feet. It was worked some after that date but was abandoned about 1880, for the vein was too thin to be profitably mined.

McFARLAND MINE (49)

The McFarland mine is in Mine Hill Township, on the east side of Canfield Avenue, 250 feet west of the Evers mine. The mine was merely an exploration (Bayley, 1910, p. 379) and it consists of several shallow pits. There are no exposures of the wall rocks or of the ore. Reconnaissance dip-needle data indicate, however, the presence of a belt of positive anomalies extending 600 feet northeast from Canfield Avenue; the maximum intensity of magnetic dip is about +70.

KING MINE (50)

The King mine is in Mine Hill Township, just east of Canfield Avenue. The mine is southwest of the McFarland mine, and on the same deposit (pl. 1). The mine was worked along a length of 600 feet and to a depth over 30 feet. Production was quite small. The deposit that was mined consisted of three layers of ore, separated by rock dipping 54° NE. (Bayley, 1910, p. 379). The upper layer was 4 feet thick, the middle 8 feet, and the lower a lean magnetite-bearing pegmatite of undetermined thickness. Dump specimens indicate that the host rock for the ore in the middle and upper layers is oligoclase-quartz gneiss. The magnetite forms narrow seams of massive block ore interlaminated with rock containing disseminated magnetite. The hanging-wall rock is a layered quartz-feldspar gneiss. The gneiss between the ore layers was described by Cook (1868, p. 566) as feldspar-quartz-mica gneiss and is probably oligoclase-quartz-biotite gneiss.

C. KING MINE (51)

The C. King mine is in Randolph Township, one-half mile southwest of the King mine, on the north side of State Highway 10. It is northeast of, and on the same deposit as, the Bryant mine. The deposit was 2 feet thick, and it was worked for a length of about 200 feet (Bayley, 1910, p. 378).

FAULON MINE

[Not located]

The Faulon mine (Bayley, 1910, p. 378) is southwest of the C. King mine, and on the same side of Highway 10. The workings consist of a few shallow pits; there are no exposures of bedrock or ore. Since the workings cannot be distinguished from those of the C. King mine, they are not shown on plate 1.

BRYANT MINE (52)

The Bryant mine is southwest of the C. King mine, in Randolph Township. The workings are between Highway 10 and the Succasunna-Mount Freedom road (pl. 1). The mine was opened prior to 1868 and in that year had been mined for a distance of 600 to 800 feet and to a depth of 100 feet (Cook, 1868, p. 566). It was in operation between 1876 and 1883 and was permanently abandoned in 1890. In 1883 there were five slopes on the vein, the longest of which was 735 feet.

The deposit is a tabular body 2 to 8 feet thick that dips about 60° SE. and plunges about 30° NE. The ore is massive magnetite that replaces plagioclase-quartz gneiss. The wall rock contains some disseminated magnetite. The deposit is reported to contain 5 shoots that range from 10 to 25 feet in height; the shoots are separated by pinches marked by narrow stringers of ore.

DALRYMPLE ORE BELT

[The numbers following the names of the prospects and mines in this belt refer to locations on plate 1]

The Dalrymple ore belt includes several mines in Randolph Township that extend from the village of Ironia northeastward for a distance of nearly 3 miles (pl. 1). The ore belt from northeast to southwest includes the following mines, now all abandoned: Trowbridge (55), Dalrymple (54), Lawrence (56), DeHart (57), David Horton (58), George (53), and Henderson (59). The belt constitutes the northeast end of a much larger ore zone, 10 miles in length, that extends southwestward beyond the limits of the Dover district, to a mile south of Hacklebarney (Bayley, 1910, see map). This ore zone includes most of the formerly important iron mines near Chester (Bayley, 1910, p. 425–442).

The mines in the Dalrymple ore belt were abandoned before 1890, and at present (1950) all the underground workings are inaccessible. The writer was able to examine many opencuts, caved stopes, and mine dumps, and the following discussions are based largely on these data, together with published material in Bayley (1910, p. 444–447).

The Dalrymple ore belt is 2½ miles long, trends about N. 50° E., and contains several southeast-dipping parallel deposits within a width of about 400 feet (pl. 1). The deposits mostly are short, but one deposit, the Dalrymple, has an outcrop length of four-fifths of a mile. All the deposits are thin, generally ranging from less than 1 foot to about 6 feet in thickness; pinches and swells within the individual deposits are rather common. The deposits typically consist of massive magnetite layers and seams, characteristically only a few inches thick, that are interlaminated with the host rock. The walls of the deposits generally are not sharply defined. To judge from the material at the mine dumps, the host rock for the ore is chiefly oligoclase-quartz-hornblende gneiss, probably a facies of oligoclase-quartz-biotite gneiss; locally, as at DeHart mine, the host rock is in part a coarse-grained pyroxene rock. The country rock is microantiperthite granite that contains local thin layers of amphibolite.

Production from the mines is estimated to be 228,000 tons of iron ore, 200,000 tons of which came from the Dalrymple mine.

TROWBRIDGE MINE (55)

The Trowbridge mine is immediately northeast of the Dalrymple mine and on the same deposit. The mine workings are now grown over with vegetation, but judging from the material on the dumps the deposit was narrow and low in grade. According to Bayley (1910, p. 447) the mine was closed shortly after 1868.

DALRYMPLE MINE (54)

The Dalrymple mine, formerly the Carbon mine, is about 2.5 miles northeast of Ironia. The mine worked the Dalrymple deposit, and is situated between the Trowbridge and Lawrence mines (pl. 1).

The mine was opened a few years before 1868 and was operated until 1876. In that year it was closed and the mine remained idle until 1879, when it was reopened and worked to 1882. In 1884 the machinery was removed and the mine was permanently abandoned, reportedly because of the great distance to the railroad (Bayley, 1910, p. 446).

The mine consists of two groups of openings about 500 feet apart. The northeast workings consisted of a large opencut and 2 shafts; the opencut is now filled with water (1948). According to Bayley (1910, p. 447) the deposit worked in the pit was 18 inches to 5 feet thick, it dipped 75° to 80° SE., and it was worked to a depth of 200 feet. The southwest opening was a shaft that probably was at least 200 feet deep.

The Dalrymple ore body strikes about N. 50° E. and dips 75° to 80° SE. It is reported to be from 18 inches to 18 feet thick where mined, but to judge from exposures in the present opencuts it averages less than 5 feet in thickness. Pinches in the ore apparently are due to a steepening of the hanging wall (Bayley, 1910, p. 447).

To judge from the material on the mine dumps, the magnetite forms thin layers and seams of magnetite that are interlaminated with the host rock, and less commonly disseminations. Analyses of the ore raised at different times are as follows (Bayley, 1910, p. 447):

	Fe	SiO_2	P	S	TiO_2
1	54.06	18.0	0.25	Tr.	
2	59.54		.366		Present.
3	55.92		.222		Present.
4	58.61		.296	0.026	

1. Sample of ore as shipped.
2. Sample from pile of 20 tons at the southwest shaft.
3. Sample from pile of a few tons at northeast pit.
4. Sample of ore shipped from dump to the Thomas Iron Co. in 1900.

LAWRENCE MINE (56)

The Lawrence, or Gordon, mine is immediately southwest of the Dalrymple mine and on the same deposit. The workings have been nearly completely destroyed, but according to Bayley (1910, p. 446) the mine workings consisted principally of 3 shafts, each of which was 110 feet deep. A caved opening on the south edge of the road probably represents the most southwesterly shaft of this group. The deposit where mined was reported to be 2.5 feet thick and to plunge southwest.

DeHART MINE (57)

The DeHart mine is on a deposit that is 200 feet southeast of and essentially parallel to the Dalrymple deposit. The mine was opened before 1868 and was worked intermittently until about 1887, when it was permanently abandoned. The extent and depth of the workings are not known, but evidently the workings do not extend much below 100 feet in depth. The southwestern part of the deposit is marked by several large opencuts and stopes.

The DeHart deposit trends N. 53° E. and dips 75° to 85° SE. It is reported to plunge northeast (Bayley, 1910, p. 445). The deposit, where mined, varied between 3 and 9 feet in thickness; open stopes along its outcrop are as much as 10 feet wide. According to Bayley (1910, p. 445) the ore at the surface was red, presumably hematitic, but below depths of a few feet in the northeast openings and below depths of 30 to 40 feet in the southwest openings the ore was magnetite. The magnetite (blue) ore contained abundant sulfides, and much of it was not suitable for shipment as lump ore. A sample of ore shipped in 1880 gave (Pumpelly, 1886, p. 167) 50.70 percent Fe, 0.633 percent P, and a trace of TiO_2.

To judge from mine dumps the magnetite forms inch-scale layers seldom greater than 6 inches thick that are interlaminated with thin seams of country rock. The host rock is principally oligoclase-quartz gneiss, but locally is pyroxene skarn. The wall rock is oligoclase-quartz gneiss in most places, but is amphibolite or granite pegmatite in other places.

DAVID HORTON MINE (58)

The David Horton mine is immediately southeast of the DeHart mine, on the south side of the Succasunna-Mount Freedom road (pl. 1). The mine was opened prior to 1868, and it was worked intermittently until 1873, when it was permanently abandoned. The extent of the mine workings is not known. Four shafts are reported, though, the deepest of which was 100 feet (Bayley, 1910, p. 445).

Five closely spaced parallel veins were worked, to judge from the present (1948) surface workings; the northwestern deposit was worked along a distance of about 1,200 feet. Evidently all the deposits were thin. The magnetite forms thin layers of massive ore that are interlaminated with oligoclase-quartz gneiss and locally irregular replacements of hornblende-pyroxene skarn.

GEORGE MINE (53)

The George (or Logan) mine, about three-fourths of a mile northeast of Ironia, consists of two groups of workings about 900 feet apart. The northwest group of openings consists of a few small pits on the west side of the small stream valley that is west of and nearly parallel to the Mount Fern-Ironia road. To judge from the material at the mine dumps the deposit is quite small, and the magnetite forms irregular seams and bunches in a layered plagioclase-quartz gneiss. The country rock consists of interlayed gneiss and amphibolite.

The southeast group of openings, now nearly destroyed, is on the west side of the Ironia-Mount Fern road. Three small deposits were worked from the time of their opening, prior to 1855, until 1873, when the mine was permanently abandoned (Bayley, 1910, p. 444). The deposit shown on plate 1 probably is not the principal one on the property.

HENDERSON MINE (59)

The Henderson mine is about 800 feet northeast of Bryants Pond, near Ironia. The mine was opened in 1868, was worked only for a short time, and was abandoned before 1873 (Bayley, 1910, p. 444). The mine openings are completely destroyed at present

(1948), and the writer was unable to determine the character of the deposit.

BEACH GLEN ORE BELT

[The numbers following the names of the prospects and mines in this belt refer to locations on plate 1.]

The Beach Glen ore belt consists of two mines—Beach Glen (62) and Swedes (60)—and a few small prospects, the largest of which is prospect 61. Both the Beach Glen and Swedes mines have shipped ore, but the total production is not known.

BEACH GLEN MINE (62)

The Beach Glen mine, at Beach Glen in Rockaway Township, is 2 miles northeast of Rockaway and 1 mile south of Hibernia. The property is now owned by the Warren Foundry and Pipe Corp.

PRODUCTION AND HISTORY

Kreutzberg (1921, p. 1207–1211) has estimated that the mine produced to 1920 an estimated 200,000 tons of iron ore, the bulk of which was of Bessemer grade, but this estimate probably is high. The writer estimates that about 50,000 tons of shipping ore was taken from the mine before 1920. About 7,000 tons of this ore was mined between 1900 and 1903 (Bayley, 1910, p. 470). Since that time the mine has yielded 117, 540 tons of crude ore and an aggregate of 81, 318 tons of lump ore and concentrates (table 17).

The Beach Glen mine probably was first operated in 1760, for a charcoal forge was built at Beach Glen in that year (Kreutzberg, 1921). It was not until 1808, though, that mining work was first recorded, when the surface was stripped and the ore was excavated to a depth of a few feet (Bayley, 1910, p. 469). The mine must have been abandoned shortly afterwards and it remained closed until 1851, when two openings were made. The mine was in operation in 1868 and continued to be worked until 1875. It was reopened in 1879 and ore was produced from two veins. Later, the operations were concentrated on the western (Main) vein, and this ore was worked until 1885. According to Bayley, (1910, p. 469) the ore was lean but of Bessemer grade. The closing of the mine in 1885 was necessitated by the influx into the market of an abundance of good Bessemer ore from the Lake Superior region. Shortly afterwards experiments in concentrating the Beach Glen ore were tried, and apparently were successful (Bayley, 1910, p. 470), but the capital needed to construct a mill was not raised and the mine was not reopened again until 1896. The property was leased to Joseph Wharton in 1898, and he operated it until November 1900 to obtain ore for concentration at Hibernia. In 1898, 900 tons of crude ore averaging 41 percent Fe was concentrated to yield 400 tons of 60 percent Fe that contained 0.009 percent phosphorus. The mine was abandoned in 1900, because it could not be worked as an open pit, but it was reopened in 1901, and a three-compartment shaft was sunk on the Main vein to a depth of 460 feet. About 7,000 tons of ore was removed before the mine was again closed in 1903.

TABLE 17.—*Iron-ore production, in long tons, from Beach Glen mine, 1921–30*

[Data on shipping ore published with permission of Warren Foundry and Pipe Corp. Shipping ore includes both lump and concentrate.]

Year	Crude ore	Grade Fe (percent)	Shipping ore (net tons)
Before 1920			[1] 50,000
1921	17,000	40	10, 200
1922	18, 876		4, 938
1923	34, 000		17, 000
1924–27	Inactive		
1928	Not known		16, 848
1929	59, 212		29, 606
1930	5, 452		2, 726
Total	117, 540		131, 318

[1] Estimate by Sims.

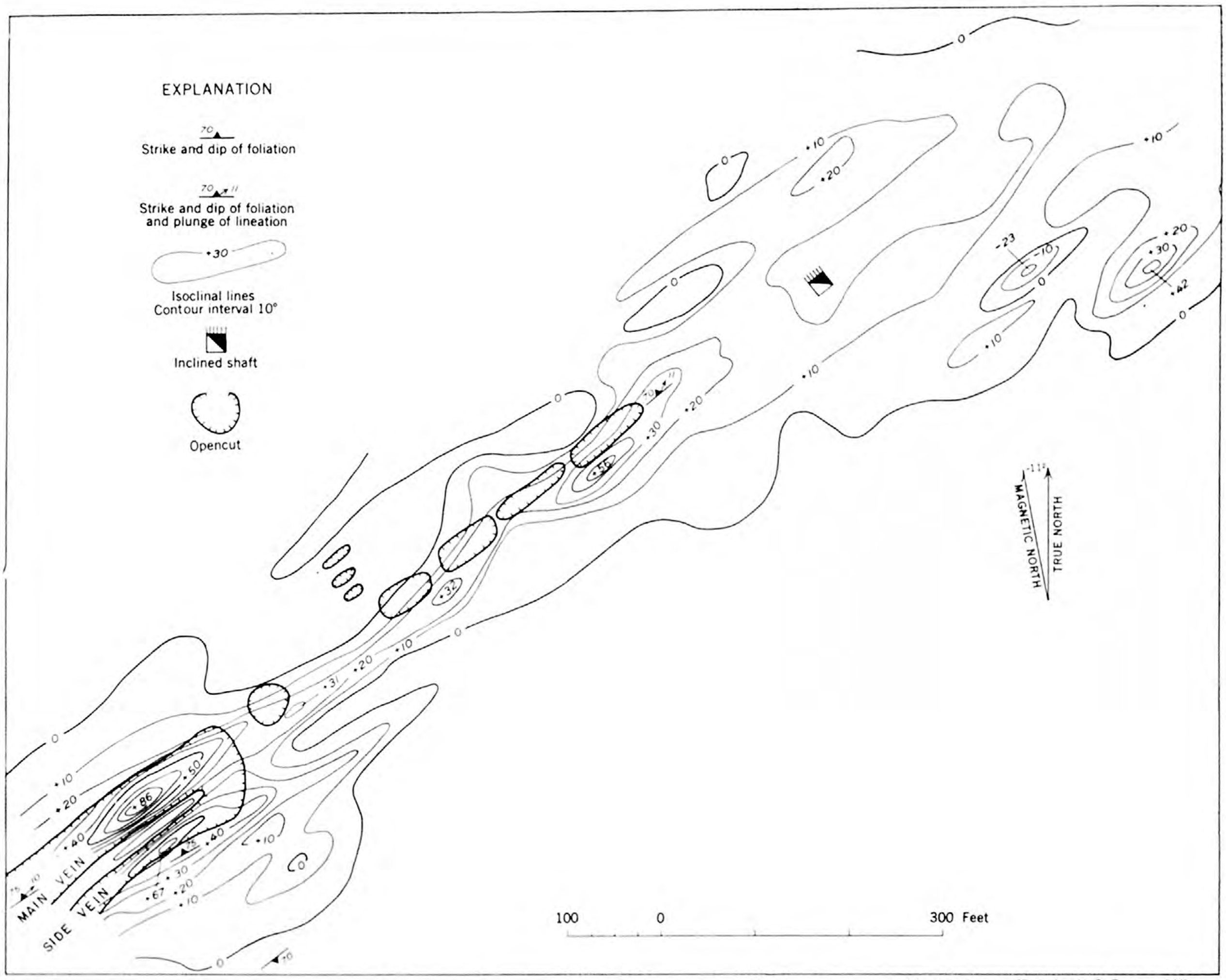
The mine remained idle until 1920 when the North Jersey Steel Co. opened it. It was in production during 1921, 1922, and 1923 but was again idle until 1926, when the mine was taken over by the Eastern Iron Ore Co. of Rockaway, N. J. The mine was exploited during the next few years, but it was finally abandoned in 1930 and has remained idle since that time. All the mine workings are now inaccessible, as the adit and main shaft are caved.

MINE WORKINGS

The mine workings, shown in plate 11, consist chiefly of a slope inclined 12° and three haulage levels about 100 feet vertically apart. Two ore bodies were worked, the Main vein and the Side vein, which are about 50 feet apart (fig. 40). Both deposits were worked for a distance of 1,500 feet and to a vertical depth of about 380 feet.

GEOLOGY

The deposits at the Beach Glen mine are essentially parallel to and about 1 mile southeast of the Hibernia deposit. The mine is in a belt of mixed rocks that consist predominantly of albite-oligoclase granite, microantiperthite granite, and albite pegmatite, with abundant amphibolite. Much of the granite is highly contaminated by hornblende and pyroxene derived from the amphibolitic rocks. The mixed rocks are bordered by alaskite (pl. 1). The rocks are complexly folded. In the exposures on the ridges southeast of the mine an intricate series of folds, from a few feet to several feet in amplitude, that plunge gently northeastward can be seen. The producing ore bodies are on the northwest limb of a slightly overturned anticline whose axis lies a short distance southeast of the opencuts.



Magnetic data modified after U. S. Bureau of Mines unpublished map, with additions by P. K. Sims

FIGURE 40.—Dip-needle map of part of the Beach Glen mine.

Two principal ore bodies—the Main and Side veins—and several minor shoots are present in the mine, as indicated on the magnetic map (fig. 40.) The largest of the minor shoots is 300 feet south of the shaft. The Main vein has a surface length of 900 feet, as measured within the +20° isoclinal, and a maximum intensity of +86°. The presence of three closed isomagnetic lines arranged in tandem along the outcrop suggests three poorly defined shoots within the deposits, the largest of which is represented by the closed isomagnetic lines over the main opencut. Mining has demonstrated that the Main vein has an average thickness of 15 feet and a mining height of 300 feet.[1] It dips northwest (pl. 11), but according to Bayley (1910, p. 470), the deposit is contorted into slight folds, in which the rocks range in dip from 75° to 80° NW. to 70° SE., the northwesterly dip being near the surface. The Main vein has been referred to in older reports as the Westernmost vein (Bayley, 1910, p. 470) and the Footwall ore shoot (Kreutzberg, 1921). The footwall contact of the Main vein is well-defined in contrast to the hanging wall.[2] The richest ore lies near the footwall. The hanging wall consists of low-grade ore of non-Bessemer grade that is as much as 20 feet thick (Kreutzberg, 1921).

