GENERAL FEATURES OF THE MAGNETITE ORES OF WESTERN NORTH CAROLINA AND EASTERN TENNESSEE.[1]

By W. S. Bayley.

INTRODUCTION.

PRODUCTION AND GENERAL DISTRIBUTION.

The iron ores of western North Carolina and Carter County, Tenn., comprise brown hematite (limonite and possibly turgite), magnetite, mixtures of magnetite and hematite, and titaniferous magnetite (mixtures of magnetite with ilmenite or with rutile). Hematite alone also occurs, but the quantity is small, and it has never been mined. The brown hematite, magnetite, and titaniferous magnetite ores have been mined and smelted, but in later years the titaniferous ores have been completely neglected because they are not adapted to modern blast-furnace practice. Until within a few years the magnetite deposits furnished nearly all the ore mined, but recently the brown ores of North Carolina have increased in importance.

Brown ore and magnetite produced in western North Carolina, 1911–1920, in short tons.[a]

	Brown ore.	Magnetite.		Brown ore.	Magnetite.
1911		84,782	1916	4,263	60,043
1912		68,322	1917	35,644	55,353
1913		69,235	1918	47,739	60,593
1914		57,667	1919	15,295	43,483
1915	857	65,596	1920	27,328	44,482

[a] From reports of North Carolina Geol. and Econ. Survey and Mineral Resources of the United States.

The total recorded production of magnetite from North Carolina is about 1,331,600 tons and of brown hematite about 136,000 tons. Probably 160,000 tons of magnetite and 4,000 tons of brown ore had been mined for local forges before statistics were gathered.

[1] Prepared in cooperation with the North Carolina Geological and Economic Survey, Joseph Hyde Pratt, Director; and the State Geological Survey of Tennessee, Wilbur A. Nelson, Director.

Most of the brown ore produced since 1915 came from Madison and Cherokee counties, N. C., the greater part from Cherokee County. In the earlier years of this century brown ore was obtained mainly from Chatham and Johnston counties, N. C., for the use of the furnace at Greensboro, which was closed about 15 years ago. The magnetite came mainly from Cranberry, in Avery County, N. C. A small quantity has been contributed by deposits at other localities from time to time, but it was obtained principally in the development of explo-

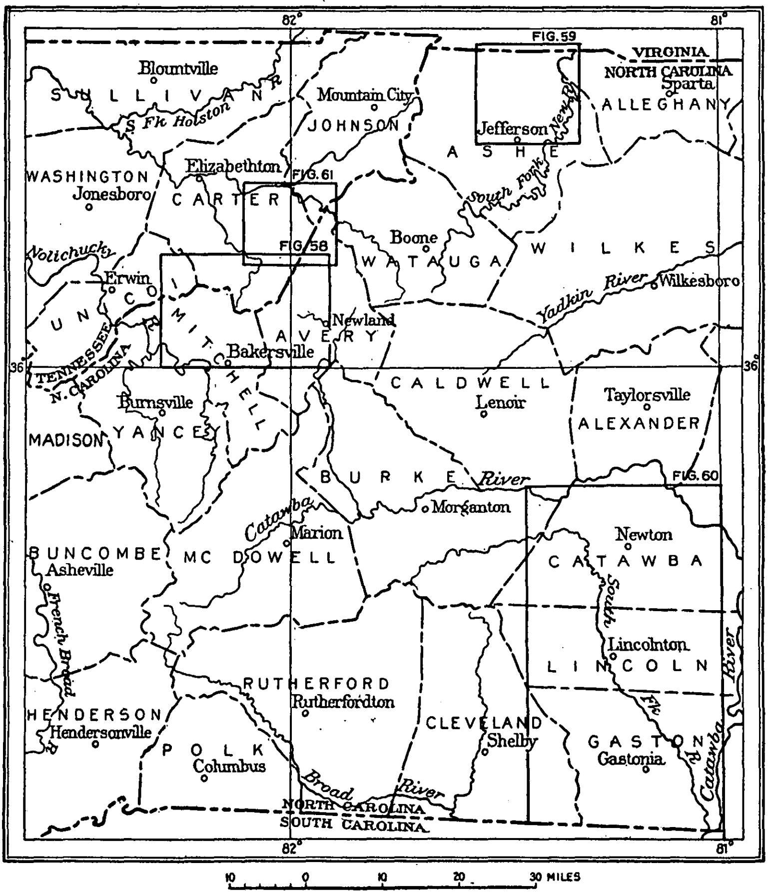

FIG. 57.—Index map of portions of North Carolina and Tennessee, showing position of areas covered by figures 58–61.

rations and consequently was only an incident. Most of it was mined from deposits in Carter County, Tenn., where search was made for the western extension of the Cranberry vein. This is probably all reported as coming from North Carolina, as it was used at the furnace of the Cranberry Furnace Co.

