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GEOLOGICAL SURVEY BULLETIN 969-A

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1949–50

DIAMOND-DRILL EXPLORATION OF THE DILLSBURG MAGNETITE DEPOSITS, YORK COUNTY, PENNSYLVANIA

By Preston E. Hotz

ABSTRACT

Here presented are the results of geologic studies of the magnetite deposits near Dillsburg, York County, Pa., made by the Geological Survey in cooperation with a program of exploration conducted by the United States Bureau of Mines from March 1945 to June 1946.

The deposits, which were actively mined for 60 years beginning about 1855, are replacement deposits similar to those at Cornwall, Pa.[1] Magnetite has replaced parts of lenticular beds of limestone conglomerate in the Triassic sedimentary rocks (Gettysburg shale). Mineralization took place in conjunction with the intrusion of diabase, which produced strong metamorphic effects in the sedimentary rocks.

The magnetite deposits replace local beds within a tabular plate of sedimentary rocks 200 to 300 feet thick enclosed between two flat-lying, discordant intrusive diabase sheets. The thin upper sheet is interpreted as an offshoot from the larger, underlying sheet of diabase. The lower diabase, because of its great thickness and consequent slow cooling, differentiated after emplacement and produced a layer of granophyre, which lies between about 210 and 300 feet below the upper contact. This differentiation is believed to have produced, also, a more fluid fraction that escaped upward from the diabase and deposited the magnetite in the overlying strata.

The ore occurs in several local shoots within an arc-shaped belt 10,000 feet long and 1,500 to 3,000 feet wide. The ore bodies range in thickness from less than 1 foot to about 30 feet and are flattened lenses dipping in conformity with the bedded structure of the stratified rocks enclosing them.

Drilling by the Bureau of Mines indicates the presence of several additional deposits of magnetite that are comparable in grade, thickness, and extent to those already mined. Magnetic exploration by the Bureau of Mines over known deposits has extended the outlines of areas of possible ore and, in addition, brought to light a heretofore unknown area of attraction. Further drilling will be necessary before dependable calculations of proved ore reserves can be made.

INTRODUCTION

The following report is based on studies made by the Geological Survey in connection with a program of exploration of the magnetite deposits near Dillsburg, York County, Pa., conducted by the United

States Bureau of Mines as part of the investigation of strategic minerals during World War II.

In July 1944 the Bureau of Mines, on the recommendation of the Geological Survey, began a magnetic survey of the Dillsburg iron district. During and following the completion of the magnetic survey in 1945, the Bureau of Mines carried on a diamond-drilling program that was completed in 1946. An area of about 2.5 square miles was explored magnetically, using the Hotchkiss superdip, and 18 drill holes totaling 5,551 feet were put down.

Geological Survey cooperation consisted of studying and logging the drill cores and interpreting the geology with a view to intelligent guidance of exploration. New information on the occurrence of the magnetite deposits and the probable process by which they formed also was sought. The mines have been thoroughly described in the reports of A. C. Spencer (1908, pp. 74–96) and E. C. Harder (1910, pp. 602–612); these descriptions are not included in the present report, which is primarily concerned with interpretation of the geology in the light of the additional information derived from the results of the recent exploration.

The work of the Geological Survey was supervised by A. F. Buddington, who, with H. E. Hawkes, spent several days in the field in 1943 and 1944 and recommended the area for exploration. P. E. Hotz, B. F. Leonard, C. L. Rogers, and A. F. Buddington logged the cores.

During the 60-year period of active mining that began about 1855, approximately 1,500,000 tons of iron ore was taken from more than 30 openings, including open pits and underground workings (Spencer, 1908, p. 74). The Dillsburg district has a greater areal extent than any of the localities furnishing ore of this type except the Cornwall district itself. The ores are commonly referred to as the Cornwall type because they are similar in mineralogy and occurrence to the deposits at Cornwall, Pa., where a very large deposit of magnetite occurs at the contact between calcareous rocks and intrusions of Triassic diabase.

The mines were first described by Frazer in 1877. A detailed report was later made by Spencer (1908). An important discussion of the origin of the magnetite deposits and a somewhat different interpretation of the structure of the deposits near Dillsburg were contributed by Harder (1910, pp. 612–622). Stose and Jonas (1939) prepared a report and map of the geology of York County but mentioned the magnetite deposits only briefly.

GEOGRAPHY

The magnetite deposits are situated 1.5 miles east of the village of Dillsburg in the northwestern part of York County, Pa., about 15 miles southwest of Harrisburg on U. S. Route 15 (pl. 1). A branch of the Reading Railroad running between Harrisburg and Shippensburg passes about 2 miles northwest of Dillsburg.

The terrain beneath which the magnetite deposits lie is a low upland devoted to small farms. Most of the cultivated land is underlain by sedimentary rocks of Triassic age; the land underlain by diabase is less fertile and generally constitutes the woodland areas. The areas of diabase are, in some places, as much as several hundred feet topographically above the areas underlain by sedimentary rocks.

GEOLOGY

The oldest rocks in the area are of Paleozoic age; they lie northwest of Dillsburg, where they are in fault contact with Triassic sedimentary rocks and intrusions of diabase (pl. 2). The Paleozoic rocks include extensive exposures of limestone. The known magnetite deposits are confined to the Triassic rocks.

The Triassic sedimentary rocks in which the magnetite deposits occur are known as the Gettysburg shale. In the mapped area the Gettysburg is the upper formation of the Newark group. The strata are predominantly red sandstone and shale, containing lenticular beds of limestone conglomerate whose pebbles and fragments are similar to and derived from the limestone of Paleozoic age. Within the formation there is also a belt of coarse arkosic sandstone and quartzose fanglomerate that is described and mapped by Stose and Jonas as the Heidlersburg member of the Gettysburg shale. Adjacent to the intruded masses of diabase the red sedimentary rocks are bleached and metamorphosed to gray and buff hornfels and quartzites, and the limestone conglomerate is recrystallized to marble or replaced by silicates. The magnetite deposits are directly related to the diabase intrusions and occur as replacements of the limestone conglomerate.

DESCRIPTIONS OF TRIASSIC ROCKS

The following rock descriptions are based primarily on field observations of drill cores and microscopic examination of thin sections taken from core specimens. Outcrops of the sedimentary rocks (Gettysburg shale) are very scanty, and the drill cores furnished a larger and fresher variety of material for study.

SEDIMENTARY ROCKS (GETTYSBURG SHALE)

SANDSTONE AND QUARTZITE

The unaltered sandstone is red in color and is soft and friable. The metamorphosed sandstone is grayish white, buff, or pale pink and commonly is mottled and streaked with green. Metamorphism has made the rock hard and dense, and the purer varieties are converted to gray quartzite. The rock is uniformly equigranular, homogeneous, and fine- to medium-grained. No coarse nor pebbly sandstone has been seen, though coarser varieties are known to occur in places in the Gettysburg shale. Slight color banding, which probably represents bedding structure, can be seen in some specimens.

Individual mineral species are difficult to recognize megascopically, but microscopic examination shows the rock to consist of a closely knit fabric of subangular grains of quartz and cloudy feldspar. Along some of the grain boundaries poorly developed suture structures can be seen, but in general there has been little recrystallization of the quartz and feldspar. The most abundant new mineral developed by the metamorphism is pale-green augite, which occurs as scattered subhedral granules and granular aggregates. A little sphene, apatite, and zircon are usually present. Magnetite occurs as minute scattered grains and locally as larger irregular bodies. Some of the sandstone is more or less calcareous, and metamorphism has resulted in the development of chlorite, epidote, and pale-brown garnet.