The footwall rock in the opencut at the southwest end of the deposit is red albite-oligoclase granite. It forms a layer that lies between the two productive ore bodies. The granite contains local thin biotite laminae. The Side vein, which has a surface length of 300 feet, has a maximum magnetic intensity of +67. (See fig. 40.) The Side vein (Middle ore shoot of Kreutzberg) is 50 feet southeast of the Main vein. It has a maximum width of about 13 feet and a mining height of 60 feet. Like the Main vein it dips northwestward. In the opencut at the southwest end of the deposit albite-oligoclase granite forms both the footwall and hanging wall of the deposit.

A prominent lineation marked by gentle rolls and

[1] Hoster, M. T., Private report for Eastern Iron Ore Co., Rockaway, N. J.

[2] Miller, Benjamin L., Private report for Eastern Iron Ore Co., 1930.

fluting can be observed on the walls of the ore bodies in the open cuts. The lineation conforms to the plunge of the two ore bodies, as determined in the mine workings, and averages 10°30′ NE.

A third deposit, the Eastern ore shoot (Kreutzberg, 1921), is 300 feet southeast of the Side vein. It is said to be 6 feet wide and to have a height of 200 feet. The ore is reported to average 50 percent iron and to be low in phosphorus. This deposit was not located by the writer.

To judge from the material on the mine dump, the ore occurs as veinlets, thin laminae, and disseminated grains in several types of rock. It is found in albite-oligoclase granite, contaminated granite, pegmatite, and a coarse hornblende aggregate that probably represents recrystallized and reconstituted amphibolite. The ore in all the deposits consists of hard granular magnetite that contains very small amounts of hematite. Much of it is reported to be of Bessemer grade. The following partial analyses are given by Miller as typical of the crude ore from the two producing deposits.

TABLE 18.—*Partial analyses of average-grade crude ore, Beach Glen mine*

[Totals in weight percent. Analyst is not known]

	Main vein	*Side vein*		*Main vein*	*Side vein*
Fe	35.0	46.0	Al_2O_3	6.11	2.50
S	.19	.13	CaO	2.20	1.40
P	.20	.05	MgO	3.32	1.54
Mn	.06	.04	Ti	.07	.06
SiO_2	31.0	22.0			

SWEDES MINE (60)

Swedes mine is about 500 yards north of State Highway 6, opposite the race track, in the east part of Dover. It was formerly an important source of shipping ore but has been idle since 1882 (Bayley, 1910, p. 449). The mine is now inaccessible; the surface openings are largely filled and are overgrown with vegetation.

To judge from the rock on a small dump near the north end of the deposit, the magnetite occurs in amphibolitic rocks that are in part recrystallized to a coarse-grained hornblende aggregate. It forms stringers and disseminations through the host rock. Pyrite is abundant in dump specimens but was not reported from the shipping ore (Bayley, 1910, p. 450). For further description of the mine workings and the deposit the reader is referred to Bayley (1910).

PROSPECT (61)

This prospect is 1,000 feet north-northeast of the shaft at Beach Glen mine. The workings consist of two small pits that are caved to shallow depths. The rock dumps indicate that the magnetite is in pyroxene skarn. Reconnaissance dip-needle data indicate, however, that the skarn is podlike and does not extend much beyond the limits of the pits.

WHITE MEADOW-COBB ORE BELT

[The numbers following the names of the prospects and mines in this belt refer to locations on plate 1]

The White Meadow-Cobb ore belt includes the White Meadow mine (72), prospect 73, prospect 74, the Righter mine (75) and Cobb mine (76). The deposits are within a narrow belt of metasedimentary rocks that is at least 5 miles long. Production from this group of mines was small.

WHITE MEADOW MINE (72)

The White Meadow mine comprises a series of openings northeast of White Meadow Lake, about 2 miles north of Rockaway. The mines were opened before 1840 as the Kitchell and Muir mines (Cook, 1868, p. 559) but were abandoned prior to 1873. Mineral rights to the property are now owned by Warren Foundry and Pipe Corp.

In 1938 the Jones and Loughlin Ore Co. made a dip-needle survey of the deposits, and shortly afterwards Warren Foundry and Pipe Corp. drilled five diamond-drill holes (pl. 12) to test the more favorable anomalies along the southwestern part of the property. The dip-needle survey shows that a nearly continuous zone of magnetic attraction of variable intensity extends from White Meadow Lake northeastward to Hibernia Avenue, a distance of about 1 mile. The anomaly is divided into a southwestern and a northeastern part by the Mount Hope fault that crosses the deposits in the topographic saddle one-half mile north of the lake. The dip-needle survey indicates that on the south side of the fault there are two parallel deposits about 150 feet apart. The western, or main, deposit has been mined to shallow depths for a distance of 2,200 feet (pl. 12). On the north side of the fault there is only one deposit. The magnetic survey discloses a series of magnetic highs arranged in tandem along the anomalies, and these are interpreted to represent separate ore shoots. On the south side of the fault the main deposit has three distinct shoots; the east vein has two. On the north side of the fault the deposit contains two prominent shoots, the largest of which is represented by a positive anomaly that has a length of 380 feet (within the +30° isocline), a width of 35 feet, and a maximum dip-angle of +80.

The deposits are within a belt of metasedimentary rocks about 250 feet wide that is enclosed within hornblende granite gneiss and alaskite (pl. 1). The magnetite occupies granulated zones in pyroxene-bearing plagioclase-quartz-biotite gneiss, a facies of oligoclase-quartz-biotite gneiss. The wall rocks are the same gneiss or amphibolite. Another small deposit is 700 feet northwest of the main vein. The surface workings along it are caved.

The deposits trend N. 40°E. and dip 60° SE. To judge from the lineation in the country rock the ore plunges about 17° NE. The main (or West) vein ranges from less than 1 foot to 3.5 feet in thickness; the East vein is 2 feet or less in thickness. The deposits consist of thin seams of massive magnetite that are intercalated with laminae of country rock. Irregular veinlets, bunches, and disseminations of magnetite commonly occur in the wall rock to constitute a few feet of low-grade ore or subore.

Polished sections of the ore from the dumps show incipient replacement of magnetite by hematite, the latter forming blades along the octahedral parting in magnetite. The hematite is undoubtedly of supergene origin. Pyrite is generally absent from the ore, but is commonly present as disseminations in the footwall rock. An analysis of the ore gave 45.1 percent Fe and 1.6 percent P (Cook, 1868, p. 559).

PROSPECT (73)

This prospect is a small pit at the base of the hill a mile north of Hibernia Avenue. A reconnaissance dip-needle survey indicates that the pit was sunk on a small local body of magnetite.

PROSPECT (74)

This prospect is a small pit 1,200 feet southwest of the Righter mine. To judge from a reconnaissance dip-needle survey, the pit is on a small body of magnetite.

RIGHTER MINE (75)

The Righter mine workings are on the east side of the valley of the stream that flows out of Splitrock Pond. The workings consist of a caved adit near the base of the hill and a small pit about 100 feet up the hill. The workings are on a thin mineralized zone that consists of magnetite which forms widely-spaced inch-thin veinlets or seams in a layered plagioclase-quartz gneiss. The wall-rock gneiss is impregnated with disseminated magnetite. The walls of the deposit dip about 87° NW. The lineation in the country rock plunges 23° NE. Gneissic hornblende granite crops out about 30 feet northwest of the pit. A thick amphibolite migmatite zone lies in the footwall of the deposit.

COBB MINE (76)

The Cobb mine, formerly known as the Splitrock mine, consists of a series of openings on a deposit that is about 1,500 feet southeast of Splitrock Pond. The surface workings extend from the edge of the valley on the south slope northeast over the crest of the hill, a distance of approximately 1,700 feet. The mine opened before 1868. In 1868 (Cook, 1868, p. 556) the workings were at two principal places: the largest near the foot of the hill, the other near its summit. (See fig. 41.) The mine was inactive in 1873, but it was reopened in 1878 and remained in operation until 1881. The mine has been abandoned since 1881. It is reported to have reached a depth of 120 feet.

A sketch map of the mine workings and the geology at Cobb mine is shown in figure 41. The deposit is in oligoclase-quartz-hornblende-pyroxene gneiss, presumably a facies of oligoclose-quartz-biotite gneiss. The host rock is enclosed by biotite-quartz-feldspar gneiss that produces distinctive reddish outcrops. The gneiss is in part injected by pegmatite to form migmatite.

The Cobb deposit is near the crest, and slightly southeast of Cobb anticline (pl. 1). The deposit trends about N. 55° E. and dips about 70° SE. in the southwestern part of the mine, but it swings to N. 30° E. and dips 77° SE. in the northeastern part. To judge from the lineation in the wall rocks the deposit plunges about 20° NE. The deposit is thin, ranging from 2 to 5 feet in thickness. It consists of 2 shoots, respectively about 800 and 400 feet high, which are separated by a pinch that is approximately 300 feet high. The deposit probably extends northeastward beyond the mine workings, but it is here masked by alluvium.

The ore is massive granular magnetite that locally contains a few percent of unreplaced fragments of the host rock and as much as 1 percent apatite. An iron-rich biotite is found in places in the ore. An analysis of ore that was calcined and crushed indicated 59.79 percent Fe and 0.426 percent P (Pumpelly, 1886, p. 174).

HIBERNIA POND-HIBERNIA ORE BELT

[The numbers following the names of the prospects and mines in this belt refer to the locations on plate 1]

The Hibernia Pond-Hibernia ore belt (pl. 1) includes the Hibernia Pond anomaly (63), prospect 70, prospect 71, Birch mine (69), Fairview mine (67), prospect 68, Hibernia mine (64), and Beach mine (65). All the mines are in Rockaway Township.

The deposits are within a nearly continuous mineralized belt that is on the nose and limbs of Hibernia anticline. Only the Hibernia mine, which ranks as the second largest producer in the district, has yielded substantial quantities of shipping ore. The Hibernia Pond anomaly, however, shows promise as a large producer of low-grade ore.

HIBERNIA POND ANOMALY (63)

The Hibernia Pond anomaly (Sims, 1953, p. 301–302) is a belt of moderate magnetic attraction, 1¼ miles long, that extends from Telemark settlement to about 1 mile

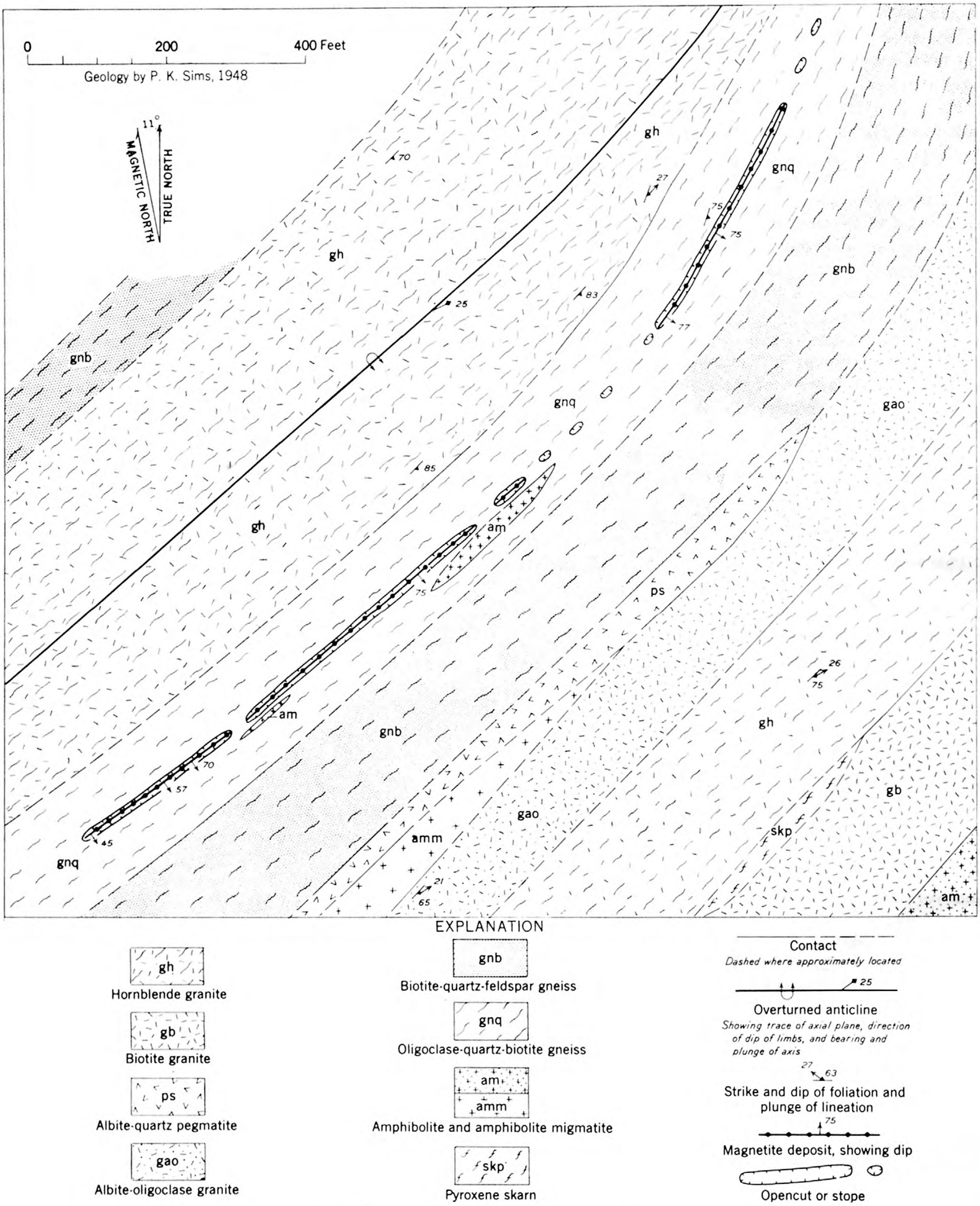


FIGURE 41.—Sketch map showing geology of the Cobb mine.

south of Hibernia Pond. (See pl. 1.) The southwestern part of the anomaly is mostly on land owned by Warren Foundry and Pipe Corp.; the northeastern part of the anomaly is on land owned by Telemark Corp., and others. There has been no production from the deposit.

The deposit was prospected by two shallow pits on the north side of Hibernia Pond but the extent of the anomaly was not known until 1938 when Hans Lundberg Ltd. of Toronto, Ontario, made a vertical magnetometer survey of the tract for Warren Foundry and Pipe Corp. In the same year the southwestern part of the anomaly was tested by four diamond-drill holes—R27, R28, R29, and R30—and in 1950 four additional holes were drilled—T72, T73, T74, and T75. The location and longitudinal projection of these holes are shown on figure 42. The core assays are given in the table below.

TABLE 19.—*Assays and drill-core data, Hibernia Pond deposit*

[Data published by permission of Warren Foundry and Pipe Corp. Thickness is given as intersected in drill hole; not true thickness]

Drill hole	Inclination (degrees)	Total depth (feet)	Depth of ore zone (feet)	Thickness (feet)	Fe (percent)
R27	90	297	53-225	172	22.52
R28	50	495	365-400	35	23.9
R29	50	139	125-133.7	8.7	20.7
R30	65	231	88-212	124	15.9
T72	65	367	284-345	61	19.1
T73	65	269	109-212.5	103.5	17.7
T74	65	364.5	215-273	58	25.1
T75	65	182	65-125	60	28.9

As can be seen on the combined magnetic and geologic map of the anomaly (fig. 42), part of the anomaly has a maximum width (within the +10° isoclinal) of 200 feet on the south side of Hibernia Pond, and it contains two isolated magnetic highs that are arranged in tandem. The high in the region of drill holes T73, T74, and T75 (within the +20° isoclinal) has a length of nearly 1,100 feet and a maximum intensity of +28°; the high on the south shore of Hibernia Pond has a length of 400 feet and a maximum intensity of +27°. The intensity of the anomalies is relatively low on the south side of Hibernia Pond because the deposit is covered by as much as 50 feet of unconsolidated material; the intensity is greater on the north side of Hibernia Pond and a maximum dip angle of +65° was recorded near the shore of the pond. Another anomaly that is parallel to the Hibernia Pond anomaly lies 500 feet to the northwest and is marked by a wide zone of weak magnetic attraction. (See fig. 42.)

The Hibernia Pond deposit trends N. 40°–45° E., dips about 60°–75° SE., and plunges 16°–20° NE., to judge from core drilling and from observation of outcrops on the northeast side of Hibernia Pond. The thickness of the deposit varies, but probably averages less than 50 feet.

The iron ore occurs in a variable metasedimentary gneiss that contains thin interlayers of albite-oligoclase granite; the wall rock is albite-oligoclase granite (fig. 42). To judge from the drill core, the hanging wall and footwall, and probably also the upper and lower edges of the deposit, are ill-defined and are marked by assay boundaries. According to A. F. Buddington (written communication, 1954) the metasedimentary gneiss consists of pyroxene-quartz-plagioclase gneiss, hornblende-quartz-plagioclase gneiss, biotitic hornblende-plagioclase gneiss, and pyroxenic mica-plagioclase gneiss. The iron ore is predominantly in a pyroxenic mica-plagioclase gneiss with accessory quartz. Locally coarse apatite accompanies the magnetite. A layer in the upper part of the mixed gneisses carries thin laminae containing nonmagnetic oxide. This oxide is principally a hematite with much exsolved ilmenite, which in turn contains a very fine intergrowth of exsolved hematite. Locally the oxide is ilmenite with exsolved hematite.

The magnetite is disseminated through the host rock, or less commonly forms inch-thin stringers and veinlets. Low-grade "ore" is exposed on the northeast shore of Hibernia Pond, and here it can be seen that some of the magnetite veinlets can be traced through the host rock for distances of more than 2 feet. Thin sections indicate that the magnetite occupies microbrecciated zones in the gneiss.

The dip-needle map and core drilling indicate that there are at least two ore shoots in the deposit. The largest shoot is marked by the magnetic high at the southwestern end of the anomaly. This shoot is indicated by drilling to have a surface length of about 1,700 feet; presumably it plunges 15° to 20° northeastward. The size of the ore shoot that underlies the magnetic high on the south shore of Hibernia Pond probably is smaller than the shoot described above, although it may extend beneath Hibernia Pond.

The grade of the deposit can be judged from the assays of drill core shown in table 19. Assays of cores from the ore shoot penetrated by drill holes R27, R28, T73, T74, and T75 average about 25 percent Fe. Assays of cores from drill hole T72 indicate only 19 percent Fe. Holes R29 and R30, to judge from the magnetic map (fig. 42), did not cut the main part of the deposit, and these cores averaged only about 15 percent Fe. The Hibernia Pond deposit represents a large reserve of low-grade ore that averages near 25 percent Fe. Even greater quantities of subore, ranging from 12 to 20 percent Fe, are present along both margins of the deposit.