For convenience of discussion the iron ores of the area under discussion may be classified as magnetic ores and brown ores. The brown ores comprise the limonites and perhaps other hydroxides that occur abundantly in Cherokee County and in smaller quantities in Madison, Lincoln, and Gaston counties, all in North Carolina. The magnetic ores are magnetites or mixtures of magnetite and a titaniferous component, usually either ilmenite or rutile, or in small part mixtures of magnetite and hematite. These occur most abundantly in the crystalline rocks of Ashe, Avery, Lincoln, and Gaston counties, N. C., and in Carter County, Tenn., but also in fairly large quantities in the other counties in North Carolina that are underlain by gneisses and schists. In Ashe County a deposit of magnetite is associated with marble, but in all or nearly all the other deposits the magnetic ores are associated with pegmatites or with basic intrusive rocks. The magnetite-hematite ores of Tennessee are associated with volcanic rocks. Only the magnetic ores are discussed here; the brown ores are described in another paper.[2] (See fig. 57.)

VARIETIES OF THE MAGNETIC ORES.

The magnetic ores comprise three types, one of which consists essentially of magnetite, another of a mixture of magnetite and a titanium-bearing mineral, and the third of a mixture of magnetite and hematite. The ores of the second type are usually spoken of as titaniferous magnetites or titaniferous iron ores. The titaniferous magnetites also contain chromium, which does not occur in the nontitaniferous magnetites. Both types are comparatively free from phosphorus and sulphur.

Analyses of nine characteristic magnetites and seven titaniferous magnetites yielded results for their principal constituents that fell within the following limits:

Limits of chemical composition of characteristic magnetites of western North Carolina and eastern Tennessee.

	SiO_2	Fe	S	P	Phosphorus ratio (P:Fe)	TiO_2	Mn	Cr_2O_3
Nontitaniferous.....	3.20–32.59	36.41–65.40	Tr.–0.2	0.004–0.060	0.006–0.105	0.060–0.95	0.16–2.58	0.00
Titaniferous..	1.80–9.90	46.81–57.66	Tr.–0.112	Tr.–0.025	0.013–0.053	4.69–14.46	0.11–0.96	0.34–1.19

All the titaniferous ores that have been analyzed contain chromium, but none has been found in the ores that contain less than 1 per cent of titanium dioxide. Another distinction between the two kinds of ore that is not brought out in the figures quoted is that many of the nontitaniferous magnetites contain comparatively large quantities of manganese, whereas in the titaniferous ores this element occurs in small quantities only. Phosphorus is below or only slightly above the Bessemer limit in both kinds of ore. But for

[2] Bayley, W. S., General features of the brown hematite ores of western North Carolina: U. S. Geol. Survey Bull. 735, pp. 157–208, 1922 (Bull. 735–F).

their high content of titanium the titaniferous ores would be available for blast-furnace use.

Both the magnetites and the titaniferous ores are alike in general appearance and in their occurrence as lenses and veins in gneiss, schist, and other crystalline rocks. Those in the mountain district are associated with Archean country rocks. Those in the Piedmont area are associated with quartzite, marble, micaceous schist, slate, gneiss, and old volcanic lava and tuff, which are younger than Archean but probably older than Cambrian and therefore of Algonkian age.

Nitze[3] describes the magnetitic ores in North Carolina as occurring in belts, inferring that they are distributed along continuous lines. This inference may be correct in a broad way—that is, most of the deposits lie in zones parallel to the general structural trends of the region—but in a narrower sense they occur in short discontinuous lines or series of parallel lines that may be close together in some places and wide apart in others.

Some of the deposits that are situated along a zone of weakness in the country rock, usually a zone along which the schistosity is more pronounced than elsewhere, are actually in line with one another. Others are in schistose zones but not in the same plane, each zone consisting of a series of planes along which marked schistosity has been produced. The deposits may lie within the limits of a comparatively narrow belt crossing the country, but not along the same line within the belt. Their long axes may have the same direction, but the projections of their strikes do not pass through one another but are parallel. Still other deposits are isolated, so far as now known.

Some of the zones within which the deposits are distributed cross the country for many miles; others are short. But even in the long zones the lines passing through deposits on the same strike are short, and often deposits that at first sight are thought to be on the same line are discovered by careful observation to be on parallel lines.

The ores that are mixtures of magnetite and hematite are limited to a small area in Carter County, Tenn., where they occur as layers between gneiss and chloritic schist, on the mountains near Elk Mills. Fairly large explorations have been made at one or two points, but the quantity of ore developed by them is not large, and so far as known not any of it has been shipped. The distance to the nearest railroad is about 6½ miles over hilly roads, so that at present the ore is not available for use in the blast furnace at Johnson City, Tenn. The most prominent ore of this type is an extremely fine grained, obscurely layered, slightly schistose specular ore that re-

[3] Nitze, H. B. C., Iron ores of North Carolina: North Carolina Geol. Survey Bull. 1, 239 pp., Raleigh, 1893.

sembles in appearance some of the most massive specular ores of the Marquette district, Mich. Others are flinty hematites.