The garnets of the metamorphosed sedimentary rocks show a variation of their refractive indices between 1.835 and 1.845, and a few that were examined have a refractive index as high as 1.855. The garnet in these rocks is probably andradite (calcium-iron garnet) with variable amounts of the grossularite (calcium-aluminum garnet) molecule.

HORNFELS

The hornfels is the baked equivalent of shale. The unaltered shale, like the sandstone with which it is interbedded, is bright red in color and is relatively soft and fissile. In the drill cores most of the hornfels is a white or cream-colored rock that is compact and tough and has a splintery or subconchoidal fracture. Some of the hornfels is a very fine grained bluish-gray rock in which color banding, revealing original bedding, is generally visible.

The fine-grained character of the hornfels makes the megascopic identification of its mineral constituents difficult. Microcrystalline grains of quartz, feldspar, and pyroxene can be recognized under the hand lens. Hornfelsic bands a fraction of an inch wide, consisting of a compact intergrowth of pyroxene, muscovite, and feldspar, have been seen in a few specimens at the contact between diabase and shale. A little cordierite was identified in one specimen.

Nodules as much as 0.5 inch in diameter occur in the quartzite and hornfels. The nodules are composed of pale-green chlorite accompanied by pale garnet, and they may contain a small amount of calcite. Part of the sedimentary rock has thin layers and laminae that are largely garnet, augite, and chlorite; some epidote is commonly present.

LIMESTONE CONGLOMERATE

Limestone conglomerate is abundant in the Dillsburg area, where it is interbedded with the siliceous and argillaceous sedimentary rocks of the formation. Outside the zone of metamorphism the conglomerate consists of fine-grained bluish limestone pebbles in a red calcareous sandstone matrix. The fragments are subangular to subrounded and range from pebbles less than an inch in diameter to boulders more than a foot across.

Within the areas of metamorphism the conglomerate is bleached and converted to white, dense, fine-grained to distinctly crystalline marble, and in some drill-core specimens the conglomeratic structure can be recognized only after wetting. In a few places the conglomerate contains green nodular bodies of augite and garnet. In the drill cores a soft green tactite developed by complete replacement of the limestone conglomerate was found. It is described in the following paragraphs.

TACTITE

This general term, meaning a rock "formed by the contact metamorphism of limestone" or calcareous rock "into which foreign matter from the intruding magma has been introduced by hot solutions or gases" (Hess, 1919, pp. 377–378) is appropriate for use when referring to the altered calcareous rocks occurring at Dillsburg. The most common variety of tactite is a friable, pale-green, granular, somewhat porous rock composed principally of pyroxene, garnet, and lesser amounts of epidote and calcite. In places this rock is intimately associated with the ore, where it may be partly or largely replaced by magnetite. Relict structures closely resembling the limestone conglomerate can be recognized in a few specimens. The abundant green mineral observed in hand specimens was identified under the microscope as diopside. Pale-brown garnet is intergrown with the pyroxene and in places encrusts small cavities in the tactite. The garnet commonly shows a pronounced zoning when viewed in thin section and is weakly birefringent in crossed polarized light.

Another variety of contact-altered calcareous rock is a greenish-gray, fine- to medium-grained, garnetiferous rock that under the microscope is seen to be composed of a granular aggregate of pale yellowish-brown subhedral to euhedral garnet. Granules of colorless pyroxene occur between the garnet crystals as well as enclosed in them, and some of the interstices between the crystal faces of the garnet are occupied by a colorless mineral identified as datolite ($HCaBSiO_5$). Datolite as veinlets and small nodular bodies has been seen, also, in thin sections of hornfels. Its occurrence is believed to be secondary, along with some of the calcite, which—in addition to being an original mineral—also occurs as later veinlets.

IGNEOUS ROCKS

DIABASE

Distribution.—The Triassic sedimentary rocks at Dillsburg, as elsewhere in Pennsylvania, have been intruded by diabase. The diabase intrusions have previously been described and considered as discordant dikes and concordant sills (Stose and Lewis, 1916, pp. 623–644; Stose and Bascom, 1929; Stose and Jonas, 1933; Stose and Jonas, 1939, pp. 120–130). A somewhat different interpretation of the form of the diabase at Dillsburg was made by Harder (1910), and the recent diamond-drill exploration has shown his concept of the diabase structure to be essentially correct. As will be brought out later in this report, the diabase in the Dillsburg district has entered the Triassic sedimentary rocks (Gettysburg shale) in the form of discordant flat-lying sheets.

A diabase body, outcropping in an elliptical area, overlies the magnetite deposits east of Dillsburg (pl. 3). The magnetite deposits are in the underlying Triassic sedimentary rocks. These sedimentary rocks occupy an area about 6 miles long in an east-west direction and nearly 3 miles across in a north-south direction at its widest part. The basin is underlain and almost completely surrounded by another body of diabase (pl. 2), which is part of a westward extension from the northeast end of the Gettysburg sill. The Gettysburg sill is a continuous westward-dipping sheet of diabase, over 35 miles long, extending from south of Gettysburg, Pa., to a point about 7 miles east of Dillsburg. Over much of the area around Dillsburg the diabase cuts across the prevailing strike of the sedimentary rocks; however, the diabase contact to the south and southeast of Dillsburg trends more or less parallel to the strike of the sedimentary beds.

The sedimentary rocks adjacent to the diabase intrusions are indurated and metamorphosed; the extent of this aureole of alteration around the diabase contact is shown in plate 2.

Character.—The diabase is a dense, fine- to medium-grained rock with a megascopically visible diabasic texture. Where fresh, the diabase is dark grayish green, and it weathers to dark gray or black. Laths of gray feldspar and interstitial green augite can be recognized with a hand lens. In coarser-grained specimens, granules of magnetite can be seen. The diabase has fine-grained to aphanitic borders that are due to rapid chilling at the contacts with the cooler sedimentary rocks. The dense aphanitic selvage is confined to the immediate vicinity of the contact; it is seldom more than 2 feet thick and in the larger intrusions may be only 6 inches wide. However, chilling effects can be noted over a distance of several feet; in this zone the texture is fine-grained (grains less than 0.5 millimeter in diameter), but it becomes increasingly coarser toward the center of the mass until it is uniformly medium-grained (average grains 1 to 1.5 millimeters in diameter).

In thin section the average medium-grained rock exhibits a uniform diabasic or intergranular texture with laths of plagioclase in random arrangement intergrown with pyroxene (augite and pigeonite). The pyroxene in part encloses the feldspar but in general occupies an interstitial position. The plagioclase is andesine-labradorite (An_{50}) to labradorite (An_{55}). A small amount of olivine, partly or completely replaced by alteration products, was observed in some specimens. The augite characteristically is slightly altered to hornblende and, rarely, to biotite. Some colorless pigeonite, mostly inverted to hypersthene, is intergrown with the augite. Opaque ilmenite-magnetite, as evenly distributed granules and elongate blebs or as larger concentrations showing skeletal arrangement, is the most abundant accessory mineral. Small, variable amounts of micropegmatite occupy an interstitial position in much of the coarser-textured rock. Sphene and apatite also are present.