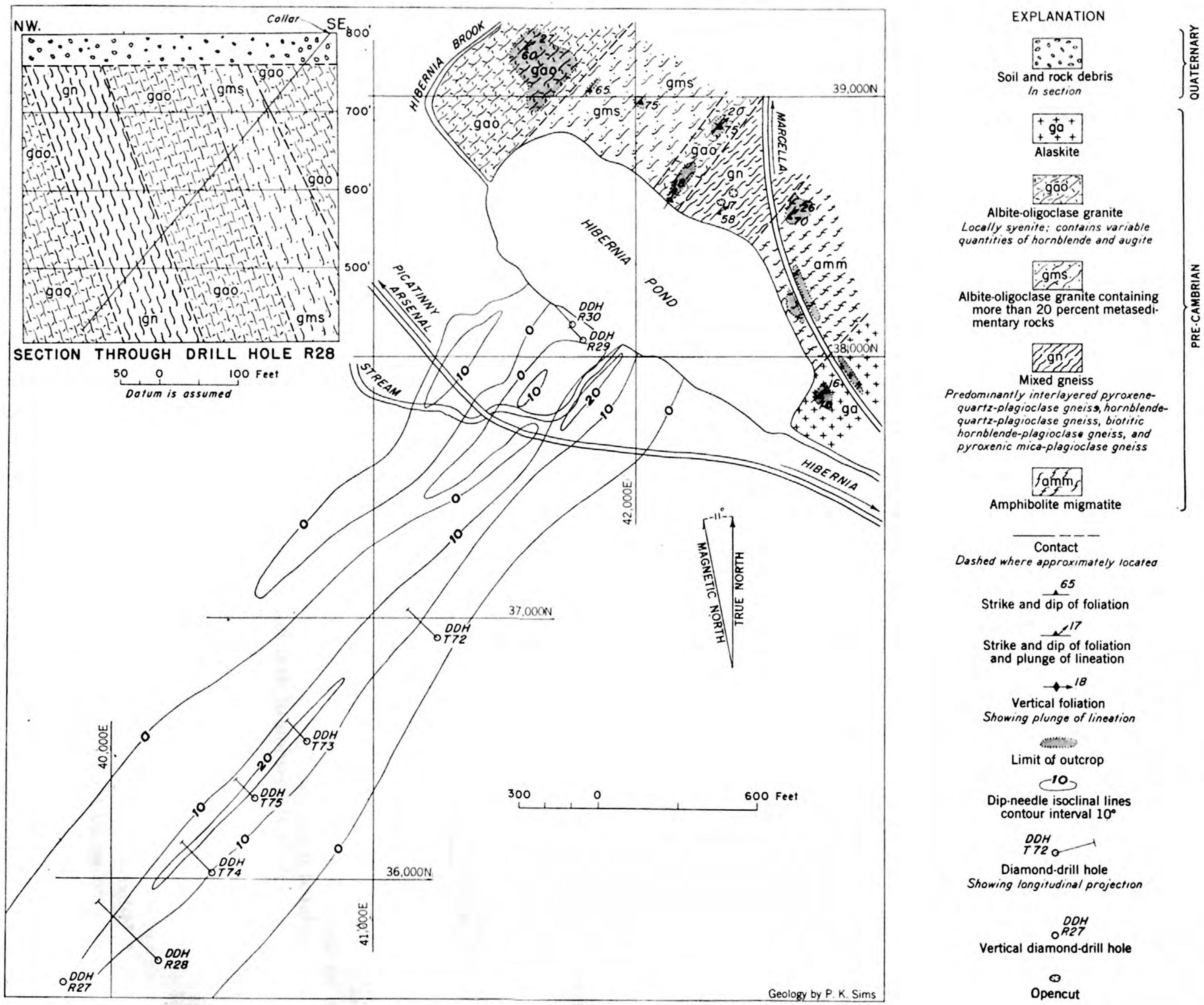


FIGURE 42.—Geologic and magnetic map and sections of part of Hibernia Pond anomaly.

PROSPECT (70)

A prospect consisting of a 70° inclined shaft, now filled with water, and a shallow opencut is 4,000 feet northeast of Hibernia Reservoir. The workings are inaccessible, but an examination of the dump material reveals that the deposit is similar to the Hibernia Pond deposit. To judge from a reconnaissance dip-needle survey the deposit is wide, perhaps as much as 20 feet thick, but low in grade. The magnetite is primarily disseminated throughout the host rock—dark layered biotite-hornblende-feldspar gneiss—but locally it forms bunches of massive ore. Albite-oligoclase granite gneiss, which locally is contaminated by incorporation of amphibolitic layers, forms both the hanging and footwall rock.

PROSPECT (71)

Several small caved shallow pits are 1,500 feet northeast of prospect (70), and on the same mineralized zone. The surface workings together with a magnetic map are shown in figure 43. The deposit is not exposed, but it is interpreted from the magnetic data to consist of two nearly parallel irregularly shaped mineralized zones that trend about N. 43° E. and dip steeply southeast. The magnetite zones are about 50 feet apart; each contains small local ore shoots that seem to have a mining height of 50 feet or less.

BIRCH MINE (69)

The Birch mine is about 1,700 feet northeast of prospect (71), on the south side of the Public Service power line. The mine is on the nose of Hibernia anticline. Evidently the production from the mine was negligible.

The mine workings consist chiefly of a 35° inclined shaft that is caved at a depth of about 20 feet. At the shaft the deposit is 3 feet thick and dips 25° to 30° NE. The ore forms thin seams of massive magnetite as much as 6 inches thick, which are interlaminated with the host rock, and disseminated grains in the amphibolite host rock. Coarse-grained albite-oligoclase granite and pegmatite form the footwall and hanging walls of the deposit. Concordant quartz veins locally are present in the footwall of the deposit.

Polished sections show that the ore contains several percent of ilmenite, in addition to magnetite. The ilmenite forms individual grains that show mutual boundaries against magnetite; it contains oriented exsolution blades of hematite and spinel. The magnetite contains exsolved spinel laths and hematite blades.

A magnetic profile across the ore body is shown in figure 12.

FAIRVIEW MINE (67)

The Fairview mine is 500 feet southeast of the Birch mine, and on the same deposit. The workings consist of a 50° inclined shaft that is at least 20 feet deep and a few shallow opencuts. The history and production of the mine are not known. It is evident, however, that some ore was produced, and later smelted, as there is a small slag pile about 75 feet east of the shaft.

The Fairview deposit trends about N. 20° W., and dips 25° to 30° NE. Where exposed, it consists of about 7 feet of low-grade ore. The magnetite forms disseminated grains and inch-thin seams that are interlaminated with the host rock, which is chiefly amphibolite but locally is plagioclase-quartz gneiss or a coarse-grained hornblende-pyroxene aggregate. The hanging-wall and footwall rock is albite-oligoclase granite gneiss which has a well-developed lineation. The ore, where exposed in a small opencut south of the shaft, is crumbly and stained brown by hydrous iron oxide produced by the weathering of magnetite.

HIBERNIA MINE (64)

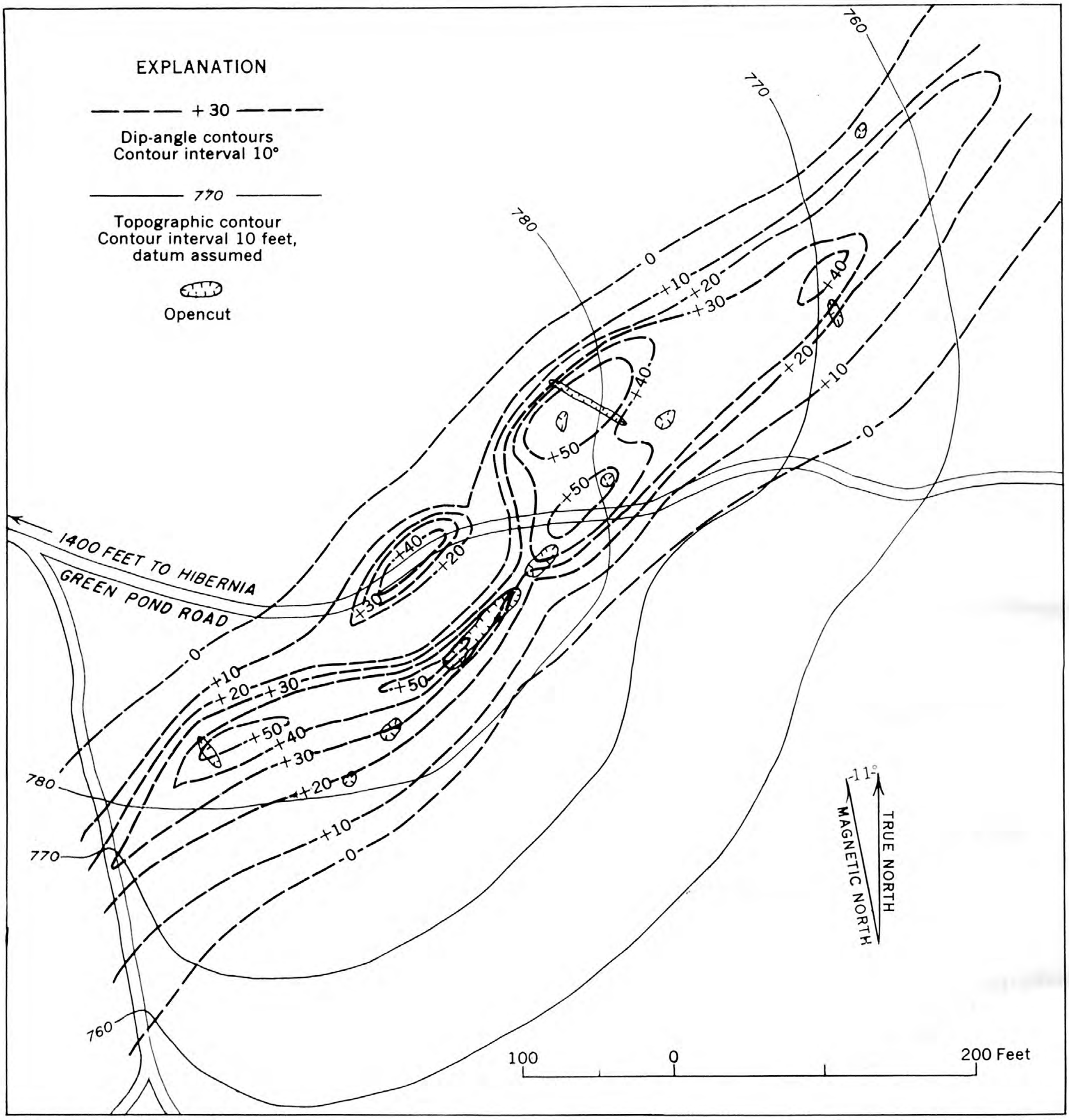
The Hibernia mine is near the village of Hibernia, in Rockaway Township. It comprises the Lower Wood, Glendon, Scott, DeCamp, Upper Wood, Willis (or Wharton), and Joseph Wharton mines of the early New Jersey Survey reports (Bayley, 1910, p. 452). The property is now owned by Warren Foundry and Pipe Corp.

The mine has yielded more than 5,000,000 tons of ore to rank as the third largest producer in the State (table 13). Large reserves of high-grade ore remain, and much of this will undoubtedly be recovered in the future. The mine workings are now filled with water, and all but two shafts, the Andover and No. 12 (66, on pl. 1), are badly caved. It was impossible to examine any of the mine workings, and the following data were in part abstracted from published reports and from material contained in the files of Warren Foundry and Pipe Corp.

Subsequent to the preparation of this report, in 1953, several long diamond-drill core holes were put down to test the Hibernia ore body. The drill holes were designed primarily to test for the extension of the ore body along its rake to determine the size and grade of the deposit. Because these holes provided a long, continuous section through a series of complex rocks, the cores of 5 holes were studied in detail by A. F. Buddington, and the results of his research are given later in this report. The location of the holes is given on figure 46, and a geologic section of holes 1–5 is given on plate 14. These data should be compared with plate 13.

HISTORY OF DEVELOPMENT, OWNERSHIP, AND PRODUCTION

It is reported that ore was mined from the Hibernia deposit as early as 1722. Prior to 1753 the ore was free to anyone who chose to mine it. In 1753 Joshua



Topography by E. S. Davidson

Geology by P. K. Sims, 1947

FIGURE 43.—Magnetic map of prospect 71.

Ball purchased the mine tract. In 1765 the "Adventure Furnace", later known as the Hibernia Furnace, was built at Hibernia, and during the Revolutionary War this furnace manufactured shot and ordnance for the Continental Army. In 1850 some ore was mined to supply the furnaces at Powerville and Beach Glen, for at that time the old "Adventure Furnace" was in ruins. In 1879 the Lower Wood, Upper Wood, and Willis tracts were owned by the New Jersey Iron Co. The Willis tract was worked by the Bethlehem Iron Co.; the Glendon Iron Co. operated the Glendon, Crane, Lower Wood, DeCamp, and Upper Wood mines. In 1873 a tunnel, called the Hibernia underground railroad, was driven along the ore shoot to drain the upper mine workings. The Andover Mining Co. in 1880 was working in the Lower Wood mine—the most southwesterly portion of the deposit. In 1885 the mines suspended operations, and in 1890 the Church or Scott mines were owned by the North Reformed Church of Newark. In that same year the Willis mines were purchased by Joseph Wharton, and the Lower Wood mine was purchased by the Andover Iron Co. In 1899 Mr. Wharton purchased the DeCamp, Upper Wood, and the Glendon mines, and in 1901 he purchased the holdings of the Andover Iron Co., thus obtaining possession of the entire deposit. The mines were operated by Mr. Wharton until 1907 when they were shut down. In 1913 the entire property was closed. H. M. Roche attempted to reopen the mine in 1917, but little progress was made, and the mine has been idle since that time.

There is no complete record of the production from the mine. Between 1864 and 1885, a total of 1,716,437 tons was reported from the mine, an average yield of about 78,000 tons per year. Between 1901 and 1905 the recorded production was 1,084,567 tons. The mine was closed for about 2 years, but was reopened in 1908 and yielded about 50,000 tons a year until it was shut down in 1913 (table 1). The estimated total production from the mine is 5,230,311 tons (table 13).

Prior to 1875 much of the ore was used for Bessemer iron, but later with the fall in price of Bessemer ore the incentive to its development ceased, and all the ore was worked together (Bayley, 1910, p. 455). Systematic cobbing of the ore was not inaugurated until 1884. In 1896 a magnetic separator was built and later others were added, and the ore was concentrated to a product with an iron content of from 58 to 62 percent.

GEOLOGY

The Hibernia deposit is on the southeast limb of Hibernia anticline (pl. 1). There is no direct evidence that the Hibernia ore body connects with the mineralized zone at Fairview mine. The deposit is a tabular body having a surface length of 7,000 feet that trends N. 40°–45° E. in the Lower Wood workings at the southwest end, but swings to about N. 62° E. in the Joseph Wharton mines at the northeast end. Where worked, the deposit ranges from 2 to 30 feet in thickness; it is reported to have an average thickness of about 9 feet. The body has a mining height of about 2,400 feet (pl. 13). According to Bayley (1910, p. 454), definite shoot structures are lacking, but pinches occur where the vein thins. About 10 of these pinches have been reported on the property. The pinches have been described as occurring where the footwall rolls in, without a corresponding outward bulge in the hanging wall.

In cross section the Hibernia ore body appears as a doubly convex lens with a generally steep easterly dip; steep northwesterly dips, however, are present locally. In the southwestern part of the vein, in the Lower Wood mine, the dip was said to be about 65° SE. (pl. 13). This conforms to the dip of the hanging wall at the surface. In the old Glendon mine, between the tunnel and the 16th level, the average dip was 69° SE. In shaft 3 of the DeCamp mine the ore dips 80° SE. In shaft 4 the ore dips about 85° NW. above a depth of about 260 feet, where it rolls over to dip 81° SE. The dip remains steep to the northwest in the near-surface workings in the Upper Wood mine, but changes to southeast at depth. In shaft 12 (66, on pl. 1) the vein dips steeply southeast where first encountered on the 4th level, but it rolls over to dip steeply northwest at 9th level and continues with this dip to the bottom of the workings on the 14th level. It is anticipated by projection of the dips encountered in the mine workings that the vein will be found to dip steeply southeast a short distance below this elevation in the shaft, and it is further expected that it will flatten to about 70° toward the bottomrock.

Near the surface at the south end of the mine the ore body consisted of 3 parallel seams of magnetite, with thicknesses of 3, 5, and 1 foot, respectively, separated by rock layers 2 feet and 3 feet thick (Bayley, 1910, p. 454). To the north the 3 seams became 2, and in the Willis (or Wharton) mine these are united into a single ore body. At depth the separate seams also merged into a single ore body (Cook, 1883, p. 117).

The toprock, or upper edge of the deposit, plunges 25° NE., as measured between shafts 10 and 12; presumably the bottomrock plunges at the same angle. The angle of plunge as estimated from lineation measurements recorded along the walls of the deposit is 23° NE. Evidently the pinches and rolls (changes in dip) plunge parallel to the ore body.

In the Lower Wood mine two transverse faults that dip steeply southwest were reported but only one of these produced a separation that exceeded the width of the ore body. The displacement of the ore in the footwall of the fault was, in each case, to the southeast.

The ore is reported to be remarkably uniform (Bayley, 1910, p. 455). It consists almost entirely of coarsely granular massive magnetite, much of which has a blocky structure. Through it are disseminated small grains of apatite and crystals of dark-green hornblende, pyroxene, and occasionally quartz, feldspar, and biotite. The ore generally has a prominent layered structure formed by alternating laminae of different mineral composition. In this respect it is similar to the ore of the Taylor deposit at Mount Hope mine. Quartz-calcite veins locally cut the ore or occur on the walls of the deposit. A green and violet fluorite was observed by Cook (1868) to occur with the calcite at some places.

The host for the ore, to judge from the material on the dumps, is principally a coarse-grained rock consisting dominantly of hornblende, presumably hornblende skarn. At places magnetite occurs in a green pyroxene rock, clearly reconstituted amphibolite, as shown in plate 19*B*. Sparse disseminated magnetite is present in the normal amphibolite. The presence of narrow magnetite layers in gneissic albite-oligoclase granite was observed on some of the dumps, indicating that locally the granitic wall rocks are partly replaced by the ore.

Polished surfaces of the ore examined by the writer indicate that the magnetite contains small amounts of ilmenite. The ilmenite forms slender blades and tiny irregular masses that can be seen only under very high magnification. Some of the ilmenite may be a replacement of magnetite that takes place along tiny fractures, but most of it seems to be due to exsolution from magnetite at a much earlier stage.

Two complete analyses of the ore are given in table 12. Bayley (1910, p. 456–457) gives several additional analyses. The analyses indicate that the ore averages about 57 percent Fe and 0.4 to 1.0 percent P. The TiO_2 content ranges from 0.5 to 1.25 percent.

BEACH MINE (65)

The Beach mine is on the southwestern part of the Hibernia ore body. The workings are in the valley west of the village of Hibernia. The history of the mine has been described by Bayley (1910, p. 451). The workings are now entirely destroyed, and the present survey did not yield any new data on the mine.

SPLITROCK POND-CHARLOTTESBURG ORE BELT

[The numbers following the names of the prospects and mines in this belt refer to locations on plate 1]

The Splitrock Pond-Charlottesburg ore belt includes the deposits that are along Timber Brook valley, north of Splitrock Pond. From south to north they are: Splitrock Pond mine (77), Wood mine (78), prospect (79), and Charlottesburg mine (80). The Charlottesburg mine was a substantial producer and yielded an estimated 100,000 tons of iron ore; the Splitrock Pond mine produced about 5,000 tons.

The deposits in the Splitrock Pond-Charlottesburg ore belt differ in many respects from most other deposits in the Dover district. At both the Splitrock Pond and Charlottesburg mines the magnetite replaces serpentine and pyroxene skarn. Pale-green mica sköls are intimately associated with both serpentine and skarn, and locally are replaced by the magnetite. Also, to judge from published mine descriptions and from reconnaissance dip-needle surveys, the deposits are podlike rather than tabular or lathlike, as in the Wharton ore belt.

SPLITROCK POND MINE (77)

The Splitrock Pond mine is in Rockaway Township, at the north end of Splitrock Pond. The mine openings have been filled in and in 1949 the rock dumps also were destroyed, but the writer was able to examine the dumps in 1948. The mine will be under water when the water level at Splitrock Pond, a reservoir for Jersey City, is raised an estimated 15 feet. The mine is an old one and its early history is not known. It was reopened in 1873 and was worked intermittently until 1880 when it was abandoned (Bayley, 1910, p. 457). The mine was worked from a shaft 100 feet deep. The production is estimated at about 5,000 tons.