NONTITANIFEROUS MAGNETITES.

GENERAL FEATURES.

The nontitaniferous magnetites include those magnetic iron ores in which titanium occurs in quantities so small as to give practically no trouble in the blast furnace. Only these are now of economic importance in the district under consideration. Like the titaniferous ores, they occur as lenses or veins in the old crystalline rocks of the mountain and Piedmont districts. Though associated with large quantities of hornblende they are not accompanied by basic intrusive rocks, like the titaniferous types, but are rather characterized by the presence near them of pegmatites. Epidote and garnet are common gangue minerals.

The magnetite deposits are found in zones crossing the country in the same direction as the major structural axes. Some of the zones are short, but others may be as long as 25 miles. They may contain a few deposits pretty nearly in a single line, a long series of deposits strung along a single line or along several parallel lines close together, or a number of scattered deposits without alinement except that the long dimensions of their exposures are parallel.

The magnetite deposits have furnished most of the iron ore that has been mined in North Carolina. Some of them were worked as early as 1802 to supply ore for use in Catalan forges. The famous Cranberry ore is of this type. It produces iron exceptionally low in phosphorus, which for this reason supplies a demand that can not be as well supplied by metal from any other source. All the magnetite in the State falls within the Bessemer limit, and most of it well below the limit.

All the magnetites occur in old crystalline rocks. Most of them are in granite and siliceous crystalline schist, but those in the Piedmont area are in crystalline schist associated with quartzite. These are of the siliceous type. One deposit in Ashe County is in marble, and there may be several others of this type. These are referred to as magnetite-marble ores.

SILICEOUS MAGNETITE.

The nontitaniferous magnetic ore associated with siliceous rocks constitutes by far the greater portion of the iron ores that occur in the pre-Cambrian areas of these two States. Unfortunately most of it is found in comparatively small deposits, and the magnetite is so intimately mixed with silicates that some form of beneficiation must be applied before the ore is fit for the furnace. As taken from the ground the ore is generally low in iron, but when concentrated it becomes very valuable for special uses.

DEPOSITS IN THE MOUNTAIN DISTRICT.

OCCURRENCE AND GENERAL GEOLOGY.

The magnetite deposits in the mountain district occur most abundantly in Ashe and Avery counties, N. C., and Carter County, Tenn., though numerous deposits are to be found in other parts of the mountain district. They are all contributary to the furnace at Johnson City, Tenn.

The geology of all parts of the mountain district has not been worked out in detail, but Keith[4] has mapped most of the pre-Cambrian area of the district and reached definite conclusions as to the sequence of the formations. He gives the following succession in the Cranberry quadrangle:

Algonkian (?):
- Metarhyolite: Grayish metarhyolite and rhyolite porphyry.
- Flattop schist: Gray and black schist; probably altered andesitic rocks.
- Montezuma schist: Blue and green epidotic schist, probably altered basalt, and amygdaloidal basalt.
- Linville metadiabase: Altered greenish diabase and gabbro.

Archean:
- Rocks of igneous origin:
  - Beech granite: Coarse or porphyritic light-reddish granite.
  - Blowing Rock gneiss: Chiefly dark coarse porphyritic gneiss.
  - Cranberry granite: Mainly granite and granite gneiss.
  - Soapstone, serpentine, and dunite, altered from peridotite and pyroxenite.
  - Roan gneiss: Chiefly hornblende gneiss and diorite.
- Metamorphic rocks of unknown origin:
  - Carolina gneiss: Chiefly mica gneiss and mica schist; includes other gneisses, granite, and diorite.

In addition there are small areas underlain by gabbroitic rocks (Bakersville gabbro), which are regarded as probably Triassic.

In the other quadrangles the variety and succession of formations are very much the same as in the Cranberry quadrangle, except that in some of them a few more granites have been differentiated and named, and small lenses of marble occur in the Carolina gneiss.

These rocks are folded into a complicated series of sharp anticlines and synclines, the outcrops of which cover irregular areas with a strong tendency to a northeasterly elongation. In many places the formations appear on the surface as narrow parallel bands that curve more or less but have a general northeasterly trend. (Compare map, fig. 58.)

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[4] U. S. Geol. Survey Geol. Atlas, Cranberry, Asheville, Mount Mitchell, and Roan Mountain folios (Nos. 90, 116, 124, and 151).