The aphanitic, chilled facies, as seen under the microscope, is generally holocrystalline with a very fine grained (grains 0.1 millimeter or less in diameter) to microcrystalline groundmass in which there are a few microphenocrysts (0.05 to 0.1 millimeter in greatest dimension) of plagioclase and granular augite. A small amount of glass was seen in one thin section. The feldspar is calcic labradorite (An_{68}). Olivine is fairly common in the aphanitic borders, where it occurs as subhedral phenocrysts partly or completely changed to green chloritic pseudomorphs accompanied by secondary magnetite. In one slide bowlingite instead of chlorite was seen to be replacing the olivine. Micropegmatite is absent in the chilled selvage.

DIABASE DIFFERENTIATES

Occurrence.—Stose and Jonas (1939, pp. 127–130) have described several small bodies of a coarse-grained pink facies of the diabase in York County, some of which are shown in plate 2. This rock is commonly called granophyre, or "red rock." In York County the granophyre lies near the top of the diabase and has a roof of fine-grained normal diabase. A similar mass of granophyre was encountered in a deep drill hole (pl. 5, drill hole 3) beneath the plate of metamorphosed sedimentary rocks in which the Dillsburg ore deposits occur. The drill core from this hole, here described in detail, afforded a complete section from the upper chilled contact of the diabase into the underlying granophyre.

The top of the diabase in contact with the overlying metamorphosed sedimentary rocks of the Gettysburg shale is very fine grained but not dense at the contact. The chilled zone of fine-grained material is about 27 feet thick. The grain size gradually increases with depth, and the diabasic texture can be recognized megascopically. The texture is somewhat heterogeneous because of an irregular meshwork of coarser material in the medium-grained diabase. With increasing depth the coarser meshwork fades out and the diabase is dominantly and uniformly medium-grained. Sparse local layers of coarser-grained diabase half an inch to 2 inches thick alternate with the medium-grained diabase. In general the diabase becomes coarser-grained in depth. A 10-foot layer of pegmatitic diabase with white plagioclase laths and dark pyroxene blades 3 to 5 millimeters long was cut by the drill about 180 feet below the roof.

Below the pegmatite the diabase begins to be slightly pinkish. The change from diabase to granophyre is transitional. The pink color becomes more pronounced, there is a noticeable decrease in the content of dark minerals, and the texture becomes somewhat finer grained.

The upper limit of true granophyre is about 210 feet below the contact of the diabase and the sedimentary rock. The layer is over 80 feet thick and is characterized by a uniformly finer grain (0.6 millimeter in diameter) and a smaller content of dark minerals than is typical of the diabase; it is definitely pinkish. Quartz can readily be seen with the hand lens.

Below a depth of approximately 300 feet the granophyre ceases to be a clearly individual unit and tends toward an intermediate development between diabase and granophyre. The grain size increases somewhat, dark minerals are once more abundant, and the rock begins to lose its pink color, though many of the feldspars still have a pink cast. More diabasic-appearing rock alternates with rock that is closer to granophyre in appearance. The drill hole did not penetrate beyond 370 feet below the upper diabase contact; normal diabase was therefore not reached below the granophyre zone, but a transitional facies was definitely indicated.

Petrography.—Microscopic examination of the granophyre reveals an abundance of quartz and micropegmatite intergrown with individual grains of anhedral to subhedral feldspar and elongate crystals of pyroxene. Under the microscope, the feldspar is seen to be highly charged with submicroscopic plates of hematite, only the largest of which can be resolved with the highest magnification. These plates give the feldspar a brownish color. The feldspar is plagioclase and is much more sodic than in the normal diabase, being about $Ab_{90}An_{10}$ (albite-oligoclase) in composition. All the feldspar shows more or less sericitic alteration. Light-green pyroxene (hedenbergite), commonly with an elongate development, encloses granules of magnetite and is partly replaced by green and brown hornblende. Numerous grains of ilvaite ($HCaFe_2''Fe'''Si_2O_9$) were identified in polished specimens under the microscope.

The transitional facies above and below the granophyre have variable amounts of micropegmatite but always less than that which occurs in the granophyre. In these transitional facies the intergrowth of quartz and sodic plagioclase occupies a position interstitial to subhedral and euhedral laths of plagioclase that are slightly more sodic than the plagioclase of normal diabase. A diabasic relationship between the earlier-crystallized plagioclase and pyroxene can usually be seen, and the pyroxene exhibits various degrees of alteration to hornblende and, to a lesser degree, biotite.

The pyroxene of the intermediate diabase is mostly augite and some hypersthene. The augite may be colorless, but more commonly it is pale brownish in hue, faintly pleochroic, and characterized by a submicroscopic parting parallel to (010). The augite is richer in iron than the pyroxene in the normal diabase; hypersthene probably is an inverted pigeonite. Abundant ilmenite-magnetite, usually as fairly coarse skeletal growths, is found in the quartz-bearing diabase above the granophyre. Its most common association is with irregular masses of chloritic (stilpnomelane) and amphibolitic material, which are believed to be the result of late hydrothermal or deuteric alteration of earlier-formed mafic minerals.

Microscopic examination of the pegmatitic diabase shows it to be composed of essentially the same primary minerals as the normal diabase. The most abundant pyroxene is brownish augite showing fine parting traces parallel to (010). Some pigeonite, mostly inverted to hypersthene, can be seen intergrown with the augite. The unaltered plagioclase is labradorite (approximately An_{60}). Interstitial micropegmatite is slightly more abundant than in the medium-grained diabase. Deuteric alteration has transformed part of the pyroxene to hornblende, and the plagioclase crystals are strongly altered to albite-oligoclase (approximately An_{10}) on their borders. Coarse skeletal crystals of ilmenite-magnetite are a characteristic feature of the pegmatitic diabase.

In summary, the pink granophyre occurs within the large masses of diabase near the top of the intrusions and has a cover of diabase, which, from the top down, passes transitionally but fairly abruptly through an intermediate facies to granophyre. The overlying diabase is cut by a fine network of slightly coarser material carrying quartz and sodic plagioclase, which are the essential constituents of the granophyre. The field relations and petrographic data indicate that the granophyre is a phase of the diabase developed by differentiation in place of diabase magma following intrusion into the Triassic sedimentary rocks.

W. H. Tomlinson (1945, pp. 526–536), who has made a study of the diabase and its derivatives, offers a different though not an entirely new suggestion for the formation of the diabase and its granophyre derivative. He considers the diabase to be a solidified hybrid magma formed by the assimilation of granitic rock by basaltic magma. On emplacement the diabase magma separated again into a "basaltic magma" and an "acid magma." The "basaltic magma," retaining some of the "acid magma," solidified first as normal granophyric diabase, whereas the rest of the "acid magma" crystallized as granophyre.

It cannot be denied that the basaltic magma in the course of its upward movement could have encountered granitic material. Moreover, if the granite that was incorporated into the rising magma lay at great depth, it might be completely assimilated before the magma was emplaced. In this event there would be no trace of the digested rock such as xenolithic inclusions, which are lacking in the diabase intrusions. There are no strong objections to the theory of assimilation as long as it is assumed to have taken place at depth prior to emplacement, for the magma is not called on to assimilate the intruded sediments. However, the emplacement and differentiation of diabase magma without assimilation will also explain adequately the development of granophyric diabase and granophyre, and there is no necessity to postulate incorporation of granite by the diabasic magma.