Two deposits, about 50 feet apart, were worked in the mine (Bayley, 1910, p. 458). The east deposit was 14 feet wide; the footwall of the deposit consisted of alternating layers of granular magnetite and mica sköls. The west deposit was a high-grade ore shoot 25 feet high and 8 feet wide. A belt of positive magnetic attraction, a maximum of 100 feet wide and 300 feet long, extends from the site of the shaft (pl. 1) northeastward obliquely across the Charlottesburg road, now abandoned. Local high negative readings are associated with the belt of positive anomalies.

To judge from the material on the mine dumps, the magnetite occurs in 3 different host rocks. The bulk of it forms thin discontinuous seams and small bodies of massive ore in serpentine. Lesser amounts of magnetite are in dark-green pyroxene skarn and in light-green mica sköls. Large fragments of marble containing sparse serpentine nodules are found on the dump with the ore-bearing rocks.

WOOD MINE (78)

The Wood mine consists of a series of small openings on the west side of the Charlottesburg-Lyonsville road, 1½ miles north of Splitrock Pond. The principal workings are two caved inclined shafts about 1,000 feet apart, the northernmost one of which is shown on plate 1. Production from the mine has been small (Bayley, 1910, p. 422). The deposit strikes north and dips about 45° E. Its thickness is not known, as the vein is not exposed. The surface length of the deposit is about 1,200 feet. Reconnaissance dip-needle readings indicate that the deposit is low in grade throughout most of its length.

The host rock for the ore is principally fine- to coarse-grained pyroxene skarn. Hornblende skarn and green-mica sköls are intercalated with the pyroxene skarn. Pegmatite locally has intruded and recrystallized the skarn. The footwall rock is interlayered pyroxene and hornblende gneiss; the hanging-wall rock is biotitic albite granite. The ore consists principally of irregular veinlets, nests, and seams of magnetite. A few percent of pyrrhotite and chalcopyrite was observed to be associated with the magnetite on the dump at the north shaft.

PROSPECT (79)

An adit that trends S. 45° E. is situated on the east side of the road, near the base of the hill, 1,100 feet southwest of the Charlottesburg mine. An examination of the rock dump revealed that the adit was driven in albite-oligoclase granite. There is no ore on the dump. The adit, which is now caved near the portal, may have been driven to intersect one of the deposits worked in the Charlottesburg mine.

CHARLOTTESBURG MINE (80)

The Charlottesburg mine, in Rockaway Township, is on the south side of the reservoir at Charlottesburg. According to Bayley (1910, p. 418) the workings consisted of a series of open pits and shafts on both sides of the Charlottesburg-Lyonsville road, but nearly all of these have been destroyed. The mine was probably opened before 1765, for about that year a furnace and a forge were built at Charlottesburg. The first openings apparently were made near the road; later openings were made on the north slope of the hill east of the road. In 1874 new deposits were discovered to the east of the old workings, and three of these were worked until 1888, when the mine was permanently abandoned. The mine has produced an estimated 100,000 tons of iron ore.

The geology of the deposits at Charlottesburg mine is little known, because all the mine workings are inaccessible and because there are no rock exposures in the mine region. According to Bayley (1910, p. 418–419) the principal deposit in the eastern group was as much as 40 feet wide in places, but to the northeast it narrowed to 12 feet. The ore on the footwall was high in grade. The deposit dipped about 75° SE. and plunged gently northeast. It apparently was worked to a depth of 200 feet. All the deposits were reported to be cut off by a fault at the south end of the reservoir.

The ore in the eastern veins contained considerable mica and hard, dark "serpentine" (Bayley, 1910, p. 419); it was probably similar to the ore at Splitrock Pond mine. Analyses of ore from the mine are given below.

Partial analyses of iron ore from the Charlottesburg mine

[References: For samples 1–4, Bayley, 1910, p. 419; for sample 5, Pumpelly, 1886, p. 174]

	Fe	S	P	TiO_2
1	61.42	0.274	0.021	----------
2	61.47	3.36	.028	----------
3	67.42	.55	.014	----------
4	64.94	.39	Tr.	1.00
5	58.15	.151	.151	----------

1. Ore from large opening on vein 9 feet wide.
2. Ore from smaller opening made in 1877 or 1878.
3. Ore from place where vein was 8 feet wide.
4. Black compact lamellar ore from hill east of old mine.
5. Ore sample from stockpile of 30 tons mined in 1880.

GREEN POND ORE BELT

[The numbers following the names of prospects and mines in this belt refer to locations on plate 1]

The Green Pond ore belt consists of a group of mines along the east side of Copperas Mountain, in Rockaway Township. From northeast to southwest the mines are: prospect 81, Bancroft shaft (82), Copperas (83), Green Pond (84), Davenport (85), Winter (86) and Pardee (87). The mines are shown on plate 1 and figures 44 and 45.

The deposits principally are replacements of pyroxene skarn that is intercalated with a folded sequence of metasedimentary rocks. They occur within complex synclines that plunge northeast. Magnetite and a few percent of sulfides constitute the ore. The sulfides, in their order of abundance, are: pyrrhotite, pyrite, and chalcopyrite. The mines are relatively small, and the aggregate production from the group is estimated to be about 100,000 tons.

PROSPECT (81)

This prospect (81) is a small cribbed shaft estimated to be 15 feet deep, which is on the west side of the road about 700 feet northeast of the Bancroft shaft and about 3,500 feet from Kitchell. (See fig. 44.) The dump has been destroyed, and there are no rock exposures near the shaft. To judge from a reconnaissance dip-needle survey, the shaft was sunk in barren rock.

BANCROFT SHAFT (82)

The Bancroft shaft is about 700 feet southwest of prospect 81 and 300 feet northeast of the most northeasterly workings at the Green Pond mines, from which it is separated by a deep valley.

The shaft was sunk on a narrow mineralized zone about 5 feet thick in plagioclase-quartz-pyroxene gneiss. Layered amphibolite constitutes the hanging wall and granitized amphibolite the footwall.

COPPERAS MINE (83)

The Copperas mine consists of several shallow shafts that are at the east base of Copperas Mountain, north

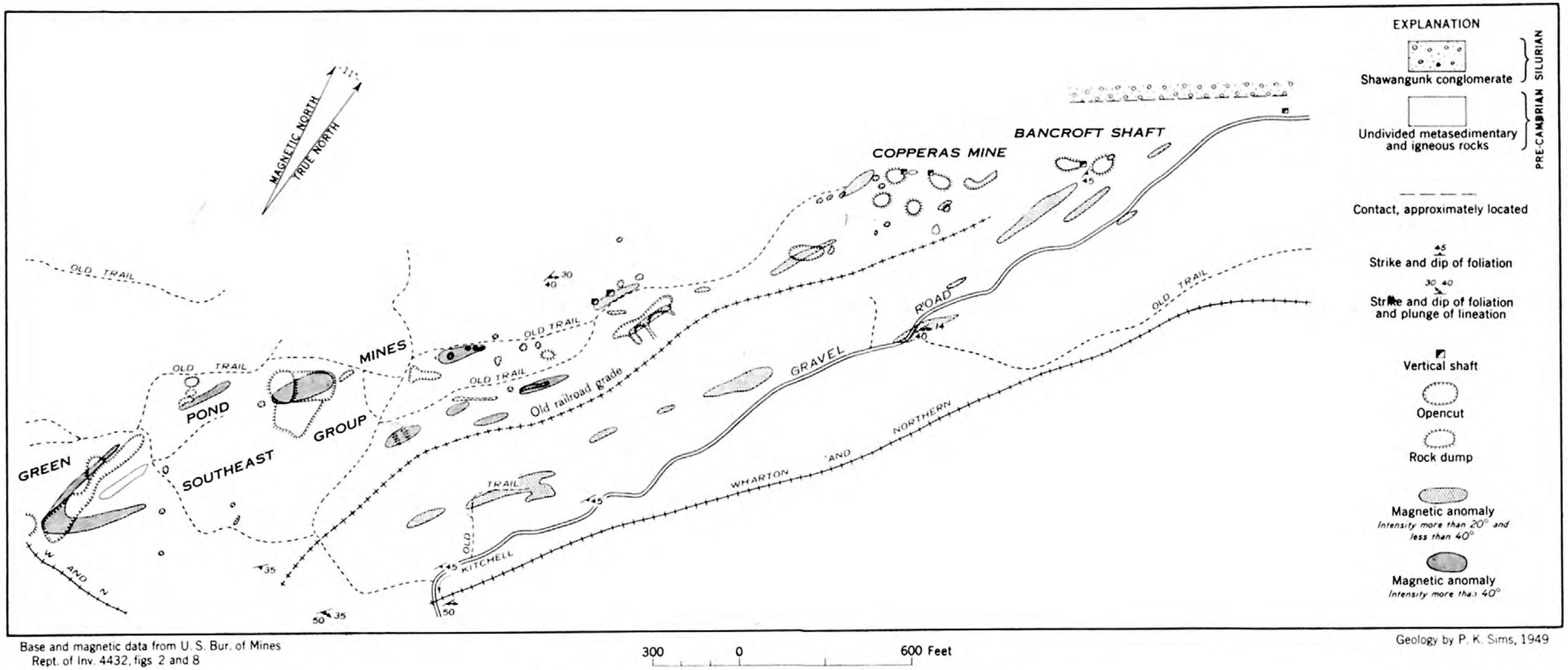


FIGURE 44.—Map of the northeast part of the Green Pond ore belt.

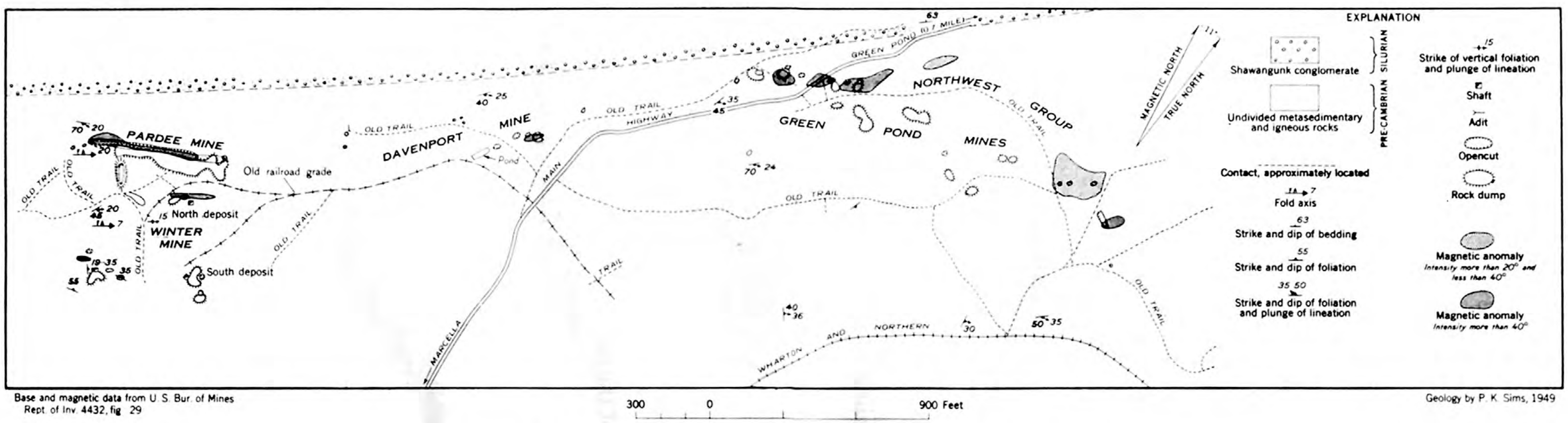


FIGURE 45.—Map of the southwest part of the Green Pond ore belt.

of the Green Pond mines and about 250 feet from the contact of the Green Pond conglomerate and the pre-Cambrian (fig. 44).

According to Bayley (1910, p. 374) the mine was worked during the War of 1812 to obtain copperas and red paint. It has not been worked for iron ore. To judge from the material at the dumps the shafts were sunk on biotitic amphibolite that contains scattered disseminated grains of magnetite. In the hanging wall there is a 100-foot layer of plagioclase-quartz-pyroxene gneiss that separates the mine workings from the most northeasterly pits of the Green Pond mine.

GREEN POND MINES (84)

The Green Pond mines are at the foot of Copperas Mountain and on the west side of the Wharton and Northern Railroad. (See figs. 44 and 45.) They constitute the most extensive workings in the Green Pond ore belt. The mines were opened in 1872 and were mined intermittently until about 1882. They were worked further in 1879, 1880, and 1899, but in 1899 they were abandoned because of an unfavorable ore market (Bayley, 1910, p. 372–373). The aggregate production from the mines is estimated at 50,000 tons.

A reconnaissance dip-needle survey of the property was made by the U. S. Bureau of Mines during World War II (Stampe and Mosier, 1949, fig. 14). The principal anomalies disclosed by this survey are shown on figures 44 and 45.

The Green Pond mines consist of several opencuts and shafts that extend from the Green Pond-Marcella road northeastward to the Copperas mine, a distance of 1 mile. For purposes of discussion the mine workings may be divided into two groups—the northwest and the southeast.

The northwest group of openings are on both sides of the Marcella-Green Pond road, near the contact of the Green Pond conglomerate (fig. 45). The workings near the highway are on a deposit that is reported to be 70 feet high and 20 to 25 feet thick. The deposit dips 25° or less SE. and plunges about 30° NE. The ore consists of magnetite that contains abundant pyrite. At the surface the ore is crumbly and stained reddish brown because of the oxidation of the pyrite. The ore replaces pyroxene skarn; the wall rocks are oligoclase-quartz-biotite gneiss and layered amphibolite. Another series of small pits (fig. 45) in the northwest group are about 1,200 feet east of the above described workings (Stampe and Mosier, 1949, fig. 13). The structure of the northwest group of deposits is not clear, because of the sparse outcrops. It seems probable, though, that the deposits are in an area of complex folding, for the foliation varies greatly from one exposure to another.

The southeast group of openings are on the lower slope of Copperas Mountain, and extend from near the Wharton and Northern Railroad northeastward to the Copperas mine. (See fig. 44.) The largest opening is at the southwest end. The dip-needle data and geologic studies indicate that the deposits in the southeast group are on the limbs and in the axial area of an overturned isoclinal syncline that plunges about 35° NE. The limbs of the syncline dip 35° to 55° SE. The deposits that have been mined are principally on the northwest limb of the syncline. The large opencut at the southwest end of the property is in the trough. The dip-needle data indicate that there are also several small deposits on the southeast limb of the syncline (fig. 44). Another linear belt consisting of small disconnected low-grade(?) pods of ore, shown by the anomalies arranged in tandem, lies in the swampy area in the valley that parallels the Kitchell road. These deposits have not been prospected.

The extent of individual deposits in the southeast group is not known, as the exposures are generally poor and mining operations have not penetrated below depths of about 350 feet. It seems probable, though, that the individual deposits are small and lenticular. The skarn forms pods, the largest of which probably does not exceed 300 feet in length, that occur in linear zones parallel to the limbs of the syncline. The host rock for the ore in the southeast group of deposits is pyroxene skarn. The wall rocks are plagioclase-quartz gneiss, feldspathic skarn, and pyroxene gneiss. Detailed studies of the wall rocks of the several pits were not made.

The magnetite ore in the Green Pond mines is granular and hard. Pyrrhotite, chalcopyrite, and pyrite are associated with magnetite and together constitute from 1 to 3 percent of the ore. Pyrrhotite is the most abundant sulfide; chalcopyrite constitutes less than 1 percent of the ore. The ore has a low phosphorus content and is reported to be of Bessemer grade (Bayley, 1910, p. 373). Outcrops of ore are conspicuously stained by the alteration products of the sulfides. Polished sections of the ore show that the magnetite contains abundant tiny oriented laths of spinel. The sulfides are later than the magnetite and have the following paragenetic sequence: pyrite, pyrrhotite, and chalcopyrite.

The grade of the ore is variable. A sample taken from a carload representing the product of four pits being worked in 1880 gave: 51.33 percent Fe and 0.033 percent P (Pumpelly, 1886, p. 174).

PARDEE MINE (87)

The Pardee mine is at the base of Copperas Mountain, a third of a mile southwest of Davenport (pl. 1). The mine was opened about 1870 (Bayley, 1910, p.

371) and was worked for 2 years, during which time 2,500 tons of ore was shipped. It was reopened in 1882 and worked until 1884. The principal opening is an opencut 450 feet long, 20 feet wide, and 15 to 30 feet deep (fig. 45). The deposit trends N. 60° E. and dips 75° to 89° SE. It ranges from 7 to 15 feet in thickness. Crenulations and mineral streaks on the walls plunge 20° NE.

The ore occurs in biotitic pyroxene skarn. Amphibolite and biotite schist in a sequence of interleaved metasedimentary rocks and alaskite form the wall rocks. The wall rocks are schistose and stained by the weathering products of sulfides. The ore is hard and compact and consists of magnetite and minor amounts of pyrite, pyrrhotite, and chalcopyrite. The microscope reveals that the magnetite contains abundant tiny blebs of spinel (Sims, 1953, pl. 28A).

DAVENPORT MINE (85)

The Davenport mine is on the west side of the Marcella-Green Pond road, near Davenport, and within 200 feet of the east contact of the Green Pond conglomerate (pl. 1). The mine was opened in 1880 on a deposit that dipped 40° SE. (Bayley, 1910, p. 372). The workings consist of four shallow shafts and a few pits that opened the deposit along a distance of 450 feet (fig. 45). Since the pits are caved and the dumps are destroyed, the writer was unable to obtain any new data on the deposit. According to Bayley (1910, p. 372) the deposit was 12 feet wide at its northeast end, but narrowed to the southwest. The ore was of good quality, but it contained considerable sulfur.

Nine hundred feet northeast of, and along strike from, the Davenport mine are several small pits that contain pyroxene skarn that is partly replaced by magnetite and pyrite. The skarn seems to form lenticular bodies and pods that are intercalated with feldspar-quartz gneisses.

WINTER MINE (86)

The Winter mine is south of the Pardee mine. The mine was worked at intervals between 1882 and 1886, but only a small amount of ore was raised. The workings consist of 3 shafts and a few small pits. The North shaft is 150 feet south of the Pardee opencut; the South shaft is 450 feet south-southwest of the North shaft. Another shaft, now caved, is 400 feet northeast of the South shaft.

The deposits are on the northwest limb and in the axial area of a complex syncline that plunges 17° to 20° N. 55° E. The North ore body is on the northwest limb of the syncline; it strikes N. 65° E. and dips steeply southeast. The South deposit is near the trough of the syncline. The North ore body has a surface length of about 300 feet and is about 8 feet thick. It replaces a layered hornblende-pyroxene skarn and serpentine derived by the alteration of the skarn. Alaskite that contains conformable layers and pods of pyroxene skarn forms the hanging wall. The footwall rock is not exposed. The South deposit is a small irregularly shaped body that is in a coarse-grained rock containing hypersthene, clinopyroxene, and hornblende, presumably a reconstituted facies of amphibolite. The skarn is locally injected by pegmatite. Amphibolite constitutes the wall rocks of the deposit. The dip-needle data (Stampe, Mosier, and others 1949, fig. 29) indicate that both deposits are small and probably do not extend much beyond the limits of the present workings.

Polished-section studies of the North deposit indicate that the magnetite forms blebs and narrow stringers in the host rock. The magnetite contains abundant tiny oriented laths of spinel along the (111) direction, and small unoriented blebs of an unknown silicate. Sulfides were not observed in the pit but are present on the rock dumps. The ore in the South deposit consists chiefly of magnetite. A few percent of pyrrhotite and traces of chalcopyrite are associated with the magnetite.

OTHER DEPOSITS

[The numbers following the names of prospects and mines given in the following paragraphs refer to locations on plate 1]

There are 4 economically unimportant mines and prospects in the district that do not lie within the ore belts described above. They are the Combs mine (88), Cooper prospect (89), prospect (90), and prospect (91).