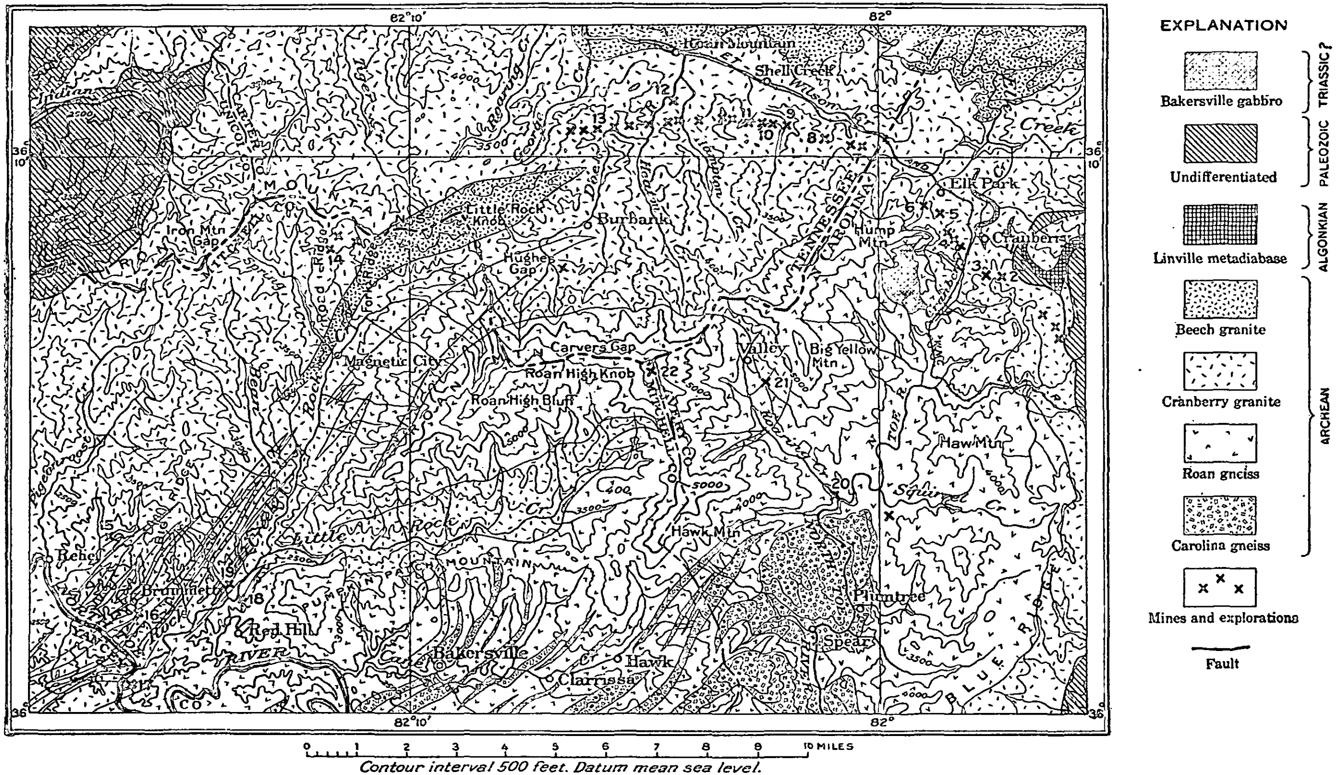

FIGURE 58.—Map showing principal mines and prospects on and near the Cranberry belt, in Avery and Mitchell counties, N. C., and Carter County, Tenn. Geology from Cranberry and Roan Mountain folios. A few of the locations of explorations copied from an unpublished map by S. H. Hamilton. 1, Johnson opening; 2, Smoky No. 1; 3, Smoky No. 2; 4, Cranberry mine; 5, Cooper mine; 6, Ellers Elk Park opening; 7, Wilder mine; 8, Red Rock mine; 9, Patrick mine; 10, Teegarden mine; 11, Ellis entry; 12, Peg Leg mine; 13, Horse Shoe mine; 14, Jenkins exploration; 15, Julie Herrell exploration; 16, Hughes exploration; 17, Bailey prospect; 18, Yelton prospect; 19, Mills Herrel exploration; 20, Toe River Land & Mining Co.; 21, Avery exploration; 22, Roan Mountain exploration. Nos. 19–21 are on titaniferous magnetites.

ASHE COUNTY, N. C.