STRUCTURE

SEDIMENTARY ROCKS

The predominant trend of the bedding structure of the Triassic sedimentary rocks in this region is northeastward, with a uniformly gentle dip to the northwest at angles ranging from 15° to 30°. Within the explored area (pl. 3) the available data indicate that the strike is east-northeast and the dip north-northwest at an angle that averages about 26°. In much of this area, however, the attitudes of the bedding are not precisely known because of lack of exposures or because of overlying diabase. Furthermore, there are no distinctive strata that can be used as markers for correlation between drill holes, and the metamorphism of the rocks has largely obliterated the original bedding. However, in some of the drill cores faint color and texture banding proved to be consistent with the dip observed at the surface.

In the eastern belt of the Triassic, formations as a whole are more or less lenticular in shape. The limestone conglomerates, which are regarded as having formed as fanglomerate, are highly lenticular and discontinuous strata.

The sedimentary rocks were deposited in a basin in which terrestrial sediments accumulated as the basin subsided along a fault on the northwest border. The beds of limestone conglomerate in the Gettysburg shale were derived from the limestone beds of Paleozoic age to the west and were deposited along the northwest edge of the basin by streams coming from the highland northwest of the fault.

DIABASE

Sill-like structures have been postulated by Stose and others (Stose and Lewis, 1916; Stose and Bascom, 1929; Stose and Jonas, 1933, p. 42; Stose and Jonas, 1939, pp. 125–126) for several of the Triassic diabase intrusions in eastern Pennsylvania. This general concept of the structure and mode of intrusion is shown in figure 1, which is taken from the report by Stose and Jonas on the Middletown quadrangle, Penn-

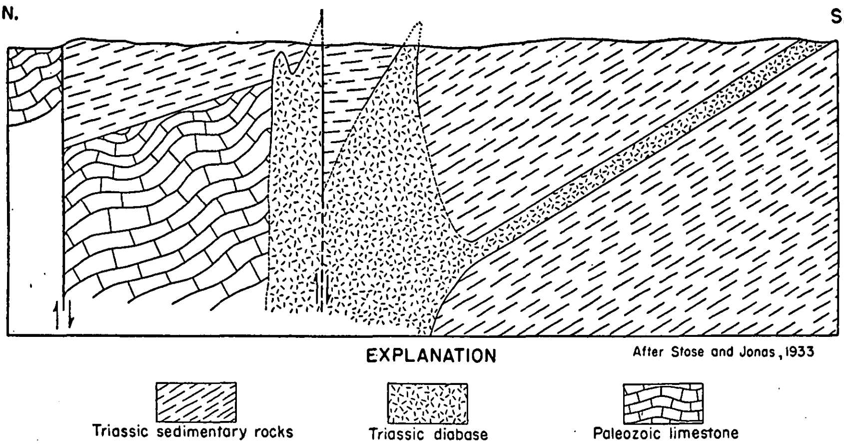

FIGURE 1.—Ideal section showing form of Triassic diabase intrusions in southeastern Pennsylvania.

sylvania. In part, as previously indicated, the diabase has concordant relations with the sedimentary rocks—for example, in the narrow prong southwest of Dillsburg and the large northeastward-trending bodies at the northern extension of the Gettysburg sill about 8 miles to the east. However, the large mass of diabase surrounding the Dillsburg area is discordant with the structure of the sedimentary rocks on all but its south side.

Spencer interpreted the oval area of diabase overlying the magnetite deposits in the Dillsburg ore field to be in part discordant, though, judging from his descriptions of the mines and the accompanying illustrations, he assumed concordant relations to exist in most places (Spencer, 1908, pp. 71–92). None of the mines was accessible when Spencer made his study, but in 1910, when the Jauss mine was unwatered, he made an inspection of the underground workings and published a report in which he noted that here the "overlying diabase contact dips in a southerly direction, cutting across the edges of the stratified rocks which dip north-northeast." (Spencer, 1910, pp. 247–249.)

Harder interpreted the upper diabase mass as a sheet which "apparently lies on the sediments with a rolling uneven contact, while the outlying smaller masses appear to be erosion remnants lying in troughs on the surface of the sediments. The sediments underneath the diabase are continuous with those surrounding them and have the same prevailing dip, which is between 10° and 30° to the north." (Harder, 1910, p. 601.)

The diamond drilling by the Bureau of Mines has proved Harder's concept of the structure of the upper diabase to be correct. In all but one drill hole a cap of diabase 60 to more than 100 feet thick was penetrated before entering the metamorphosed sedimentary rocks of the Gettysburg shale. In each hole a thin chilled selvage occurs in the diabase at the contact. From structure sections drawn through the drill holes (pls. 5, 6, 7, and 8) it is evident that the contact is discordant and essentially a smooth, undulating surface.

Spencer suggested that limestone of Paleozoic age might be present at moderate depth (50 to 100 feet) beneath the Jauss ore (Spencer, 1910, p. 249). Inasmuch as the presence of limestone close to the diabase might indicate a favorable site for the deposition of ore, it was desirable to test the possibility with a wildcat hole during the course of exploration by the Bureau of Mines. Therefore drill hole 3 at the Longnecker mine, which is near the Jauss mine, was continued beyond the depths to which holes 1 and 2 had been drilled.

Beneath the sedimentary rocks this drill hole encountered another body of diabase (pl. 5), which heretofore had not been known because none of the early mining operations was sufficiently deep to discover it. The hole was extended 370 feet below the top of the second diabase and was still in it when the hole was abandoned after passing through the zone of granophyre described on page 8. The drill hole was extended, after it reached the diabase below the sediments, with the expectation that the diabase might be a relatively thin sheet, below which more sedimentary rocks and possibly new ore bodies might occur. However, it was realized when the granophyre was encountered that in all probability the intrusion was relatively thick (over 1,000 feet) and might even be part of the main mass of diabase that surrounds the mineralized area.

Several of the other drill holes were extended until the underlying diabase was reached. Its upper surface, as shown in plates 5, 6, and 7, like the bottom of the overlying sheet is discordant and gently undulating.

FIELD IN GENERAL

The underlying diabase with its granophyric differentiate is now interpreted as one and the same body as the main mass that surrounds the Dillsburg field. Hence its general structure is probably that of a broadly concave, platterlike sheet that truncates the gently dipping sedimentary rocks (pl. 4).

Drilling in the southern part of the area shown in plate 3 indicated that the upper diabase sheet is probably an offshoot of the lower sheet and has now been separated from the main sheet by erosion (pls. 2, 3, and 4). The magnetic survey of the district conducted by the Bureau of Mines outlined an area of magnetic attraction on the inner (north) edge of the diabase mass south of the main part of the Dillsburg district. Subsequent drilling on the anomaly proved the existence of ore-bearing sedimentary rocks beneath the diabase, and diabase was shown to be present underneath the metamorphosed sedimentary rocks. Examination of the surface failed to show the presence of sedimentary rocks within the diabase, but some coarse-grained granophyre occurs at the surface southeast of the anomaly. Therefore it appears that the lower diabase body underneath the Dillsburg ore field must come to the surface here and form the large mass to the south and east and that the thin upper sheet of diabase is a flat-lying discordant offshoot from it. Thus the ore deposits are in a plate of sedimentary rocks 200 to 300 feet thick that lies between two intrusive diabase sheets. The plate wedges out where the two bodies of diabase join (pl. 4, section *C–C′*) south of the area of magnetic attraction.