COMBS MINE (88)

Combs mine is on the east side of Dawsons Brook, 2 miles west-southwest of Mount Freedom (pl. 1). The history and development work have been described by Bayley (1910, p. 468).

The deposit, where mined, strikes about N. 45° E., dips 40° to 45° SE., and is 1 to 12 feet wide. The ore is hard and siliceous and contains several percent of quartz and feldspar. The hanging wall, where exposed in the opencut north of the Mount Freedom road, is dark, medium-grained amphibolite. Diopside skarn, sheared feldspathic quartzite containing diopside lenticles, and alaskite are present on the dump.

An analysis of ore from the southwest end of the property gave: 37.15 percent Fe, 0.036 percent P, and a trace of TiO_2 (Pumpelly, 1886, p. 166).

COOPER PROSPECT (89)

A prospect that consists of several small shallow pits in alaskite is on the south slope of the hill south of Dover. There is no ore on the dumps.

PROSPECT (90)

This prospect is on the west side of the Meriden-Lyonsville road, one-third mile east of Meriden. The deposit is small and unimportant. Two pits, approximately 20 by 20 by 15 feet, that trend N. 40° E. constitute the mine workings. The ore is not exposed in the openings, but dump specimens indicate that the magnetite forms massive inch-thin layers in amphibolite. Contaminated albite-oligoclase granite forms the wall rocks.

PROSPECT (91)

This prospect, in the village of Hibernia, is a small pit on a weak zone of magnetic attraction that appears to be of no economic importance. The wall rocks are amphibolite.

The following additional mines that have been described previously were not located during the present survey: Pikes Peak (or Stony Brook) mine, Frenchman's mine, Sigler mine, Meriden mine, Howell mine, and Greenville mine. For a brief description of these mines the reader is referred to Bayley (1910).

GEOLOGIC SECTION AT HIBERNIA MINE

By A. F. Buddington

The Warren Foundry and Pipe Corp. in 1953 put down eight long drill holes to explore the Hibernia magnetite vein at depth (fig. 46). The corporation generously permitted the Geological Survey to have full access to the cores for examination and study. We are indebted to Allan James, general superintendent, and R. Hagerman, engineer, for courtesies extended us during the work. Mr. D. R. Baker, of the U. S. Geological Survey, collaborated with the author in logging the drill core.

Five holes were put down as a fan in one plane. These were studied in detail. The core of two other holes (Nos. 7 and 11) were logged by visual inspection only. Because several significant facies of the rocks do not lend themselves very well to visual megascopic identification, the work was controlled by microscopic study of 250 thin sections. It was thought that such continuous cores through the rocks might afford evidence toward the solution of some general problems of the geology of the pre-Cambrian of New Jersey, and this has proven to be the case.

The study disclosed (1) that, like the magnetite-ore bodies, certain lithologic units appear to plunge parallel to the lineation and (2) that the feldspar of the microantiperthite granite, a widespread rock in the Dover district, is largely the result of alteration and recrystallization of a primary "film" microantiperthite.

The descriptions which follow refer wholly to the rocks of the section (pl. 14), unless otherwise specified. The term "thickness" will be used in the sense of stratigraphic thickness at right angles to the layering. Otherwise the figures given will be the intercepts on the drill core. The rock units shown in the section are distinguished primarily on the basis of lithologic character which can be distinguished megascopically, whereas others are distinguished by features observable only under the microscope.

The nature of the feldspar is used as a major factor in discriminating between different rocks. The microperthite is an intergrowth on a microscopic scale of potash feldspar and sodic plagioclase, with the potash feldspar very slightly in excess and forming the groundmass for the plagioclase. The plagioclase, however, is nearly equal in volume to the potash feldspar. Microantiperthite also is a microscopic intergrowth of potash feldspar and sodic plagioclase, but with the plagioclase in excess and forming the groundmass for the potash feldspar component. Typical "film" microantiperthite is shown in plate 22*A*.

The term "pseudodiorite" will be used for rock which has the character and appearance of a pyroxene diorite but which is the product of modification and reconstitution of amphibolite in the solid state, rather than having crystallized from a magma. The term "alaskite" will be used for granites containing less than 5 percent dark minerals.

The rock herein called albite-oligoclase alaskite is a facies of that mapped by Sims (pl. 1) as albite-oligoclase granite, and the rock here referred to as microantiperthite alaskite is included by Sims with the rocks under the term "alaskite with minor microantiperthite granite."

Correlation of lithologic units from hole to hole in the Hibernia zone is exceptionally difficult because the units vary in thickness along both the strike and the dip and also vary in composition. A unit which is almost entirely amphibolite in one hole may correspond to one which is mostly pyroxene syenite with only relics of amphibolite in another. Also, some of the alaskite sheets consist of uniform microantiperthite alaskite in one hole but are composite in another hole—albite-oligoclase alaskite forms a central zone which is overlain and underlain by microantiperthite alaskite. The unit carrying the ore zone fortunately is one of the most persistent and readily identifiable in the sequence, and it was used as a key "marker bed" in determining the stratigraphic correlations.

STRUCTURAL SETTING

The rocks enclosing the Hibernia vein have been interpreted by Sims to form the southeast limb of an overturned anticline named by him the Hibernia anticline; a northeast extension, possibly a prong

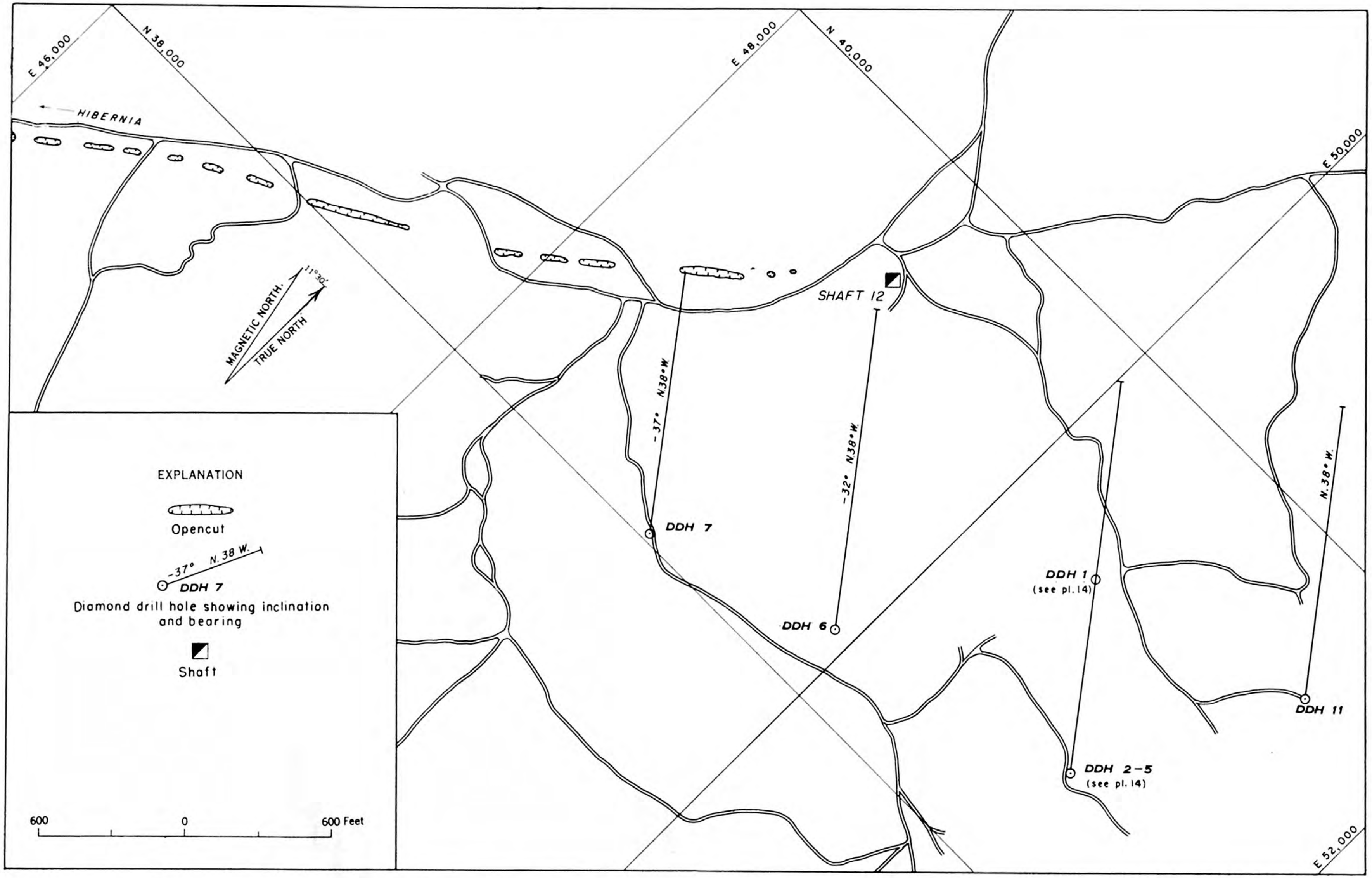


FIGURE 46.—Map of part of Hibernia mine, showing location of diamond-drill holes.

from the Hibernia anticline, has been named the Cobb anticline. The Hibernia anticline is described as having both limbs overturned toward the northwest, with an average general dip of 60° or more SE and a gentle northeast plunge. The fan of diamond-drill holes (pl. 14) shows the lithologic layering to have a very steep dip southeast in the upper part and a generally steep dip northwest in the lower part. This reversal in dip is in accord with reversals in dip of the Hibernia ore body encountered in the mine workings. (See pl. 13.) Possibly the change in dip from southeast to northwest correlates with the change in dip between levels 8 and 16 in shaft 12.

The writer did no additional surface mapping; Sims' interpretation is accepted. The layers in the northwest part of the section (pl. 14) will therefore be referred to as "lower" layers and successive layers to the southeast as "upper" layers, regardless of the direction of dip.

PETROLOGY OF ROCK UNITS

The rocks of drill holes 1–5 (pl. 14) consist dominantly of 3 alaskite sheets, each about 150-300 feet thick and separated from one another by layers of amphibolite and associated igneous rocks. Above these are a zone of metasedimentary gneisses and amphibolites about 200 feet thick, and an upper sheet of pink microperthite-hornblende granite and alaskite, the top of which is not shown. The alaskite sheets contain local layers and lenses of amphibolite. The thick amphibolite layers in turn have lenses of green pyroxene-microantiperthite syenite or granite and in addition have sheets of pink microperthite alaskite in the zone near the main upper sheet of pink microperthite alaskite (zone H, pl. 14).

The magnetite ore (holes 1–5) occurs in a narrow zone of dark gneisses between an albite-oligoclase alaskite sheet below and a zone of albite-quartz pegmatite with local associated microantiperthite alaskite above.

Although the rocks cut in drill hole 11 are similar to those cut in holes 1–5, the rocks cut in holes 6 and 7 are in some respects different (fig. 46). The rock units change in lithologic character along strike. Zone C—albite-quartz pegmatite and microantiperthite alaskite—which overlies the ore-bearing zone of holes 1–5 (pl. 14) is represented by microantiperthite alaskite with included layers of amphibolite in holes 6 and 7; and zone D—albite-oligoclase alaskite—of holes 1–5 is thinned to 25 feet in hole 6 and is absent from hole 7. Amphibolite is much more abundant in hole 7 than in the holes to the northeast (fig. 46), a relation consistent with the surface geology; for Sims (pl. 1) shows a layer of amphibolite starting just southwest of the line of section for holes 1–5 and extending for a mile and a half to the southwest. The zone of heterogeneous mixed gneisses in hole 6, which is between the composite alaskite sheet corresponding to zone F of holes 1–5 (pl. 14) and the hornblende-microperthite granite and alaskite sheet corresponding to zone H, is thicker in hole 6 than in holes 1–5. These gneisses, intersected from 102 to 1,155 feet in the core, consist mainly of amphibolite, pyroxene-plagioclase gneiss, and biotitic and hornblendic plagioclase gneiss, with interlayers of green microantiperthite alaskite, syenite, and albite-quartz pegmatite. A sheet of green pyroxene-microantiperthite alaskite was cut at depths between 311 and 560 feet, and a layer of hornblende-microperthite granite was cut between 560 and 612 feet. Much of this zone of heterogeneous rocks probably is paragneiss.

The ore shoot in zone B, the bottom of the albite-oligoclase alaskite lenses in zones D and F, and the bottom of zone E, in which pyroxene microantiperthite syenite and granite predominate, all plunge gently northeast. The pegmatite of zone C also probably has a similar gentle plunge to the northeast.

ALBITE-OLIGOCLASE ALASKITE SHEET

[Zone A, pl. 14]

A sheet of pale-pink to pale-gray medium-grained (± 1.5 mm) strongly gneissoid albite-oligoclase alaskite lies beneath the ore zone. The rock is characterized by sparse small distinctly reddish brown feldspars. The sheet is about 200 feet thick in drill hole 2 (1,728–1,949 ft.) and is at least 300 feet thick in drill hole 11, but the other drill holes did not penetrate through the sheet. In drill hole 2 the albite-oligoclase alaskite sheet is underlain by amphibolite with a few thin interlayers of granite (1,949–1,981 ft.). The rocks below the amphibolite are predominantly biotitic film microantiperthite gneiss with minor quartz, and thin interlayers of albite-oligoclase alaskite and amphibolite. The alaskite contains sparse layers of amphibolite from several inches to 3 feet thick, but much of it is exceptionally homogeneous.

The feldspars of the alaskite in drill hole 1 almost entirely are clear albite, but in most of the rock there are some feldspars with a slight microantiperthitic network of film potash feldspar; locally the feldspar has bleb microantiperthite or a patch-microcline network. In part, there are small microcline grains on the borders of the albite. The quartz contains many short, extremely fine hairlike needles, possibly rutile, arranged in a systematic angular grid pattern. Magnetite and ilmenite are accessory minerals, and zircons are rarely present. The feldspars are commonly flecked with muscovite plates.

The albite-oligoclase alaskite becomes coarse grained to pegmatitic and contains variable amounts of pyroxene in a zone several feet wide adjacent to the ore-bearing amphibolite. A part of the plagioclase in the pegmatite has a microcline-patch network. The rock in the contact zone between the albite-oligoclase alaskite and its pegmatitic facies and the amphibolite is changed on the amphibolite side to a recrystallized pyroxenic plagioclase rock or pseudodiorite with accessory magnetite.

ORE-BEARING ZONE OF DARK GNEISSES

[Zone B, pl. 14]

The country rock of the ore-bearing zone B is a layer of dark gneisses consisting mostly of amphibolite and pseudodiorite, interpreted as a modified equivalent of amphibolite, together with local lenses of green microantiperthite syenite and albite-quartz pegmatite.

The drill holes show that the dark gneiss layer increases in thickness from the southwest to the northeast (fig. 46). Successively to the northeast the layer is about 20 feet thick in hole 7, 42 feet thick in hole 6, 50–60 feet thick in the fan of holes 1–5 (pl. 14) and about 65–70 feet thick in hole 11. The ore occurs almost entirely in the lower part of the zone; in hole 7, however, the whole layer constitutes ore. The contact of the ore layer with the albite-oligoclase alaskite (or its pyroxene-bearing coarser equivalent) below generally is sharp, but the contact with amphibolite above is gradational—a disseminated magnetite zone (sub-ore) separates the ore from barren amphibolite above. The vein has been mined to the surface for nearly a mile to the southwest of drill hole 7 (pl. 13) and the material on the dumps is consistent with the interpretation that the ore layer throughout its length is in the same dominantly amphibolite zone.

The term "sub-ore" is used in this report for rock with less than 20 percent iron in magnetite, "low-grade ore" for material with 20–35 percent iron in magnetite, "moderate-grade ore" for 35–50 percent iron in magnetite, and "high-grade ore" for ore with greater than 50 percent iron in magnetite. The ore layer in general consists of about half moderate- to high-grade ore and half low-grade ore.

The rocks within the ore-bearing zone consist of hornblende-plagioclase amphibolite or biotitic hornblende-plagioclase amphibolite, pseudodiorite, and local lenses of pyroxene-microantiperthite syenite, albite-quartz pegmatite, and microantiperthite alaskite. At places 1-inch biotite-rich layers are closely associated with the pseudodiorite. The amphibolite contains sparse magnetite; the feldspars within the rock typically are cloudy. The pyroxene-microantiperthite syenite contains as much as several percent magnetite, and the pegmatite contains variable quantities of disseminated magnetite, locally as much as 20 percent. The pyroxene in the syenite is in part clinopyroxene and in part orthopyroxene. The pyroxene pseudodiorite occurs immediately adjacent to the syenite and pegmatite. It is a light-green medium-grained rock that contains both clinopyroxene and orthopyroxene, hornblende, and plagioclase feldspar. It is lighter in color, more massive in appearance, and slightly more feldspathic than the amphibolite. The plagioclase is clear and subhedral; it is slightly coarser than in the amphibolite. The orthopyroxene is in part or wholly altered to a microcrystalline aggregate, possibly talc.

The pseudodiorite grades into amphibolite and clearly was derived from it by reconstitution effected by the ore-forming solutions and solutions accompanying the intrusions. During the alteration the hornblende of the amphibolite was largely converted to clinopyroxene or to both clinopyroxene and orthopyroxene with the coordinate development of a little magnetite; locally, however, some hornblende recrystallized essentially simultaneously with the pyroxenes.

The ore-forming solutions modified and replaced only the stratigraphically lower part of the layer of dark gneisses. Magnetite was selectively introduced into part of the pseudodiorite and part of the microantiperthite syenite. Neither the pegmatite nor the unaltered amphibolite was mineralized. The biotite-rich layers were only locally slightly replaced by magnetite. The magnetite, accompanied by a little quartz and some apatite, forms small veinlike replacements in the host. The quartz commonly occurs as borders around the magnetite grains. At places secondary biotite plates formed against the magnetite.

ALBITE-QUARTZ PEGMATITE ZONE WITH ASSOCIATED MICROANTIPERTHITE ALASKITE

[Zone C, pl. 14]

The ore-bearing layer of dark gneisses is overlain by a zone consisting predominantly of pink granitic rocks, which vary in texture from a coarse pegmatite to a fine-grained aplite. Albite-quartz pegmatite is the dominant rock type in the zone, but it is associated with microantiperthite alaskite and microperthite alaskite. These rocks, thought to be a generally coarse-grained facies of the albite-oligoclase alaskite and microantiperthite alaskite sheet of zone D (pl. 14), vary considerably in grain size along both the dip and strike. The zone is 80–90 feet thick in holes 1–4, inclusive, but thins to about 30 feet in hole 5.

In drill hole 5 the rock constituting zone C, between depths of 2,600 feet and 2,642 feet, is a coarse- to medium-grained pink microantiperthite alaskite. In drill hole 4 the zone is wider; the upper part consists of a coarse medium-grained pink granite (2,190–2,270 ft.) and the lower part consists of a coarse albite-quartz pegmatite (2,261–2,351 ft.). The central part (2,296–2,329 ft.) of the pegmatite zone contains about 20 percent magnetite, which is erratically distributed as coarse irregular aggregates. The magnetite carries 1.3 percent TiO_2. The bordering pegmatite carries magnetite as an accessory mineral but in much smaller quantity than in the central part. A pegmatite vein (2,361–2,372 ft.) in the amphibolite is syenitic and contains considerable coarse pyroxene and several percent of magnetite. So far as known, the magnetite-rich part of this zone does not extend far vertically. In drill hole 2 the zone consists of albite-quartz pegmatite and contaminated alaskite (1,562–1,569 ft.), albite-quartz pegmatite with variable amount of coarse hornblende (1,569–1,593 ft.), and pegmatite interlayered with amphibolite and some contaminated alaskite (1,593–1,635 ft.). In drill hole 1 the zone consists (867–985 ft.) of a fine-grained (± 1 mm) pink microperthite alaskite (? aplite) with about 25 feet of granite pegmatite in the central part.