The siliceous magnetite deposits of Ashe County occur in two belts that have been called the Ballou or River belt and the Red Hill or Poison Branch belt. The Ballou belt extends along the North Fork of New River, crossing it several times, and the Red Hill belt is parallel to the Ballou belt but 2 miles farther west. (See map, fig. 59.) Each belt comprises a number of independent deposits on a series of nearly parallel veins lying close together. Some of the

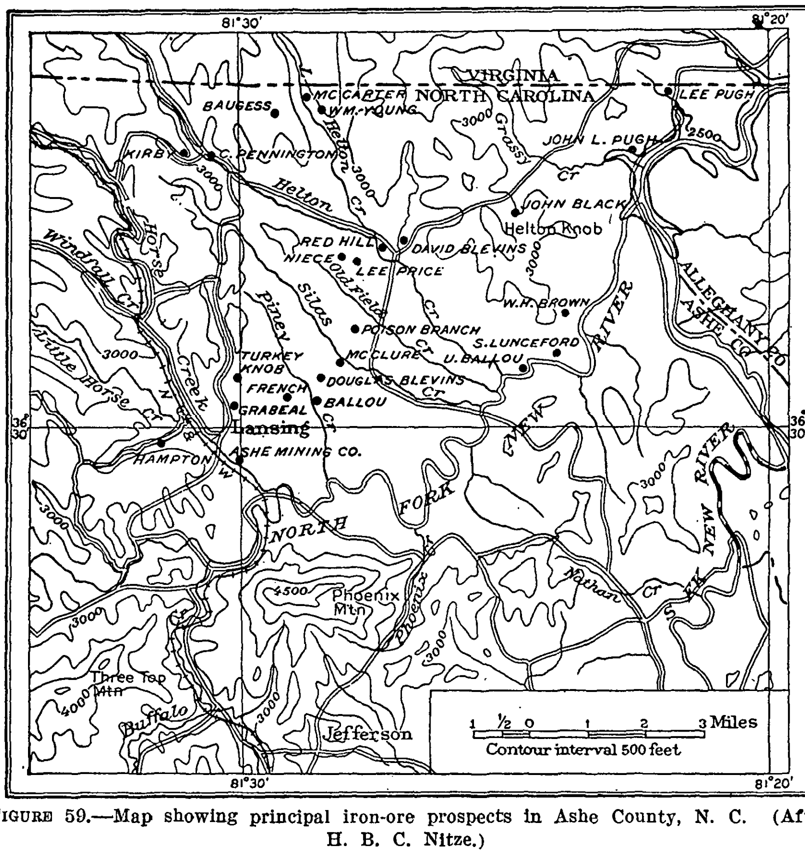

FIGURE 59.—Map showing principal iron-ore prospects in Ashe County, N. C. (After H. B. C. Nitze.)

veins are short, being limited to the length of a single lens of ore; others continue for comparatively long distances and comprise several such lenses, separated by siliceous gangue. The longest vein, perhaps, and the one containing the greatest number of distinct deposits is on the east side of New River about 1½ miles west of Crumpler. All the ore lenses lie with their long dimensions in the courses of the veins, which in turn are parallel to the structure of the schist in which they occur.

The veins consist of more or less banded mixtures of pegmatite, epidote, and various hornblendic schists, in which are lenticular masses of a mixture of hornblende and magnetite. Many of the lenses are too lean to be of commercial value, but many are traversed by small veins of magnetite, which have so enriched them that they may be mined with profit.

Pratt[5] states that

> the deposits are undoubtedly lenticular * * * and are pinching and widening in all dimensions. These lenses may continue for long distances along the strike and on the dip; then again there may be a series of smaller lenses separated from each other by country rock or connected with each other by a thin seam of ore. Sometimes they may be so small as to be of no commercial value; while at other times they attain enormous size, both in length and depth. Usually these ore deposits are conformable to the inclosing country rock. Each ore locality has to be investigated as a separate unit, inasmuch as there is great variation in them.

The old mines are difficult to study, for they have been long abandoned and were never thoroughly developed. There is now little visible at their openings. Most of the information concerning the character of their deposits must be gleaned by an examination of the dumps and a study of the descriptions[6] given by those who visited them when active work was being done. These descriptions relate mainly to the quality of the ore and the size of the ore deposits.

The principal openings in Ashe County are the Kirby prospect, about half a mile north of Sturgill; the Blevins pits, on Helton Knob; the Red Hill openings, near the junction of Helton Creek and Roberts Branch; the Poison Branch mine; Ballou's Piney Creek opening; the Graybeal prospects, near Lansing; and Ballou's home place and the Sand Bank prospects, on the North Fork of New River. Many other pits, trenches, and shafts have exposed siliceous magnetite, but none of them are important.[7] The most promising prospects are those on the North Fork, those on the Graybeal property, and the Ballou opening on Piney Creek. From nearly all the openings more or less ore has been taken to supply forges in the vicinity, but so far as known the only deposit from which ore has been sent to modern blast furnaces is one of those on the Graybeal property.