MAGNETITE DEPOSITS

The deposits of magnetite occur in the Triassic sedimentary rocks either underneath the upper diabase sheet or adjacent to its western margin. The deposits that are not capped by diabase may have been originally overlain by diabase that was subsequently removed by erosion. Limestone conglomerate, which occurs as layers and lenses in the sedimentary formation, is the host rock in which the magnetite is concentrated.

CHARACTER

The deposits consist of magnetite, minor quantities of specularite, and varying amounts of gangue. All the magnetite cut in the drill holes (pls. 5–10; figs. 2–4) and in specimens picked up on the surface near old workings is finely crystalline. Some coarsely crystalline magnetite has been reported, but none was seen during the recent exploration.

In the drill holes some nearly pure masses of magnetite were encountered, but most of the ore is a streaked or mottled mixture of small masses of magnetite in a greenish gangue of pyroxene, chlorite, quartz, and feldspar with more or less carbonate. The original structure pattern of the limestone conglomerate is preserved in many specimens; this is interpreted as indicating replacement by magnetite and newly formed silicates. In these specimens, small magnetite masses whose outlines are like the angular to subangular limestone fragments in the unaltered conglomerate occupy a green, silicated matrix. One specimen showed the replacement of angular to subrounded limestone fragments by magnetite, leaving cherty white pebbles and a barren silicated argillaceous groundmass. Another consisted of ribbons of magnetite alternating with argillite partings—obviously the result of replacement of the calcareous layers in a laminated rock.

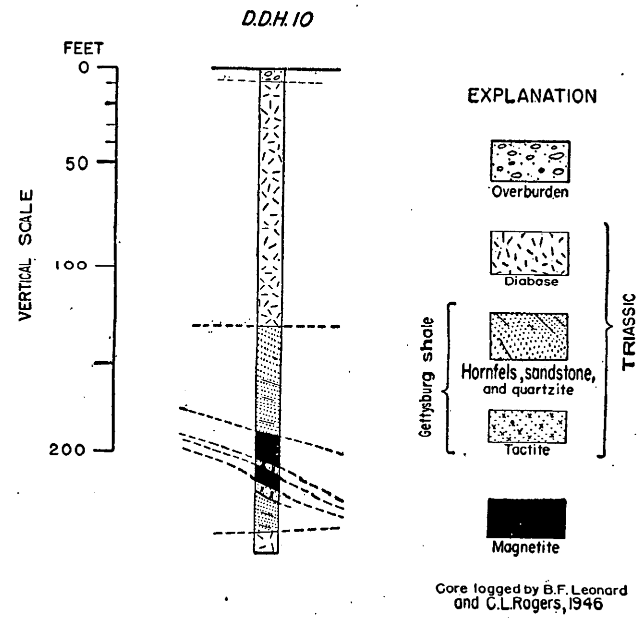

FIGURE 2.—Geologic section through Bureau of Mines drill hole 10, Dillsburg iron district, York County, Pa.

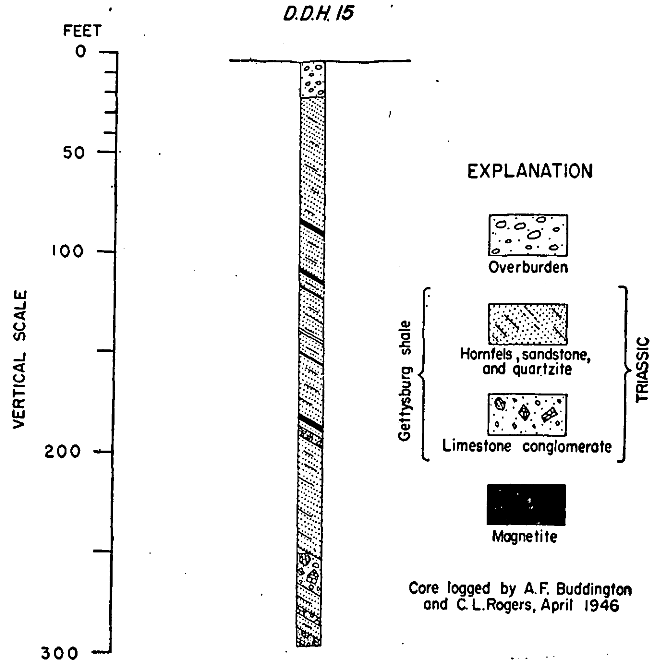

FIGURE 3.—Geologic section through Bureau of Mines drill hole 15, Dillsburg iron district, York County, Pa.

Callahan and Newhouse (1929, pp. 403–411) reported two kinds of magnetite in the ore from the Cornwall mine. In polished sections they observed a brownish magnetite that apparently had replaced magnetite with a bluish color. They considered the brown variety to be maghemite, a ferromagnetic ferric oxide. In his study of the deposits at Cornwall, Hickok (1933, pp. 193–255) also observed brown and blue magnetite but, because of contradictory evidence, was not able to determine definitely which of the two was maghemite. Schneiderhöhn and Ramdohr (1931, pp. 535–536) disagree strongly with Callahan and Newhouse's classification of the brownish "magnetite" as maghemite, saying: "Contrary to Newhouse, * * * normal magnetite in polished section, especially in oil, has a strong, though variable, brownish-rose color, the maghemite a grayish-blue." The identification of maghemite in polished section is difficult because of the lack of definite etch reactions.

Several polished sections of the Dillsburg magnetite were examined under the microscope to ascertain whether they contained material similar to that found at Cornwall. Only one magnetic mineral was seen and, judging from its black streak and powder, it is magnetite. Maghemite gives a brown streak and powder.