The alaskite in thin section is found to consist of film microperthite and quartz with a little accessory magnetite and ilmenite and sparse zircon crystals. A few grains of microperthite are partly albitized and some grains of plagioclase have patch microcline. The feldspar of the coarse-grained microantiperthite alaskite is plagioclase with coarse patch microcline intergrowth. There may be a little chloritized mafic mineral. Some microcline grains are present.

The feldspar of the albite-quartz pegmatite is predominantly albite with a patch intergrowth of microcline. Rarely relict film microantiperthite occurs in the larger plagioclase grains. Microcline also forms smaller interstitial grains to the plagioclase and quartz. The mafic minerals are in part altered to chlorite and some of the ilmenite is changed to leucoxene. Locally, accessory biotite is present. Pyroxene and hornblende are the common mafic minerals. The distribution and occurrence of the more common mafic minerals indicate that they are certainly in part if not in whole developed by incorporation of material from the amphibolite country rock.

In holes 6 and 7 the rock within zone C is a normal medium-grained microantiperthite alaskite, whereas in hole 11 there is a great thickness (about 150 ft., 1,329–1,522 ft.) of albite-quartz pegmatite with subordinate coarse-grained microantiperthite alaskite and a little interlayered amphibolite.

COMPOSITE SHEET OF ALBITE-OLIGOCLASE ALASKITE AND ALBITE-MICROANTIPERTHITE ALASKITE

[Zone D, pl. 14]

A composite sheet consisting largely of albite-microantiperthite alaskite and albite-oligoclase alaskite overlies zone C. The rocks constituting the sheet are thought to be of igneous origin. The zone (D) is about 200 feet thick in holes 3, 4, and 5 but is 275 to 300 feet thick in holes 1 and 2. The thickening of the sheet in the upper holes coincides directly with the appearance of a central zone of albite-oligoclase alaskite in what is otherwise albite-microantiperthite alaskite. The pegmatitic zone (C) could well have been included as a subfacies of this sheet.

The upper and lower stratigraphic facies of zone D consist of a pale-greenish-gray medium-grained (1–1.5 mm) microantiperthite alaskite. The feldspar in most of the rock is plagioclase with a patch intergrowth of microcline, but in part the plagioclase has relicts of a film intergrowth of potash feldspar. Also, small grains of microcline occur locally in the groundmass. In a single thin section the feldspar grains vary widely and they may consist of the following types: (1) grains of apparently homogeneous plagioclase, (2) grains consisting entirely of film microantiperthite, (3) grains having a core of film microantiperthite and a border of more coarsely recrystallized material in which the potash feldspar occurs in irregular bleblike intergrowths, (4) microantiperthite grains in which the potash feldspar occurs entirely as bleblike intergrowths, (5) plagioclase grains which contain the potash feldspar entirely as a microcline patch network intergrowth, and (6) plagioclase grains with a slight amount of potash feldspar as an irregular thin network of veinlets. A clear albite selvage is common around all grains having a potash-feldspar intergrowth. In the upper part of the sheet in drill hole 5, however, the feldspar is predominantly or exclusively a film microantiperthite. The lower stratigraphic facies usually carry accessory hornblende and locally a trace of augite or biotite, whereas the mafic mineral in the upper facies is pyroxene. The mafic minerals are partly chloritized. Oxide minerals and small zircon crystals are present as accessory minerals in all the microantiperthite alaskite.

The central part of the sheet (zone D) in holes 1, 2, and 3 is albite-oligoclase alaskite. This rock is about 115 feet thick in holes 1 and 2 and 40 feet thick in hole 3; it was not found in holes 4 and 5. The albite-oligoclase alaskite is pale gray, locally pink, mottled with reddish or reddish-brown disseminated feldspar grains, and medium grained (±1 mm). The normal feldspar throughout is a twinned albite-oligoclase. A few grains have a slight film or less often a little coarse irregular bleb-shaped intergrowth of potash feldspar. Rarely there is a facies containing some feldspar grains that have a core of normal typical film potash-feldspar microantiperthite; no typical microcline patch microantiperthite was seen. All gradations between film microantiperthite and a coarser recrystallized irregular narrow bleblike intergrowth are present. Also, though rarely, albite replaces the film antiperthite systematically as lamellae across the orientation of the films. Albite-oligoclase with potash-feldspar intergrowths usually have a clear selvage. At least part of the reddish-brown feldspar grains have a microscopic intergrowth of extremely small thin platelets, presumably hematite. Iron and iron-titanium oxides are uniformly present as accessory minerals throughout the rock. Indeed, magnetite is the most commonly noted accessory in much of the rock. Pyroxene and, to a lesser extent, apatite occur as accessory minerals in most of the alaskite. Small zircon crystals are present occasionally. The augite is in part altered to chlorite, locally with sphene, and the ilmenite may be changed to leucoxene. Sparse hornblende is present sporadically.

At the contacts between the albite-oligoclase alaskite and amphibolite an inch or so of pseudodiorite, a clinopyroxene-plagioclase rock, is present on the amphibolite side. The contact between the albite-oligoclase alaskite and the pseudodiorite is sharp. There is much more magnetite in the pyroxene pseudodiorite facies than in the normal hornblende-plagioclase amphibolite.

The alaskite sheet contains two thin lenticular layers of pyroxenic quartz-plagioclase gneiss. Some of this rock contains as much as several percent of disseminated sphene and is interpreted as metasedimentary in origin. In part the beds of paragneiss form septae between the lowest part of the albite alaskite sheet and the microantiperthite alaskite. Pyroxene-microantiperthite syenite and pyroxenic quartz-albite pegmatite occur with the pyroxenic quartz-plagioclase gneiss beds. Occasional thin layers of amphibolite are also included in the alaskite.

In hole 11 this composite sheet of alaskite, between intercepts on the core of 901 and 1,329 feet, is about 300 feet thick; about 170 feet (964–1,207 ft.) of the sheet is albite-oligoclase alaskite. In most respects the sheet is similar to that in hole 2. In hole 7 the sheet is composed largely of microantiperthite granite (1,642-1,978 ft.), with a considerable number of these amphibolite layers (1,642–1,850 ft.) and with much interlayered amphibolite (1,850–1,907 ft.). Very little rock that might be albite-oligoclase alaskite was identified in hole 5, 6, or 7. Accordingly, the bottom of the albite-oligoclase sheet must have a gentle plunge to the northeast, analogous to the ore shoot in zone B.

MIXED AMPHIBOLITE AND GREEN MICROANTIPERTHITE SYENITE AND GRANITE

[Zone E, pl. 14]

The composite alaskite sheet (D) is overlain by a zone (E), 40–60 feet thick, composed of mixed amphibolite and dark-green microantiperthite syenite and granite. The ratio of the amphibolite to the green rocks increases in the lower holes, whereas pyroxene-microantiperthite syenite or quartz syenite is predominant in drill hole 1. The microantiperthite rocks include clinopyroxene-, clinopyroxene-orthopyroxene-, or orthopyroxene-microantiperthite syenite (in part more or less albitized), clinopyroxene-microantiperthite granite, hypersthene-microantiperthite granite and local lenses of pyroxene pseudodiorite in which the pyroxene may be orthopyroxene alone or clinopyroxene alone. Oxide minerals are present as accessories in all the rocks except for much of the biotitic hornblende-plagioclase amphibolite. The pyroxenic facies of the amphibolite carries magnetite. Apatite is an accessory mineral in all the rocks. Local pegmatite veins, a foot or so wide, also are present, as are facies of the amphibolite thought to be modified by solutions from the intrusive bodies. A layer of the amphibolite, an inch or so thick, adjacent to the microantiperthite igneous rocks is reconstituted to a pyroxene (hypersthene in part)–plagioclase gneiss; the reconstituted rock contains no potash feldspar. The contact between antiperthitic and nonantiperthitic facies is sharp. Rarely the feldspar of the pyroxene syenite is microperthite, and accordingly the rock is a green pyroxene-microperthite syenite (drill hole 4, 1,783 ft.) with several percent of quartz. The pyroxene syenite commonly contains as much as several percent of magnetite.

This unit of dark-colored rocks is slightly thicker in hole 11 than in the fan of holes 1–5. Here it is about 90 feet thick (757–901 ft.), and it consists predominantly of green pyroxene syenite and pyroxene syenite pegmatite, with some green pyroxene granite. Amphibolite is minor. Eighteen hundred feet southwest of the section (holes 1–5), in hole 7, this unit appears to be represented entirely by about 60 feet of amphibolite.

COMPOSITE SHEET OF MICROANTIPERTHITE ALASKITE AND ALBITE-OLIGOCLASE ALASKITE

[Zone F, pl. 14]

A composite alaskite sheet (zone F) overlies the zone of mixed rock (E). The sheet is about 110-130 feet thick in holes 5, 4, and 3, but thickens to about 200 feet in hole 2, and must be more than 200 feet thick in hole 1. Similarly to the composite alaskite sheet (D), the thickening of the sheet largely is the result of the thickening of a zone of albite-oligoclase alaskite in its central part. (See pl. 14.)

The rocks within the zone have a uniform grain size and a strongly developed gneissoid structure. The feldspar and quartz grains are mostly 1 to 4 mm in breadth, but the quartz grains generally are elongate and are 3 to 6 mm long. Many smaller grains of both minerals are present in the groundmass. Texturally, the rock in general is of coarse-medium grain. At places the alaskite contains thin amphibolite layers that constitute 1 or 2 percent of the whole; rarely, a layer of pyroxenic quartz-plagioclase gneiss is present in the alaskite.

The alaskite has three mineralogical facies. In the lower part of the sheet the alaskite contains three varieties of feldspar—clear albite, film microantiperthite, and patch microantiperthite; in the central part of the sheet the feldspar is albite-oligoclase; and in the upper part of the sheet the feldspar is almost entirely a microantiperthite with patch intergrowths of microcline.

The rock of the lower stratigraphic part is greenish white to pale greenish gray. The feldspars include three varieties which vary greatly in their ratio to each other: one is a clear albite, another a plagioclase with varying amounts of microantiperthite film intergrowth of potash feldspar, and a third is plagioclase with a coarse microantiperthitic patchwork intergrowth of microcline. In drill hole 5 (2,105 ft.) the normal green alaskite shows ramifying, pink, veinlike facies (pl. 21*A*). Examination under the microscope shows that there is a much higher percentage of microantiperthitic patchwork microcline in the plagioclase of the pink alaskite and higher percentage of plagioclase with microantiperthitic film intergrowth of potash feldspar in the green alaskite. This is interpreted to indicate that the solutions which produced the change in color from green to pink also permitted the segregation of the films of potash feldspar in the primary antiperthite into patches of microcline. The microcline within the patches commonly has a breadth of 0.2 to 0.4 mm, though locally the microcline has exsolved largely to the borders of the plagioclase where it may form grains as much as 0.8 mm in size. Some of the quartz grains in rock near the central part of the sheet contain a trace of microscopic small needles, possibly rutile.

The central part of the alaskite sheet is an albite-oligoclase facies, with little or no microantiperthitic intergrowth of potash feldspar. The color is pale gray with a greenish tint, usually with a few reddish feldspar grains. It is very similar to the albite-oligoclase alaskite of the alaskite sheet D, except that it is of slightly coarser grain.

The rock in most of the upper part of the sheet is pale pinkish to pinkish white, though locally it is pale greenish. The feldspar is almost exclusively a microantiperthitic plagioclase with a patchwork intergrowth of microcline of the same size as that in the northwest part of the sheet. Locally the microcline forms a selvage completely around a plagioclase grain. The quartz grains characteristically have an abundant microscopic intergrowth of very thin needles, possibly rutile, which are about 0.01 to 0.10 mm long and are arranged on parallel planes intersecting at an angle. The needles are not present in the quartz of the uppermost part of the sheet.

The needles of rutile(?) in the quartz correlate with the presence of strained quartz and slip surfaces of cataclastic crushing through the central part of the sheet; possibly they are the product of exsolution accompanying the deformation. The laminae of crushed quartz are parallel to the foliation and occur in both the microantiperthite alaskite and the albite alaskite. The rock of the entire sheet in hole 1 shows no crushing and no needles in the quartz.

The rock overlying the pink patch microcline-microantiperthite alaskite is a thin sheet of hornblende-microperthite granite, part of zone G. It is possible that solutions from the magma that yielded the hornblende granite permeated an adjacent film microantiperthite alaskite and permitted its recrystallization to a patch microantiperthite facies, though this is dependent on the microperthite granite being younger, which is not known.

In hole 11 (900 ft. northwest of hole 2) the composite alaskite sheet (zone F) is thicker (320 ft. thick, 284–757 ft. intercepts) than in the fan of holes 1 to 5 and has a central portion of albite-oligoclase alaskite about 65 feet thick (429–520 ft.). To the southwest the albite-oligoclase alaskite is present in hole 6 but was not found in hole 7.

ZONE OF MIXED METASEDIMENTARY GNEISSES AND AMPHIBOLITE

[Zone G, pl. 14]

Between the composite alaskite sheet of zone F below and a sheet of hornblende microperthite granite (hornblende granite of Sims) above there is a zone of heterogeneous layered gneisses and granite sheets 275 to 325 feet thick. The zone consists largely of pyroxenic quartz-oligoclase gneiss and amphibolite, but it also contains local sheets of hornblende-microperthite granite associated with the thicker amphibolite layers, a sheet of hypersthene-microantiperthite granite, small lenses of clinopyroxene-microantiperthite granite and hypersthene-microantiperthite quartz syenite, local layers of migmatitic biotite-quartz-plagioclase gneiss and migmatitic amphibolite and lenticular bodies of plagioclase alaskite pegmatite, and local "beds" consisting of thin-layered (fractions of an inch) amphibolite and light-colored pyroxenic plagioclase gneiss. The pyroxene-microantiperthite granite forms thin-layered migmatitic zones with amphibolite. Biotite is associated with the hornblende in such rocks. The

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pyroxenic quartz-plagioclase gneisses, pyroxene-plagioclase gneiss, amphibolite, and biotite-quartz-plagioclase gneiss are all interpreted as metasediments; the pink hornblende-microperthite granite, green pyroxene-microantiperthite granite, and plagioclase pegmatite probably are intrusive igneous rocks.

The distinction between thin-layered metasedimentary beds and thin microantiperthite granite laminae is not possible except by examination under the microscope.

This zone of heterogeneous dark gneisses thickens greatly to the southwest. In hole 7, which is 1,800 feet southwest, it probably is about 800 feet thick (125–1,345 ft.), and consists of amphibolite, pyroxenic amphibolite, pseudodiorite, dark-green pyroxene-microantiperthite granite and syenite, pyroxene-quartz-oligoclase gneiss, and a thick sheet (between 357- and 751-ft. intercepts on core) of largely uniform microantiperthite alaskite. In hole 11 (900 ft. northeast) this unit appears to be represented by the rock between core intercepts of 18 feet and 284 feet and consists of pink microperthite alaskite and two layers of amphibolite.

AMPHIBOLITE

Amphibolite occurs as several layers of sufficient thickness and continuity to serve as stratigraphic "marker beds," as layers a few inches to a few feet thick interlayered with pyroxene-quartz-plagioclase gneiss of presumed metasedimentary origin, and as included layers and schlieren within all the granites.

The normal country-rock amphibolite is a hornblende-plagioclase gneiss, in part slightly biotitic. The feldspar grains often are clouded. This rock at the contact with granite or granitic stringers and in local layers is transformed to a clinopyroxene-plagioclase gneiss, in part with minor orthopyroxene. The clinopyroxene-bearing gneiss commonly has less mafic minerals and more plagioclase than the hornblende amphibolite. It carries as much as several percent accessory magnetite, which is absent or sparse in the normal amphibolite; and it also contains large apatite grains (as much as 1 mm in length) which also are generally absent or small and meagre in the normal amphibolite. The amphibolite immediately adjacent to the clinopyroxene-plagioclase gneiss may in part show pyroxene as partial replacement of hornblende and highly clouded plagioclase with many altered grains. Adjacent to the sheets of hornblende-microperthite granite, laminar veinlets of microperthite alaskite may occur in the amphibolite, with associated development of both clinopyroxene- and orthopyroxene-plagioclase gneiss from the amphibolite. The amphibolite commonly has a good foliation but the reconstituted pyroxene-plagioclase facies is more massive pseudodiorite.

PYROXENE-QUARTZ-OLIGOCLASE GNEISS

The other major metasedimentary gneiss, in addition to amphibolite, is a green to pale-greenish-gray pyroxenic quartz-oligoclase gneiss that contains from 5 to 25 percent of intermixed layers of amphibolite. These gneisses are heterogeneous on a small scale and have local lenses and sheets of green pyroxene-microantiperthite granite. Adjacent to the granite contacts the amphibolite has been altered for a distance from 5 mm to several centimeters. The contact-metamorphic rock contains both clinopyroxene and orthopyroxene. Potash feldspar is absent. The lower zone of gneiss contains a thin central "bed" of migmatitic biotite-plagioclase gneiss. The introduced vein material of the migmatite is microantiperthite alaskite.

The pyroxene of the gneiss is either a dark-green clinopyroxene or an orthopyroxene, generally largely altered. Locally there may be a little associated hornblende. Iron oxides and apatite are present as accessory minerals. The mafic minerals at most constitute only a few percent of the rock. The plagioclase in some of the gneiss has a slight microantiperthitic intergrowth of potash feldspar. Rarely within the gneiss there is a pyroxene skarn aggregate a foot or so thick.

HORNBLENDE-MICROPERTHITE GRANITE AND ALASKITE

[Zone H, pl. 14]

The uppermost zone (H) of rock intersected by holes 2–5 consists of a pink fine-medium grained granite or alaskite and equivalent gneiss. The rock varies from a granite with several percent of dark minerals to an alaskitic facies with only a percent or two of mafic minerals. The structure varies from that of a gneissoid granite to a fine-grained (average, 0.5 mm) granoblastic gneiss. The prevailing gneissoid hornblende-microperthite granite and alaskite consists of microperthite, quartz, and subordinate plagioclase as major minerals, with a variable amount of hornblende and iron oxides and accessory zircon. Apatite is rare. A small amount of myrmekite is present locally. The potash feldspar locally shows an indistinct microcline grid. The gneissoid structure is due to the dimensional orientation of inequidimensional feldspar and quartz grains. The size of the feldspar grains is variable and the finer grained aggregates could be interpreted as due to crushing and recrystallization in the magmatic stage. The smaller grains also are microperthite; they have an interlocking texture.

The fine-grained granoblastic gneiss consists of a mosaic of potash feldspars, plagioclase, and quartz with hornblende in part altered to chlorite and magnetite. Grains of iron oxides and zircon are accessory minerals. The potash feldspar is in part clear microcline and in part has no distinct microcline twinning but contains a small intergrowth of albite. The gneiss is interpreted to be the product of recrystallization and deformation at a lower temperature range than that for the development of the gneissoid structure.

Hole 6, which is 1,000 feet southwest, is collared in pink hornblende-microperthite granite (15–102 ft.), and hole 7, which is 1,800 feet southwest, also is collared in a pink pegmatitic hornblende granite. Possibly hole 11 (900 ft. northeast) also started in the microperthite granite, but the microantiperthite alaskite sheet (F) definitely starts at intercept 240 feet in the drill core.

INTERPRETATION OF ORIGIN OF THE ROCKS

METASEDIMENTARY GNEISSES

The amphibolites, pyroxenic quartz-plagioclase gneiss, and biotitic hornblende-plagioclase gneisses with mosaic texture, and biotitic plagioclase gneiss with varying amounts of quartz are all interpreted as metasedimentary in origin and as part of the original country rock. This interpretation is not based on positive criteria, as one would like, but results from a balancing of probabilities. The major lines of reasoning are based on the repeatedly interlayered character of these types of rock, occasionally on a very small scale; the association of accessory graphite with similar biotitic plagioclase gneisses in adjoining areas of New Jersey; and the conclusions of geologists in general based on studies of metamorphic rocks that layers of this nature may result from reconstitution, with different degrees of modification, from sedimentary rocks.