The ores of all the deposits are granular mixtures of pyroxene, hornblende, and magnetite or of magnetite, hornblende, epidote, and quartz. The pyroxene and magnetite are usually cracked or shattered and the quartz is largely granulated. The epidote is an alteration product of plagioclase. These rather low-grade ores occur in veins from a few inches to 20 feet wide traversing gneiss or gneissoid granite parallel to the schistosity. Most of the veins dip at high

[5] Pratt, J. H., North Carolina Geol. and Econ. Survey Econ. Paper 34, p. 65, 1914.

[6] Willis, Bailey, Notes on samples of iron ore collected in North Carolina: Tenth Census, vol. 15, pp, 324–325, 1886. Nitze, H. B. C., Iron ores of North Carolina: North Carolina Geol. Survey Bull. 1, 1893.

[7] Descriptions of all these deposits will be given in a paper now in preparation.

angles, and in many places they are cut by veinlets of nearly pure magnetite, which enhance their content of iron. In some places the richer parts of the veins swell into lenses; in others they pinch to very narrow streaks.

In every respect except size the Ashe County deposits are exactly like the Cranberry deposit, in Avery County, which, because it affords the best opportunity for the study of the features of the magnetite deposits of the mountain district, is described in detail on pages 221–227. The origin of the Ashe County and the Cranberry ores is believed to be similar.

A few analyses of the ore furnished by the openings in Ashe County are quoted below.

Analyses of magnetite ores from Ashe County, N. C.

	1	2	3	4	5
Silica (SiO_2)	21.76	20.65	2.06	12.16	20.79
Iron (Fe)	43.10	45.25	64.56	61.80	45.50
Sulphur (S)	.036	1.58	Tr.	....	.002
Phosphorus (P)	.057	.052	.014	{ .0088 .0262 }	.024
Titanium dioxide (TiO_2)	Tr.	Tr.	....	.012	....
Phosphorus ratio (P: Fe)	.132	.115	.020	....	.052
Manganese (Mn)	....	....	2.59	1.82	....

1. Kirby mine. Pratt, J. H., North Carolina Geol. and Econ. Survey Econ. Paper 34, p. 71, 1914.
2. Poison Branch mine, average sample. Pratt, J. H., idem, p. 71.
3. Piney Creek opening, compact ore. Nitze, H. B. C., op. cit., pp. 152–153.
4. Graybeal property, carload lot, June, 1916. Furnished by Cranberry Furnace Co.
5. Ballou's home place, North Fork of New River. Nitze, H. B. C., op. cit., p. 137.

In spite of the fact that all these analyses except No. 4 represent selected samples, all of them except No. 3 show the presence of silica in reasonably large quantities. The shipment represented by No. 4 consisted of material carefully selected in the mine from a small vein. The mining of this material was practicable because it could be removed from an open cut without breaking down any poorer material and without hoisting. In most places it would be necessary to remove the entire width of a steeply dipping vein 15 or 20 feet wide to gain room for mining. This would mean that work could not be limited to the rich narrow veins that intersect the lower-grade material which forms the greater parts of the larger veins. Consequently it would seem unwise to attempt to work any of the deposits without providing some means for concentrating the ore. Some of them might be worked profitably for a short time, but only by following the richest veins until a depth was reached beyond which the cost of raising the crude ore would be prohibitive. This depth would not be great on veins only 4 or 5 feet wide. Moreover, all but the richest ore would be left and therefore wasted, as it would not of itself bear the cost of mining.

The most extensive explorations have been made on the Ballou property, North Fork. The old "home place" has been explored by the Virginia Iron, Coal & Coke Co., which now owns the mineral rights, but unfortunately the results of the work done are not available. South of the "home place" the veins extend through the Calloway property, owned by N. Ballou.

The openings on the "home place" are reported to have shown a vein 22 feet wide, dipping 45°–50° SE. The vein consists in part of compact magnetite interbanded with mixtures of magnetite and hornblende and in part of this mixture interlayered with epidote-hornblende schist that probably represents a squeezed pegmatite. On the Calloway property the vein strikes N. 45° E. and is 20 feet wide. It was developed by a tunnel driven into the hill about 140 feet from its top. Pratt[8] says:

> By means of float and a few crosscuts this ore belt can be traced in a southwesterly direction for a distance of about a mile across what is known as the Davis property and the Neaves property, when it crosses the North Fork of New River. On the Calloway property it is estimated that there is a distance of 450 feet of the vein from the tunnel to where it crosses onto the property owned by the Virginia Iron, Coal & Coke Co.

Samples of the ore taken across the vein in the tunnel showed 17.37 per cent of silica, 31.26 per cent of iron, 0.10 per cent of sulphur, and 0.028 per cent of phosphorus.

The quantity of merchantable ore in the "home place" and the Calloway property is greater than in any other equal area in Ashe County, but it is not as great as has been supposed by interested parties. As no records of the results of the explorations on the "home place" are available, and as the explorations on the Calloway property have not been sufficiently thorough to prove the continuation of the vein or to determine the presence of any wide portions, it is plainly imposible to estimate except in a very general way the amount of ore in the area.