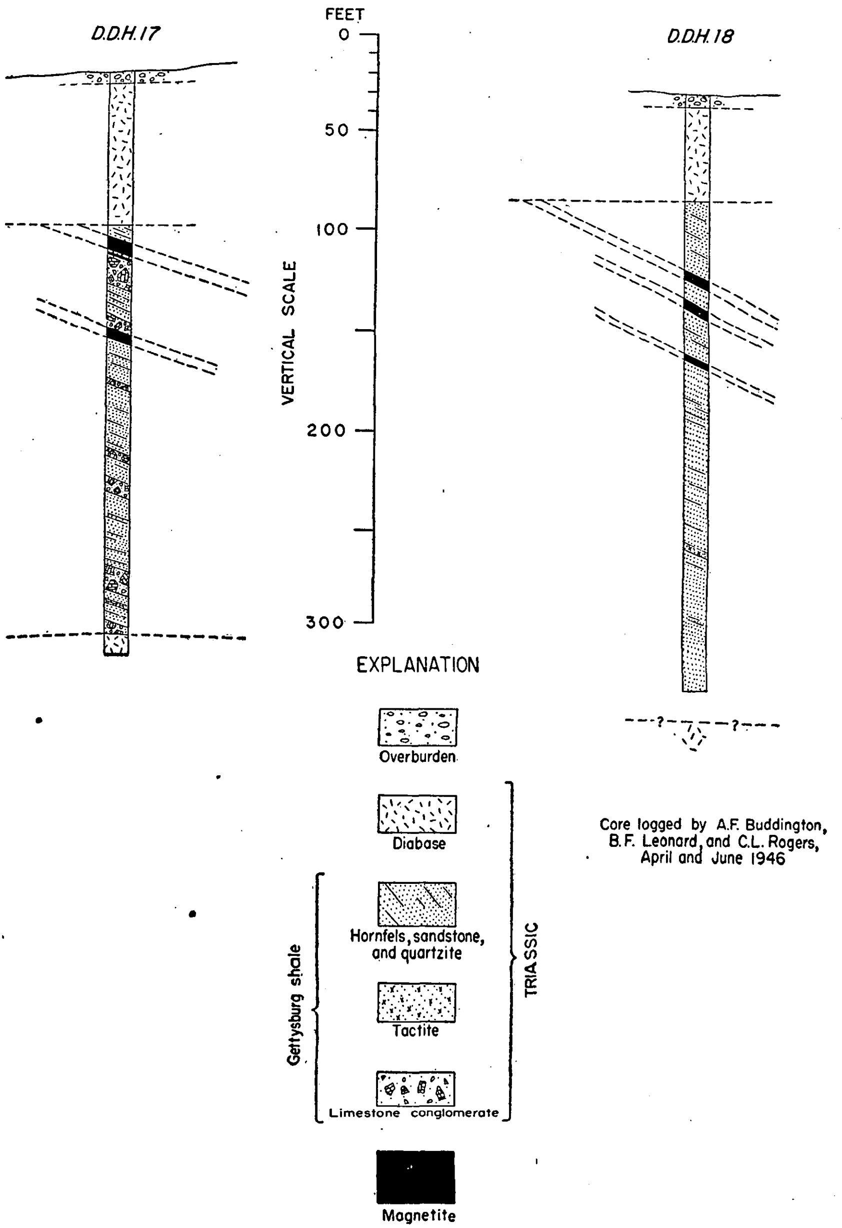

FIGURE 4.—Geologic section through Bureau of Mines drill holes 17 and 18, Dillsburg iron district, York County, Pa.

Small quantities of specularite accompany magnetite in some specimens. Specularite occurs in only one of the specimens that were examined microscopically (drill hole 5, 216 feet 8 inches to 220 feet). In this specimen it occurs interstitially to the magnetite grains; there is no apparent replacement of either mineral by the other. The age relations between them could not be established with certainty. Small plates and rosettes of specularite were seen on a few of the fracture surfaces in the metamorphosed sedimentary rocks, and a greenish pyroxenic quartzite from hole 15 contains some disseminated specularite.

The gangue minerals are mostly green, finely crystalline pyroxene (diopside) and lesser amounts of chlorite. In addition, pale-brownish garnet and fibrous, actinolitic amphibole are present in some specimens. Plagioclase, quartz, and calcite are ubiquitous but differ widely in abundance from place to place. Most of the calcite is original and not the result of metamorphism. Small amounts of talc and unidentified zeolites are occasionally present. Pyrite is the most abundant metallic gangue mineral. It occurs as scattered grains and as small, irregular, fine-grained masses in the magnetite as well as in the barren silicate or carbonate gangue. The pyrite probably contains cobalt, as does the pyrite from similar deposits at Cornwall, which is known to contain about 1 percent cobalt (Hickock, 1933, p. 232). A spectrographic analysis of a composite sample of material containing magnetite by the United States Bureau of Mines shows less than 0.001 percent cobalt in the magnetic fraction and 0.001 to 0.01 percent cobalt in the nonmagnetic portion. Small amounts of chalcopyrite and pyrrhotite likewise are present.

In general the deposits are medium to low in grade. The following are analyses of ore taken from cars loaded for shipment from the Dillsburg mines (Tenth Census, 1880, vol. 15, p. 233):

	Bell mine	*Longnecker mine*	*Underwood mine*
Metallic iron	39.55	43.63	44.10
Phosphorus	.016	.016	.018

The analyses of ore cut by the drills during the recent exploration of the Dillsburg district by the Bureau of Mines are listed in table 1. Some analyses of split core material show 45.4 percent soluble iron, whereas the majority of samples range between 30 and 35 percent iron.

DISTRIBUTION

The magnetite deposits occur as local shoots in the sediments throughout a stratigraphic thickness of 2,000 to 3,000 feet. The location of the old mine workings and the areas of magnetic attraction outline a general area of mineralization in which the shoots occur. As shown in plate 3, this is an arc-shaped belt, 10,000 feet long and 1,500 to 3,000 feet wide, trending north to northwest. The pattern obtained from the magnetic survey shows that the belts of attraction lie roughly parallel to one another and that their outlines, though irregular, are elongate in an east-west direction that more or less

TABLE 1.—*Analyses of diamond-drill core material containing magnetite, Dillsburg magnetite deposits, York County, Pa.*

[Data furnished by U. S. Bureau of Mines]

Hole No.	Depth (feet)		Thickness (feet)		Analysis (percent)	
	From	To	Drilled	True	Fe	Insoluble
1	70.5	83.0	12.5	11.25	25.20	-----------
	107.7	116.0	8.3	7.5	13.96	-----------
	151.0	155.0	4.0	3.6	8.88	-----------
2	70.0	72.0	2.0	1.8	39.68	-----------
	107.5	110.75	3.2	2.9	36.79	-----------
	151.3	157.0	5.7	5.1	45.21	-----------
3	79.5	89.5	10.0	9.0	26.3	[1] 50.2
	118.0	120.0	2.0	1.8	14.6	62.2
	162.5	165.5	3.0	2.7	41.8	22.4
	193.5	202.5	9.0	8.1	[1] 33.7	[1] 42.3
5	48.0	48.5	0.5	.45	24.6	47.6
	129.2	129.7	.5	.45	25.5	42.7
	155.7	157.0	1.3	1.2	19.6	48.9
	216.7	220.3	3.6	3.2	39.6	25.2
6	142.0	152.0	10.0	9.0	[1] 45.4	[1] 26.7
8	212.0	214.0	2.0	1.8	28.2	52.6
9	117.0	128.5	11.5	10.1	24.8	58.0
	137.0	140.0	17.0	15.3	31.2	47.7
	166.0	173.0	7.0	6.3	14.6	49.8
10	188.0	213.0	25.0	22.5	[1] 31.88	[1] 43.1
11	165	170	5.0	4.5	37.2	39.9
	175	189	14.0	12.6	[1] 40.8	[1] 36.6
	234	243	9.0	8.1	[1] 21.5	[1] 48.9
	252	254	2.0	1.8	21.5	64.3
	342	348	6.0	5.4	21.3	56.7
	355	357	2.0	1.8	25.3	60.2
12	239	246	7.0	6.3	37.40	40.42
	247	248	1.0	.9	31.02	50.54
	265	270	5.0	4.5	24.60	57.54
13	125	131	6.0	5.4	18.60	65.32
	148	170	22.0	19.8	[1] 33.32	[1] 46.23
	175	185	10.0	9.0	34.68	41.98
	189	199	10.0	9.0	30.50	50.50
14	230	238	8.0	7.2	27.35	51.30
	275	278	3.0	2.7	21.12	60.18
15	107	109	2.0	1.8	29.45	51.38
	180	183	3.0	2.7	23.15	50.54
16	73	80	7.0	6.3	40.85	40.70
	246	251	9.0	8.1	41.90	33.96
17	86	96	10	9.0	40.20	31.70
	131	137	6	5.4	28.40	46.62
18	94	97	3	2.7	22.95	55.54
	106	110	4	3.6	23.00	50.88
	132	134	2	1.8	19.20	54.00

[1] Weighted average.

coincides with the strike of the bedded rocks. The areas of magnetic attraction are separated from one another across the strike by areas of weak or negative attraction, indicating an absence of important magnetite mineralization.