IGNEOUS ROCKS, GENERAL

Fundamentally there are two major groups of igneous rocks intersected by the drill holes. One group includes the pink hornblende-microperthite granite with its alaskitic facies and local equivalent hornblende-microcline-plagioclase gneiss (the hornblende granite and alaskite of Sims). The other group includes a series of rocks characterized by variable, but generally small, quantities of pyroxene and the predominance of a sodic plagioclase. This rock varies from one in which the plagioclase and potash feldspar are approximately equal in volume in a microantiperthitic (actually, though rarely, microperthitic) intergrowth to one in which the feldspar is almost exclusively albite-oligoclase (the albite-oligoclase granite of Sims). The rocks in this group may also contain facies that vary from pyroxene syenite and pyroxene granite to alaskite. Alaskite is by far the predominant facies. Northwest of the Dover district, pyroxene-microantiperthite granite and syenite occur in large volume. The pyroxene-microantiperthite alaskite in the Hibernia cores has sharp contacts with the darker green pyroxene syenite and granite and is reasonably interpreted as a younger member of a related group of rocks.

All these rocks have been interpreted by Sims as igneous rocks formed by crystallization from magma, and this is consistent with the data obtained from the cores at the Hibernia mine.

The relative age relationship between the green pyroxene-microantiperthite group of rocks and the pink hornblende-microperthite granite and alaskite has not been determined for the Hibernia cores.

ORIGIN OF MICROANTIPERTHITIC INTERGROWTHS

The microantiperthitic intergrowths in the feldspars (pls. 21*B*, *C*, and 22*A*–*C*) of the alaskites are highly variable. They range from a uniform film microperthite or film microantiperthite (pl. 21*B*) through an irregular bleb intergrowth (pl. 21*C*) to a coarse microcline patch microantiperthitic intergrowth (pl. 22*A*–*C*) or a mixture of film and bleb, or a mixture of film, bleb, and patch fabrics. There may or may not be an increase in the ratio of albite to potash feldspar in the coarser intergrowths. The film microantiperthite is a texture which is best interpreted as the product of exsolution from a primary homogeneous anorthoclase. The bleb and patch microcline intergrowths grade into the film type. The coarsening of the intergrowth through bleb to patch fabric is often accompanied by an increase in the amount of albite which in part has a replacement relationship. The bleb and microcline patch microantiperthite is interpreted as the product of aggregation and recrystallization of the primary film potash feldspar into coarser particles. In large part this was probably facilitated by solutions the same as or similar to those which effected the partial albitization where this occurs. The patch microcline microantiperthite in all cases has the appearance of a replacement relationship to the plagioclase. This need not mean, however, that the microcline has been introduced from outside the system. Not only has no example been found which requires the introduction of potash, but, on the contrary, microcline patch microantiperthite has been formed to a substantial extent during the introduction of albite which has effected a partial replacement of the primary potash feldspar in the film microantiperthite. There is at least no more microcline in any of the patch microantiperthite than there was in the primary film microantiperthite, and in much of the rock there is less. The microcline patch antiperthite can be adequately explained as the product essentially of the intermigration of potash and sodium atoms in such a fashion that the potash feldspar originally present as films is in part or as a whole aggregated into a patch network which has a replacement relationship to the plagioclase. Such aggregation may have taken place (1) under the influence of soda-bearing solutions which developed the intermediate partly albitized microantiperthite alaskite, (2) in the presence of late-stage volatile-rich solutions which permitted the development of the pink coarse-grained and pegmatitic facies of the alaskite, and perhaps (3) in the presence of solutions which may have originated in the magma which yielded the hornblende-microperthite granite, if this is younger.

Alkali determinations were made on several samples of these rocks, and the data are given in the table below.

	H-2 (1417)	H-4 (2286)	H-2 (1285)	H-5 (2326)
Na_2O	6.70	5.24	4.79	3.98
K_2O	.85	2.89	3.04	4.08
Equivalent albite	91.9	72.0	69.2	58.2
Equivalent potash feldspar	8.1	28.0	30.8	41.8

NOTE.—Analyst, Doris Thaemlitz, Rock Analysis Laboratory, University of Minnesota.

H-2 (1417 ft). Albite-oligoclase granite. Only local slight intergrowth of potash feldspar.
H-4 (2286 ft). Microantiperthite alaskite, patch intergrowth of microcline in plagioclase, local relicts of bleb and film intergrowth.
H-2 (1285 ft). Microantiperthite alaskite, patch intergrowth of microcline in plagioclase, local relicts of bleb and film intergrowth.
H-5 (2326 ft). Microantiperthite alaskite, film intergrowth only between potash feldspar and plagioclase.

ORIGIN OF ALBITE-OLIGOCLASE ALASKITE

The microantiperthite granite and alaskite in part show such a degree of partial replacement by albite that the hypothesis must be considered that the albite-oligoclase alaskite (pl. 22*D*) is simply an end product of such a replacement to a more intensive degree.

The arguments against a replacement origin follow. No local facies has been found within the areas of partially albitized microantiperthite alaskite where the albitization has gone to completion to yield an albite-oligoclase alaskite. The albite-oligoclase alaskite sheet (zone A of pl. 14) occurs as a uniform homogeneous body independent of any microantiperthite alaskite, and its contacts with the amphibolite layers are sharp. The amphibolitic layers B and E are about 230–240 feet apart in holes 4 and 5 but are 360–400 feet apart in holes 1 and 2. This difference could be largely accounted for if it is assumed that the albite-oligoclase alaskite, which is about 120 feet wide in holes 1 and 2 and is missing in holes 4 and 5, was emplaced as a magma intrusion which spread its walls apart. Similarly, the amphibolitic layers above and below the alaskite sheet (zone F) are wider apart in hole 2 by about the same amount as the increase in thickness of the central albite-oligoclase alaskite part ot the composite alaskite sheet (zone F). All the contacts between the amphibolites and the albite-oligoclase alaskite are sharp and not gradational. Actual contacts between the albite-oligoclase alaskite and microantiperthite alaskite have not been identified, but the two rocks have been studied within a few feet of each other in several places. No systematic variation in the degree of albitization of the microantiperthite alaskite relative to the albite-oligoclase alaskite has been found. A gradation might be expected between them if the albite-oligoclase alaskite were due to albitization of the microantiperthite alaskite. One of the accessory oxides is ilmenomagnetite carrying about 3 percent TiO_2. Ilmenite with exsolved intergrowths of hematite films also occurs as an accessory oxide. Such oxides are appropriate as crystallization from a residual magma rich in volatile constituents.

The arguments in favor of an origin of the albite-oligoclase alaskite by albitization of the microantiperthite alaskite follow. Locally throughout the albite-oligoclase alaskite there are facies in which the plagioclase has a little microantiperthitic intergrowth of potash feldspar similar to the partly albitized microantiperthite. The albite-oligoclase alaskite in the central zone of the composite alaskite sheet (zone F) has the same grain size and strongly gneissoid structure as the enclosing microantiperthite alaskite. Both of these phenomena, however, might be expected, since the albite-oligoclase alaskite, if formed from a magma, certainly formed from one which was directly related to and a late stage of the magma which yielded the film microantiperthite alaskite.

Another possibility is that the albite-oligoclase alaskite represents a recrystallization of pyroxenic quartz-plagioclase paragneiss. There are thin layers of such gneiss adjoining the albite-oligoclase granite in zone D, holes 2 and 3, and plagioclase gneiss occurs where the albite-oligoclase granite might be expected to occur in the equivalent of zone D in hole 6. No confirmatory evidence for this mode of origin, however, was seen.

An hypothesis which fits the data would be that the albite-oligoclase alaskite is a late magmatic residuum from crystallization of a main mass of magma which yielded both the microantiperthite alaskite and the more sodic type. The latter has moved somewhat relative to the former. Some modification and replacement of primary, somewhat more potash-rich, crystallized parts of the albite-oligoclase alaskite has been effected by late-stage sodic fluids.

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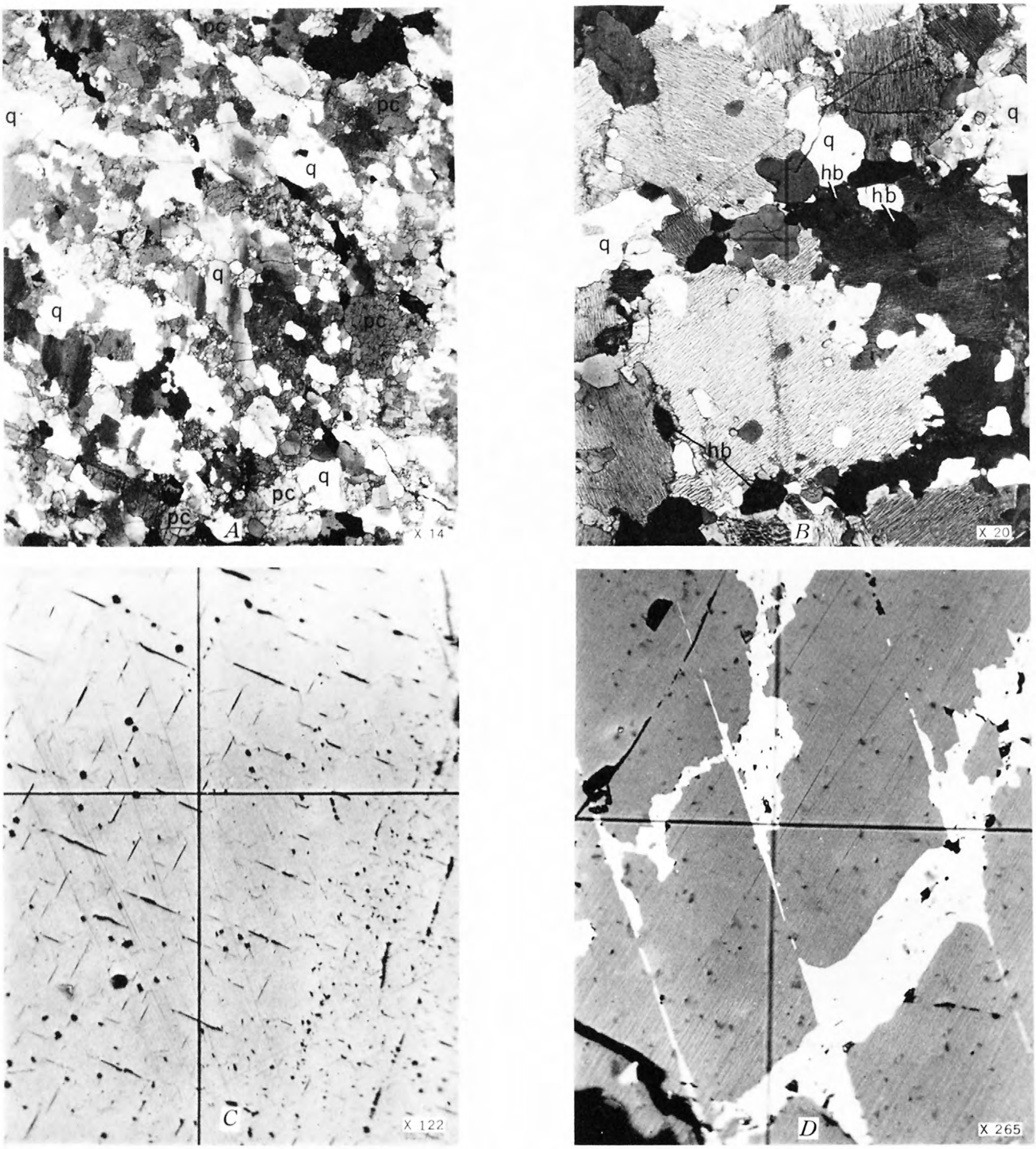
INDEX

AERIAL PHOTOGRAPH OF THE REGION NEAR WHITE MEADOW LAKE

Shows contrast in topography of terminal moraine of Wisconsin glacial stage and the pre-Cambrian bedrock. Note transverse valley developed along trace of Mount Hope fault.

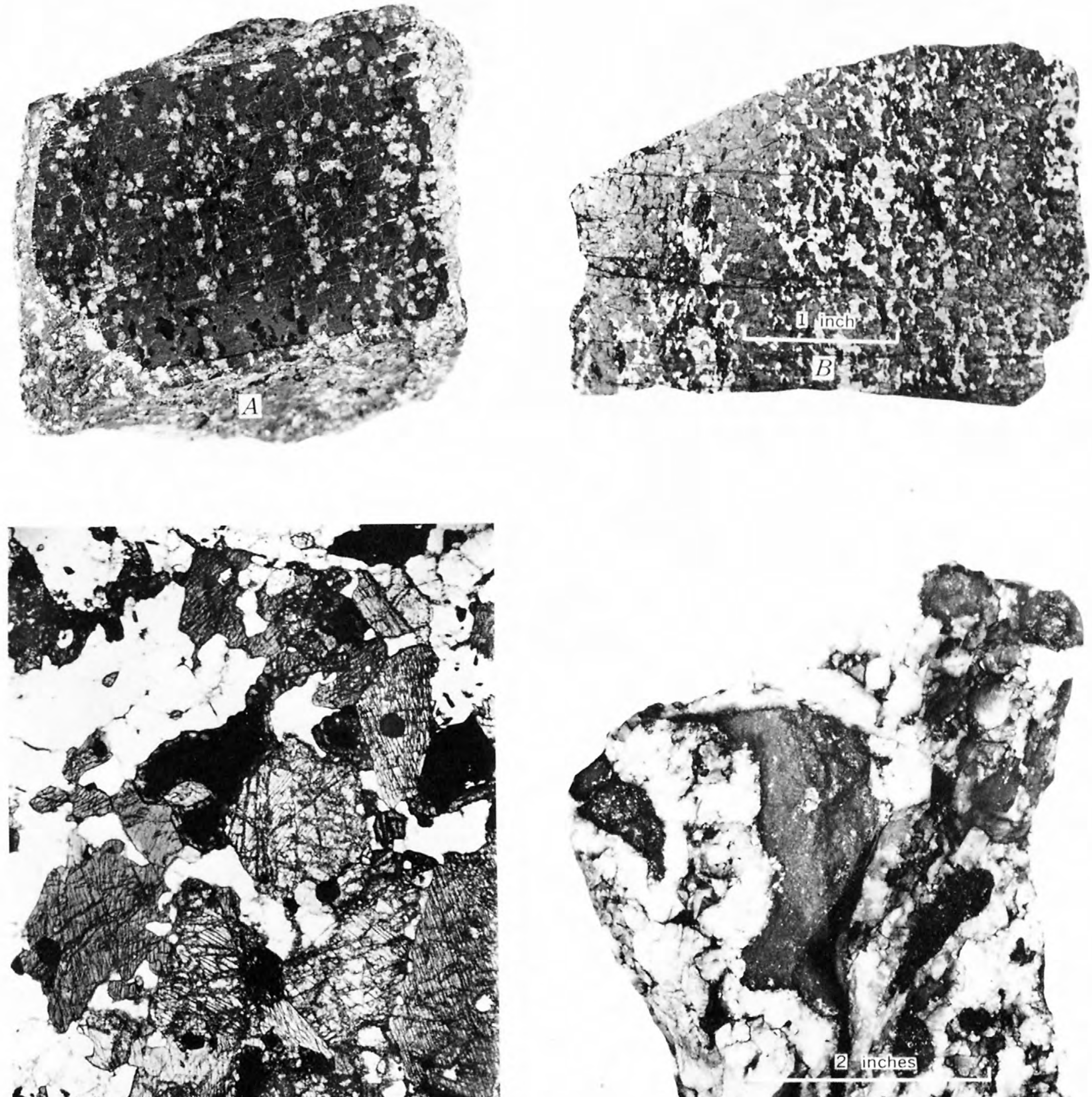


A. Photomicrograph of oligoclase-quartz-biotite gneiss from Finley deposit, Mount Hope mine. Shows cataclastic texture formed by pre-ore microbrecciation. The quartz is sutured and shows strain shadows; the oligoclase contains some orthoclase in antiperthitic intergrowth. Black areas are magnetite; *q*, quartz; *pc*, oligoclase. Biotite is sparse. Crossed nicols. × 14.

B. Photomicrograph of hornblende granite exposed in road cut on southwest side of Salem Street in Dover. Shows normal primary interlocking texture. The quartz is intergrown with and is included within the microperthite. *q*, quartz; *hb*, hornblende. Crossed nicols. × 20.

C. Photomicrograph of polished specimen of magnetite from dump at Pardee mine. Magnetite (gray) contains oriented laths and scattered blebs of spinel. The spinel was exsolved from the magnetite on cooling and formed along the octahedral planes of the magnetite. × 122.

D. Photomicrograph of polished specimen of ore from level 5 of Scrub Oaks mine, showing incipient martitization. Martite (white) replaces magnetite (gray) as thin blades and as nearly parallel ragged veinlets along the octahedral planes of the magnetite. The veinlets extinguish simultaneously; the blades extinguish separately from the veinlets. × 265.

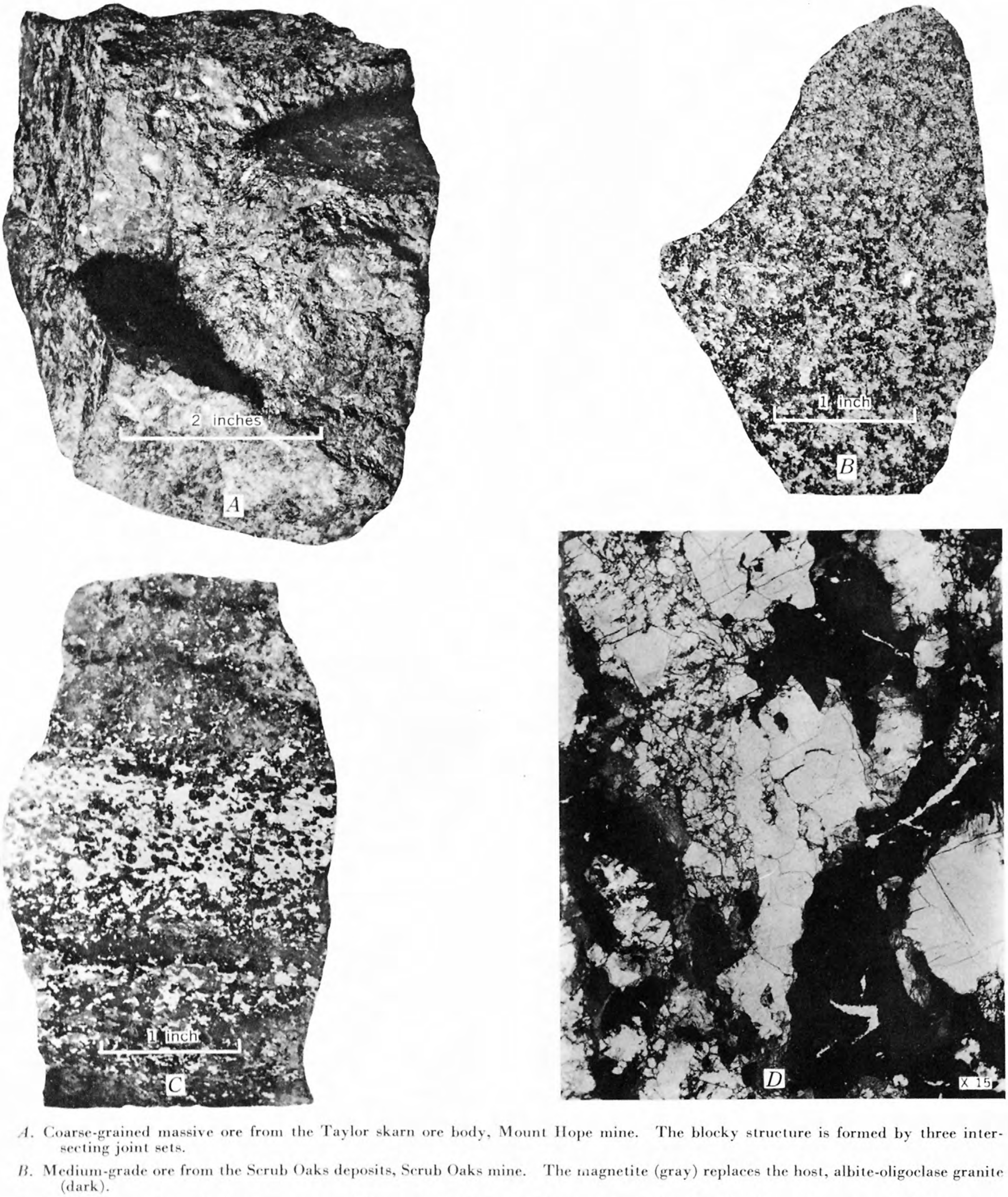


A. Massive ore in oligoclase-quartz-biotite gneiss from Mount Hope mine. The ore consists of aggregates of magnetite grains and contains several percent of apatite (light gray) and pyroxene (black). The apatite laminae are essentially parallel to the walls of the ore. Princeton Museum specimen 11430.