On the supposition that a continuous vein 20 feet wide has been proved on the Calloway property, there is between the top of the hill and the North Fork about 350,000 tons of magnetite above the river level. On the same assumption with reference to the Virginia Iron, Coal & Coke Co.'s property there is about 250,000 tons between the top of the hill and the river. In both these estimates the vein is supposed to be capable of yielding about 65 per cent of merchantable ore.

So far as can now be judged the portion of the vein on the west side of the river is at present of no value, for it is too narrow to bear the cost of mining and concentrating. If, however, a concentrating plant were near at hand, perhaps some part of it might be mined with profit.

[8] Pratt, J. H., op. cit., p. 66.

None of the ore on these properties could be shipped without beneficiation. It would have to be mechanically concentrated before being placed on the market, as the amount of rich ore that might be picked by hand from the rock is too small to pay mining costs. A small concentrating plant so situated as to take care of the product of these properties and of any material that might be furnished by deposits farther southwest on the same general belt might be made to pay, but no investment in any kind of mining or concentrating plant would be justifiable until some outlet to furnaces is provided. At present the nearest railroad is about 8 miles distant over hilly roads.

The most promising of all the deposits in the county are those on the Graybeal property and at Piney Creek, near Lansing, principally because they are close to the railroad. It is estimated that on the Graybeal property there is available in the hill above the valley levels about 150,000 tons, on the assumption that the vein is 17 feet wide and 800 feet long and that it will yield 75 per cent of merchantable ore. The estimate for the Piney Creek locality indicates about 65,000 tons above a depth of 100 feet below the level of the creek, on the assumption that the vein is 12 feet and that its length is about 350 feet, the distance between the two most widely separated openings upon it.

In either of these localities some magnetic concentration would be necessary to obtain the full estimated yield, though at Piney Creek a large portion of the yield might be produced by hand cobbing alone. The deposits are too small to warrant the erection of an efficient concentrating plant, even though the output of both properties should be treated together.

AVERY AND MITCHELL COUNTIES, N. C., AND CARTER COUNTY, TENN.

LOCATION OF DEPOSITS.

The only mine in either North Carolina or Tennessee that produces siliceous magnetite is in Avery County, at Cranberry, on the East Tennessee & Western North Carolina Railroad, about 32 miles from Johnson City, Tenn. Other deposits have contributed to the output of magnetic ore from time to time, but the Cranberry mine has been operated almost continuously for 45 years and has furnished many times as much ore as all the other mines combined. The Cranberry ore is famous because of its low content of phosphorus, and the metal made from it has been eagerly sought by manufacturers who desire unusually tough iron. The ore, however, presents no especially peculiar features. There are many other deposits that might furnish ore of the same quality if the quantity were known to be great enough to warrant the erection of a plant of sufficient capacity to keep the mining costs at a reasonable figure.

Careful mapping of the known deposits in Avery and Mitchell counties, N. C., and Carter County, Tenn., suggests that most of them lie in a belt that follows the structural axes of the country from Cranberry west and southwest to Toe River (see fig. 58), beyond which no openings have been made and no outcrops of ore have been reported except at the Big Ivy mine, in Madison County, which is about 25 miles southwest of the point at which the line of openings in Mitchell County crosses Toe River.

The belt of deposits on which the Cranberry mine is situated is the most conspicuous in either State. Its best known deposit is that at Cranberry, from which ore had been taken for the use of Catalan forges as far back as 1820. The belt extends at least as far east as Vale, 4 miles southeast of Cranberry, beyond which Cambrian sediments cover the pre-Cambrian rocks that contain the magnetites and consequently prevent further tracing of the belt. To the west the belt extends into Tennessee to a point beyond Doe River, a distance of 8 miles. Here it is lost as a distinct belt, and no deposits are known for a distance of 3 miles, but Nitze [9] thinks that it bends to the southwest, passes through Grassy Knob, near Magnetic City, and continues southwest, crossing Toe River at Relief. Near Toe River there are a number of small deposits, but they are distributed over a strip of country 2½ miles wide, not in a definite belt, like that at Cranberry.

CRANBERRY MINE.

History.—In 1876 the Cranberry mine, on the southeast slope of Cranberry Ridge, came into possession of its present owners, and in 1882 it was connected with Johnson City by rail. In 1884 a small blast furnace was built at Cranberry and smelting of the ore was begun. In 1900 this furnace was abandoned, a larger one having been built by the Cranberry Furnace Co. at Johnson City, and since May, 1902, the ore has been smelted there. Since 1884 the mine has produced about 1,250,000 tons of merchantable ore, and during the four years 1917 to 1920 it produced about 50,000 tons annually. In 1921 the mine was temporarily closed.