The western limit of mineralization in the Dillsburg field is near the west contact of the diabase, at the surface, with the sedimentary rocks (pl. 3). The eastern limit of mineralization is approximately the west limit of the Heidlersburg member of the Gettysburg shale (pl. 2), a series of hard sandstones (Stose and Jonas, 1939, pp. 107, 116–117) that may mark the eastern limit of the limestone conglomerate lenses and therefore the limit of a favorable host for magnetite replacement.

The arrangement of the magnetite deposits along zones trending in a northeast-southwest direction is probably controlled by the arrangement of the beds of limestone conglomerate. The trends are essentially parallel to the strike of the sedimentary rocks. However, since the intervening barren areas were not drilled, the absence of limestone conglomerate lenses cannot be proved. As an alternate explanation it has been suggested that the parallel arrangement of the zones of magnetic attraction is due to a series of parallel fractures that were subsequently mineralized. The hypothesis is possible but has no supporting structural data.

FORM AND STRUCTURE

The ore bodies and mineralized rock cut in the drill holes range in thickness from less than 1 foot to not more than about 20 feet, and the maximum thickness of ore occurring in the underground workings of the old mines is about 30 feet. Where mineralization occurs, however, there are commonly several beds of ore separated from one another by relatively thin partings of barren rock. Data obtained from the drilling and from the descriptions of underground and surface workings in the old mines show that the magnetite bodies are flattened lenses dipping gently to the northwest and striking northeast in conformity with the bedded structure of the stratified rocks in which they are enclosed. The mineralized zones pinch out down the dip as well as laterally, and though the plans of the underground workings of the Underwood and Bell mines suggest that these ore bodies had a gentle plunge to the north-northeast, drilling did not indicate that the direction of plunge differed from the direction of dip.

Where drill holes are closely spaced, a reasonable correlation from hole to hole may be made between limestone conglomerate layers, tactite zones, and mineralized zones by using the average dip observed in drill-core specimens. The correlation becomes more dubious where the holes are farther apart, since slight differences in the angle of dip used in constructing the section result in important differences in interpretation.

Except at the Longnecker mine, exploration has not been adequate to determine the slope length of the ore bodies. In most of the old mines the slopes range in length from 250 to 400 feet. The length of the Bell slope is reported as 1,100 feet. At the Longnecker mine, an ore seam appears in each of three successive drill holes (drill holes 2, 3, and 5). The most reasonable interpretation of the structure indicates that it is the same zone, with a slope distance of 335 feet between drill holes (pl. 5). Hole 2 penetrated old workings in this ore body. It was also possible to correlate other magnetite bodies in drill holes 1, 2, and 3. Because of the structure of the area the maximum possible distance down dip is between 500 and 800 feet, assuming that the thickness of the plate of sediments between the upper and lower diabase is 200 to 300 feet and the average dip of the beds is 26°.

The strike length of the ore shoots cannot be determined from the drilling that has been done. The long open-cut at the McCormick mine indicates that the ore bed was opened for a distance of 325 feet along the strike. Drill hole 6 on the small anomaly northeast of the Longnecker mine shaft penetrated a true thickness of ore amounting to about 13 feet. The magnetite body may correspond to one of the several bodies cut by the line of holes drilled at the Longnecker mine, but lack of distinctive marker beds prevents positive correlation. If an ore seam were continuous from hole 6 to the line of holes at the Longnecker mine, it would have a strike length of about 800 feet. However, plate 6 shows that the anomaly at hole 6 is not continuous with the Longnecker anomaly. This and the fact that hole 7, only about 250 feet along the strike from hole 6, was blank suggest that the body of magnetite in hole 6 has no great lateral continuity.

A general zone may be mineralized for several hundred feet along its strike and be indicated at the surface by elongate areas of magnetic attraction. Thus a mineralized zone cut in drill hole 11, according to stratigraphic correlation, is also cut in hole 13, which is 530 feet distant along the strike (pl. 9). Within such a zone there is a general continuity of mineralization, though the zone may pinch or swell. Magnetite-bearing strata may terminate against the upper diabase along their strike, where, because of slight irregularities, the diabase crosscuts the strata. (See pls. 6 and 9.)

The best, as well as most, of the magnetite deposits occur in the upper part of the plate of sedimentary rock near the upper diabase sheet. In many places where the calcareous strata near the lower diabase are encountered in drill holes, recrystallization to marble without silication is the only metamorphism the limestone conglomerate has undergone. Near the upper diabase, on the other hand, pyroxenic and garnetiferous tactites and magnetite-bearing rock replace the limestone conglomerate, and unaltered marble or limestone conglomerate is the exception. Furthermore, Spencer's descriptions of the mines show that none of the workings continued deep enough to encounter the lower diabase. If the ore had persisted down the dip or had become thicker with depth, it would surely have been exploited.

The profiles of the magnetic anomalies, at right angles to their strike, show that the magnetic gradient is considerably steeper on the northern flank than on the southern. Furthermore, prominent negative areas are characteristically found on the north side of the prominent anomalies. Over certain magnetic ore deposits elsewhere—for example, the magnetite deposits in the regions of pre-Cambrian rocks in New York and New Jersey—the gentle slope of the magnetic profile is in the direction in which the ore body dips. Because of this relation between the magnetic profile and the dip of the ore deposits in these pre-Cambrian terranes, the magnetic profiles at Dillsburg were interpreted by some geologists prior to the drilling as possibly indicating a southward dip for the ore shoots. However, a magnetic body that continues in depth for a long distance has a different magnetic field at the earth's surface from a body having a short dip length. The magnetite ore bodies in the pre-Cambrian rocks continue in depth for long distances in contrast to the short dip length of the known magnetite bodies at Dillsburg. It has been shown that the lower end of a gently dipping magnetic ore body of finite length, such as the Dillsburg bodies are by virtue of being closely limited by the upper and lower diabase masses, can produce profiles similar to those in the Dillsburg area (Hotchkiss and Bean, 1929, pp. 84–95). A magnetite body dipping gently to the north will thus have a positive anomaly over its south end, which is near the surface, and a negative anomaly above its north end.

The recent drill-hole data show, also, that the structure of the ore bodies conforms to the bedding structure of the stratified rocks. (See pls. 5, 8, and 9.) Thus the available evidence from past mining in the area, the recent drilling data, and the magnetic survey combine to support the hypothesis that the magnetite deposits of the Dillsburg field dip gently to the north more or less in conformity with the structure of the associated sedimentary rocks. The alternative hypothetical form for the bodies, which is that of southward-dipping shoots whose minor offshoots only have been cut in the drill holes, has no basis of observed fact.

ORIGIN

Prior to 1908 the Cornwall type of ore deposit was considered to be either sedimentary in origin or due to change and concentration of the iron present in the sediments, in place, by heat from the diabase (Hickok, 1933, pp. 233–234). Spencer (1908) first proposed contact metamorphism to account for this type of deposit.

The ore and its mineral associations are characteristic of contact-metamorphic replacement deposits, and the consistent association of the deposits with diabase points to the diabase's being the source of the mineralization. The host rock for mineralization was limestone conglomerate, which occurs as lenses in the sedimentary series. This limestone conglomerate was profoundly altered in places to a pyroxene-chlorite rock locally replaced by magnetite.