B. Low-grade ore from Canfield's phosphate shaft. The magnetite (white) corrodes and surrounds the apatite (gray).

C. Photomicrograph of migmatized amphibolite from footwall of Mount Pleasant ore body, level S 1,100 W, Richard mine. Sphene (dark gray) rims magnetite (black). Plain light. × 35.

D. Magnetite breccia from Richard ore body, Mount Hope mine. The magnetite fragments (black) are cemented by quartz (white) and carbonate (gray).

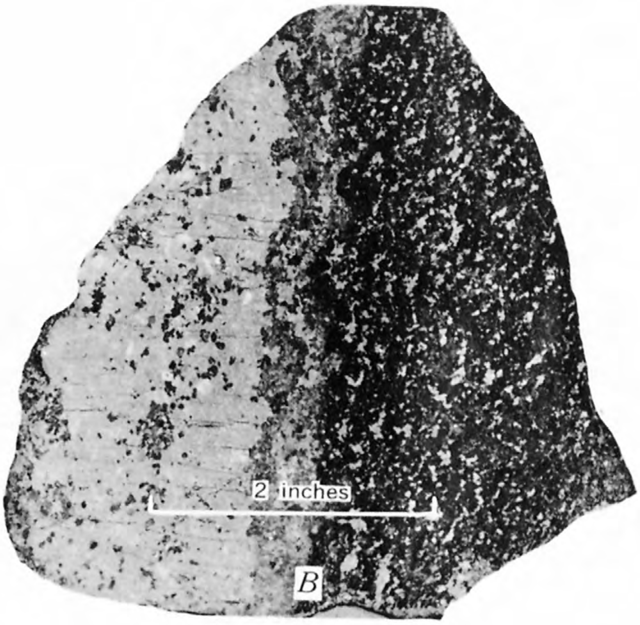


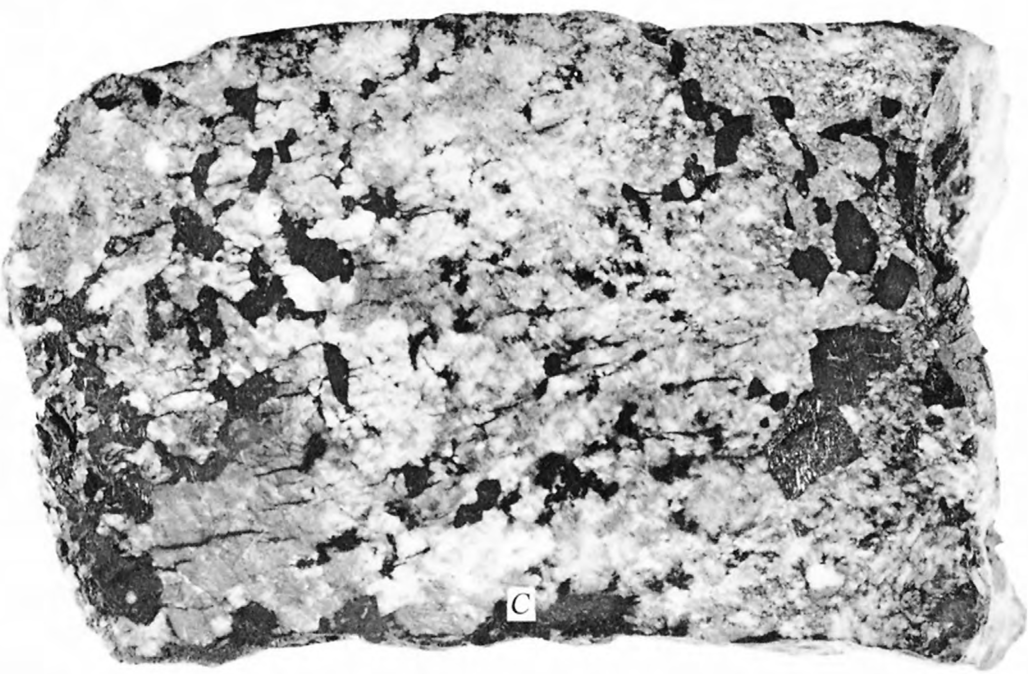
A. Coarse-grained massive ore from the Taylor skarn ore body, Mount Hope mine. The blocky structure is formed by three intersecting joint sets.

B. Medium-grade ore from the Scrub Oaks deposits, Scrub Oaks mine. The magnetite (gray) replaces the host, albite-oligoclase granite (dark).

C. Low-grade ore from the Lee Hart mine. The magnetite (white) embays and corrodes the oligoclase and quartz of the host rock, oligoclase-quartz-biotite gneiss.

D. Photomicrograph of low-grade ore in oligoclase-quartz-biotite gneiss from the Brotherton mine. Magnetite (black) embays the host along granulated zones formed by pre-ore microbrecciation.

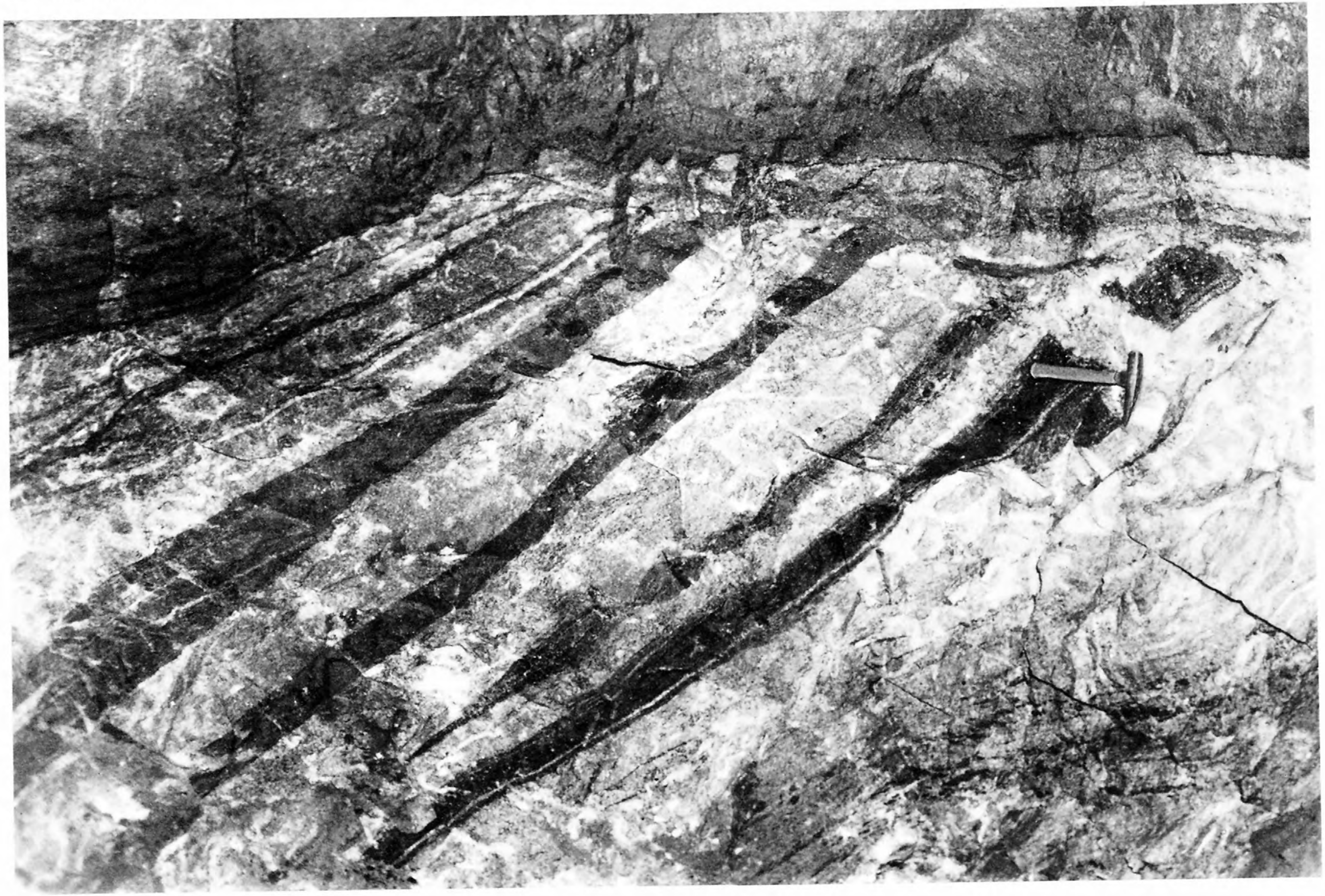




A. Photomicrograph of ore in hornblende skarn from Mount Pleasant ore body, 1,300-foot level, Richard mine. The magnetite embays and corrodes the hornblende. Plain light. $\times$ 15.

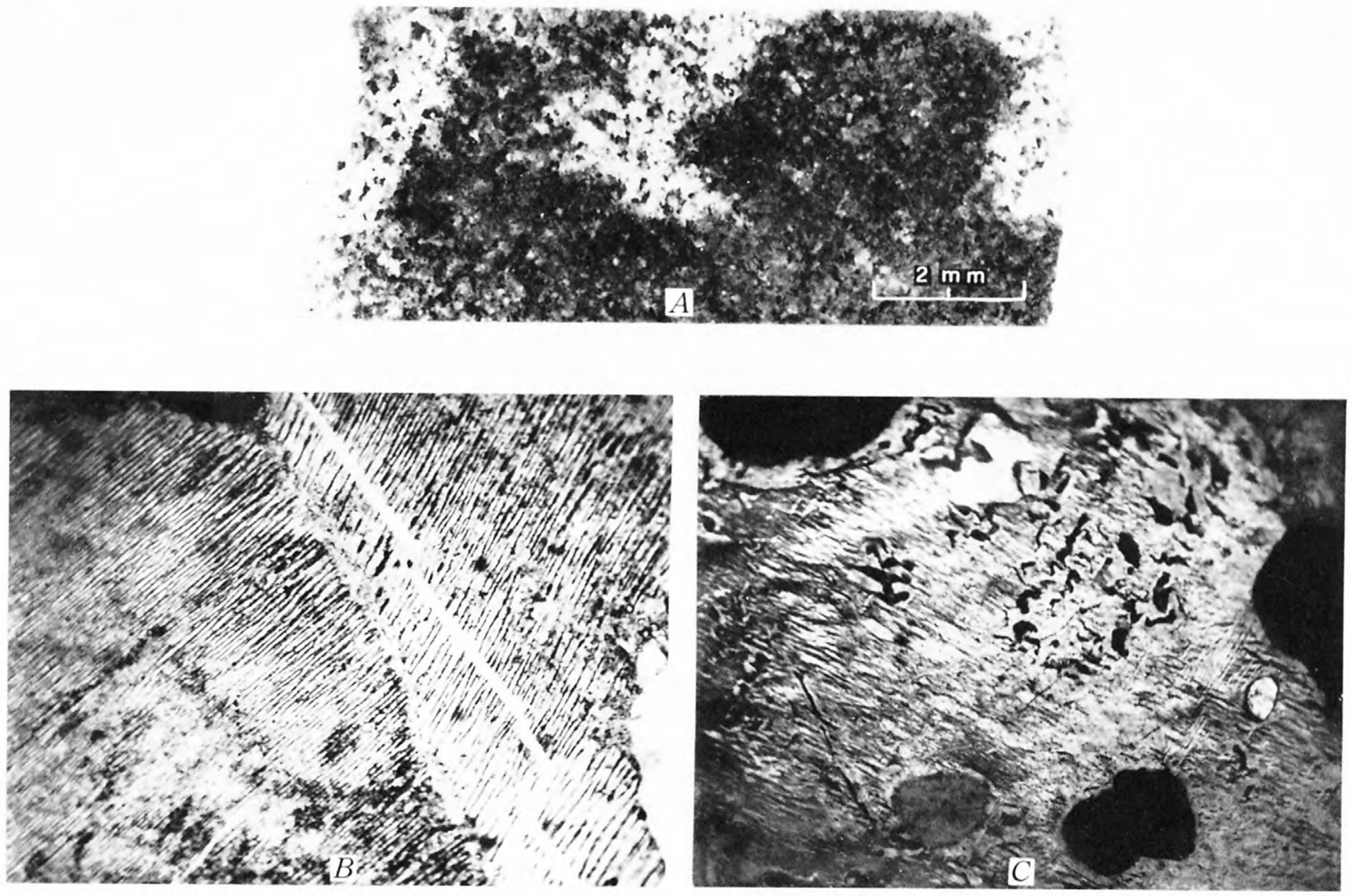
B. Magnetite in pyroxene rock, Hibernia mine. The magnetite (light gray) selectively replaces green pyroxene, an alteration product of hornblende amphibolite. Scattered, irregular blebs and veinlets of magnetite also occur in the amphibolite.

C. Magnetite in granite pegmatite. The magnetite occurs as (1) large subhedral to euhedral grains, (2) irregular grains and aggregates that embay feldspar grains, and (3) thin vienlets along cleavage planes of the feldspar. The feldspar locally is green. Mount Hope mine. Princeton Museum specimen 11420. Natural size.



FOOTWALL OF MOUNT PLEASANT ORE BODY, A SKARN DEPOSIT, LEVEL N 1,300 W, RICHARD MINE

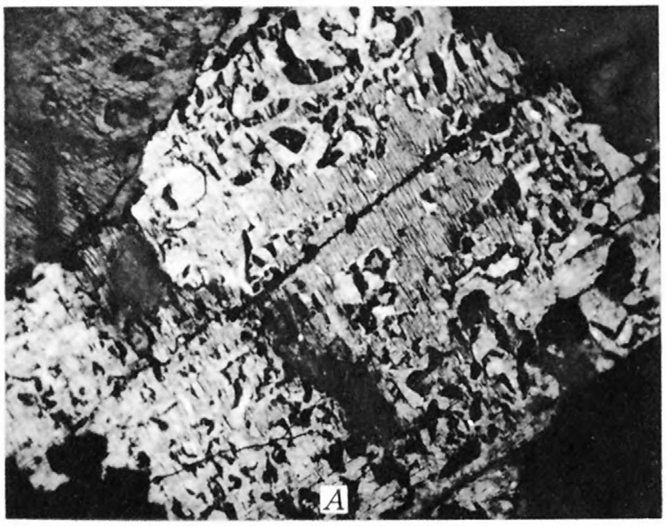
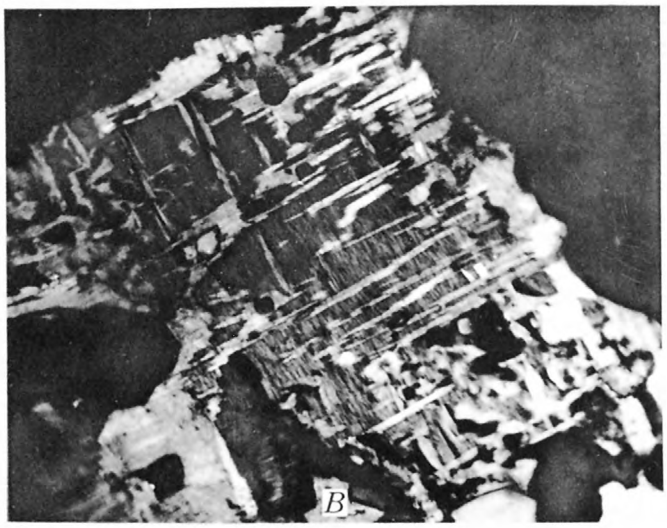
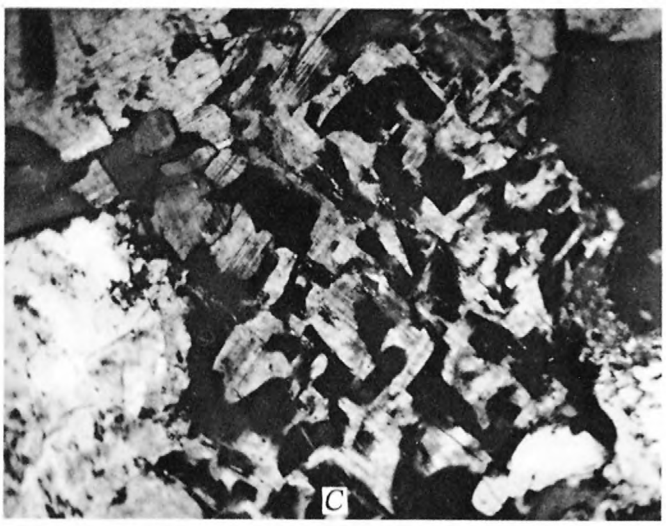
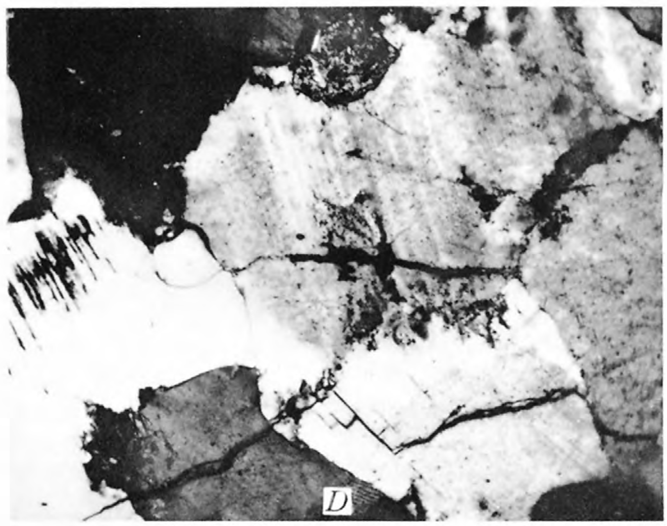
The ore (dark gray) at top of photo cuts sharply across the alaskite wall rocks. The thin layers of amphibolite in the alaskite show the gneissic structure of the wall rocks.



A. Green-film microantiperthite alaskite (dark) with modified areas (light) of pink-patch microantiperthite alaskite.

B. Film microantiperthite of microantiperthite alaskite. H–5 (2326). Polarized light. × 53.

C. Film microantiperthite of microantiperthite alaskite with incipient development of bleb microcline (black) from film potash feldspar. Polarized light. × 53.

A. Film microantiperthite of microantiperthite alaskite partly replaced by sodic plagioclase with development of patch microcline (black) antiperthite. H-4 (2286). Polarized light. × 53.

B. Film microantiperthite of microantiperthite alaskite partly replaced by sodic plagioclase with incipient development of patchmicrocline (black). Polarized light. × 53.

C. Sodic plagioclase of microantiperthite alaskite with patch microcline (black) developed from film microantiperthite by partial replacement and recrystallization. Polarized light. × 53.

D. Albite-oligoclase of albite-oligoclase alaskite. H-2 (1417). Polarized light. × 53.