A relatively small volume of limestone conglomerate has been altered and directly replaced by magnetite. Drill holes show that within the sedimentary plate much of the limestone conglomerate has been recrystallized with no attendant alteration or replacement. The controlling factors for localization of the deposits in certain beds or parts of beds of limestone conglomerate are not completely understood. Localization may be due to favorable structural control in the host rock at the time of mineralization, or, as Harder has indicated, "solutions given off * * * in different parts of a single intrusive mass [of diabase] may have differed materially in composition." (Harder, 1910, p. 617.) Minor fracturing or shattering of parts of the limestone conglomerate when the diabase was intruded could conceivably render some parts more permeable than others, and the conglomeratic structure itself may have constituted a relatively permeable channelway along which the mineralizing solutions could pass.

In the low-grade ore there are repeated examples of the original conglomerate structure's being preserved by the replacement of pebbles of limestone by fine-grained magnetite, leaving a matrix of relatively barren silicated groundmass. Specimens of higher-grade material show replacement of the matrix as well as of the pebbles. In some places limestone pebbles have been replaced, whereas argillite or hornfels fragments remain barren.

Significantly, magnetite rarely occurs alone, but is accompanied by pyroxene, chlorite, or garnet, the products of silication of the calcareous rocks. Hence the magnetite mineralization is closely related to the metasomatic processes responsible for the transformation of the calcareous rocks to masses of silicate. The magnetite mineralization followed the development of the silicates, though it probably overlapped it to some extent. Magnetite not only replaces the limestone pebbles that were not affected by the silicating solutions but in places replaces the silicates as well. Minor sulfide mineralization followed the introduction of magnetite, though it too may have overlapped the magnetite phase.

Metasomatic alteration has been neither the only nor the principal metamorphic change that these rocks have undergone. Large volumes of sandstone and shale have been converted to quartzite, hornfels, and argillite, and beds of limestone conglomerate have recrystallized to marble. In these rocks, hardening and recrystallization without the addition of foreign material were the principal changes. Two kinds of metamorphism, which may or may not be different stages separated by an interval of time, are thus represented.

The possibility of the iron's having been derived from the Triassic sedimentary rocks as a result of the metamorphic effects accompanying intrusion of the diabase deserves some consideration. The original red color of the sedimentary rocks is bleached to white or gray wherever the diabase has been intruded. It is not certain how much of the original iron in the rocks has been converted to more stable forms under the conditions existing at the time of intrusion or how much has been driven out to become lost entirely or possibly to accumulate and be concentrated elsewhere. Some of the iron may have remained in the rock in the form of new minerals such as pyroxene, magnetite, and garnet. These iron-bearing minerals, however, occur only in small amounts in the metamorphosed sandstones and shales.

Removal and transportation of some of the iron in solution could have been accomplished by circulating ground water that was heated by the intrusions, although aqueous solutions given off from the diabase would seem to be the more probable source of the transporting medium. Spencer (1908, p. 15) objected to the concept that circulating liquids or vapors transported and concentrated the iron from the sedimentary rocks because, as he says, the water "could hardly have made an excursion through the stratified rocks and later returned to the contact, as they must have done to deposit the ore bodies. * * *" However, considering the structure of the Dillsburg field as it is now known, the transporting fluids would only have had to rise vertically upward through the plate of sedimentary rocks from the lower diabase and deposit the iron as magnetite and iron silicates in the limestone conglomerate beneath the upper diabase sheet.

Certainly it is difficult to see how the Triassic strata alone could have yielded the total amount of iron necessary or how the concentration and accumulation could have been accomplished to form as large an amount of magnetite as that at Cornwall. The similarity between the deposit at Cornwall and the deposits of the Dillsburg district has already been pointed out. Furthermore, the magnetite deposits of French Creek, Pa., which are replacement deposits in a marble layer in pre-Cambrian gneiss, are associated with Triassic diabase that intruded the pre-Cambrian rocks directly, so that the iron could have been only of igneous origin.

It is believed that at least some iron was removed from the Triassic redbeds at Dillsburg by magmatic vapors and solutions or by heated ground water. At favorable locations this iron could have been deposited as magnetite more or less contemporaneously with the deposition of iron from magmatic sources.

From the factual data concerning the distribution and mode of occurrence of the magnetite deposits, the petrologic relationships observed in the diabase, and the presence of a large differentiated mass of diabase beneath the ore deposits, it is concluded that the source of the iron-bearing solutions was the intruded diabase magma.

The tendency for the magnetite to be concentrated in largest volume near the top of the plate of sedimentary rocks near the lower contact of the upper diabase has been pointed out. The control over magnetite deposition was not the relative abundance of limestone conglomerate in the upper part of the plate as compared with that occurring at greater depth, because there is actually more unreplaced, marbleized limestone conglomerate toward the bottom of many drill holes than toward the top, where it has been replaced by silicates or magnetite. The greater abundance of magnetite in the upper part of the plate of sedimentary rocks is probably due to a combination of temperature gradient and the damming effect of the upper diabase.

The lower diabase mass, as shown, was sufficiently large to permit slow cooling after emplacement; consequently it differentiated to form more acid granophyre and pegmatitic phases. The pegmatitic phase and the coarser-textured network of veinlets traversing the chill zone of the diabase above the granophyre, judging by their textures and mineral composition, were derived from a more fluid phase brought about by differentiation.

Thin sections show an abundance of titaniferous magnetite in these types. It is to be expected that the iron would be concentrated in and transported by the late-stage differentiates of the diabase. It seems unlikely, though not impossible, that the upper diabase sheet was of very great thickness (in one drill hole the top of the upper diabase is fine-grained and grades down into coarser material and back to fine at the lower contact) and hence not likely to develop an abundance of magnetite-bearing solutions or vapors by differentiation. Furthermore, coarse-grained pegmatite veinlets or other evidence of a volatile phase carrying iron and traversing the chilled lower contact of the upper diabase is lacking.

The thin upper diabase sheet cooled more rapidly than the large main mass, and the stratified rocks enclosed between the intrusive bodies were cooler near the top than near the bottom. The upper diabase, which chilled rapidly to form a dense selvage, constituted a barrier to the solutions or vapors rising from the lower diabase. Thus cooling, in combination with the retardation of the rising solutions, permitted precipitation of the magnetite in the upper part of the sedimentary rocks.

FUTURE OF THE DISTRICT

Spencer (1908, p. 74) states that the aggregate of ore shipped from the Dillsburg field is probably less than 1,500,000 tons. Data on the amount of ore mined from the different deposits are not available, but undoubtedly the major part of the ore came from the McCormick-Underwood-Longnecker group of mines. The Jauss and Bell mines were the only other important producers, and taken together, judging from the size of their workings, they probably produced less than half the total ore shipped.

The drill holes at the Longnecker mine show that some ore still remains, but none of the bodies is as thick as the deposit that was mined. Furthermore, there is little continuity in the different ore layers. Drilling of the other anomalies, including the large, newly located area of magnetic attraction at the south edge of the field, indicates the presence of several deposits of magnetite that are comparable in grade, thickness, and extent to those already mined.

The indicated magnetite bodies are small compared to those now generally mined economically in the eastern United States under present prices of iron ore. Further drilling will be necessary if dependable calculations are to be made of proved ore reserves.

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