The ore as it comes from the mine is a nontitaniferous magnetite, which may be almost pure or intimately mixed with hornblende or with hornblende and other components of the gangue. Recently it has been shipped to the furnace as mined. Formerly the purer ore was separated from the leaner product by hand picking, and the leaner ore was concentrated by crushing, screening, and treatment with electro magnets. The result of this method of concentration was not regarded as satisfactory in view of its cost, and therefore it was abandoned in 1920.

[9] Nitze, H. B. C., op. cit., pp. 168–182.

A complete analysis of a selected sample of the ore was made by J. G. Fairchild in the Survey laboratory, and the result was published in a general discussion of the origin of the Cranberry ore.[10] Other analyses are given below.

Analyses of ore from Cranberry mine.

	1	2	3	4
Silica (SiO_2)	20.97	26.64	20.74	16.09
Iron (Fe)	45.93	42.78	48.57	50.91
Manganese (Mn)	.31	.51		
Lime (CaO)	10.10	10.80	8.01	5.69
Magnesia (MgO)	1.43	1.85	1.74	1.59
Sulphur (S)	.02	.023		
Phosphorus (P)	Trace.	.0064	.0093	.0071
Phosphorus ratio (P : Fe)	Trace.	.015	.019	.014
Moisture				3.10

1, 2. Crude ore from mine, 1892.
3. Hand-cobbed ore, 1919.
4. Concentrates from hand-cobbed ore, 1919.

Ore vein.—The Cranberry vein, which incloses the deposit at the mine, has been traced for 6,400 feet by pits, cuts, and underground workings, so that it is regarded as being continuous through this distance. The workable ore, however, is not continuous. Some stretches of the vein contain so little available magnetite that they may be regarded as barren. All the ore bodies lie within the vein, but they are separated from one another by portions of the vein that are occupied mainly by gangue. Even these portions contain a little magnetite in strings or threads connecting the ore bodies with one another.

The country rock surrounding the vein consists of a crushed and sheared complex of acidic feldspathic rocks, some of which are dark gray and others almost white, occurring in alternating layers with black gabbroitic gneiss, believed by Keith to be the Roan gneiss, which has been intruded into the more acidic rocks. The lighter-colored layers constitute by far the greater part of the complex, which has been called by Keith the Cranberry granite.[11]

The vein follows the schistosity of the country rock and ranges in width from a few feet to 200 feet. It comprises a plexus of rocks in the midst of which occurs the commercial ore as a series of lenses that, so far as development has gone, appear to have no pitch. Pegmatite cuts irregularly through the vein plexus, twisting and turning in a complicated way and gradually fingering out. In some places it incloses lenses of ore and in others lenses of coarse green hornblende. In places it cuts rather cleanly through the other rocks, commonly with only one sharp wall, rarely with both walls sharp. Usually, however, the walls are indefinite—the pegmatitic material grading

[10] Econ. Geology, vol. 16, p. 151, 1921.
[11] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (No. 90), p. 3, 1903.

into gneiss, so that there is a little seam of gneiss between the pegmatite and the vein matter. The plexus is also cut by veins of almost pure magnetite.

The main portion of the vein, aside from the horses that occur in it and the veins of pegmatite and magnetite, consists of masses of hornblende, or hornblende and magnetite, of hornblende and epidote, of epidote and magnetite, or of epidote and quartz. Small quantities of molybdenite have been noted in places.[12]

All the rock masses are slightly schistose parallel to the strike of the vein, and some of them, especially the aggregates containing epidote, are well-defined gneisses.

The epidote that is so abundant everywhere has apparently been formed by the alteration of feldspar. Some specimens show a continuous gradation from one mineral to the other. Others show a graphic arrangement of quartz and epidote identical with that exhibited by quartz and feldspar in graphic granite. Still others show veinlets of epidote extending from large masses of pegmatite into adjacent rocks, like the ordinary veins of feldspar so frequently found radiating from pegmatite masses. Rarely veins of epidote and quartz pass into veins of magnetite along their strike, apparently indicating that the two were introduced at the same time. That they were once part of the same intrusion is indicated also by the fact that epidote and magnetite are everywhere closely associated.

The magnetite occurs close to the pegmatite. The miners declare that the richest ore is always near pegmatite. The pegmatite and magnetite veins both cut the lean ore—the mixture of hornblende and magnetite referred to above—in the same way, and magnetite extending from the walls of the magnetite veins and impregnating the bordering rocks has enriched them and given rise to magnetite gneisses. Moreover, in many places magnetite forms a constituent of coarse pegmatite, like feldspar, quartz, and hornblende. More commonly, however, the magnetite forms groups, either alone or with hornblende, and these constitute lenses in the pegmatite. There is a strong tendency for the hornblende and magnetite to occur together. They appear to be among the last components to separate, and in places they occur in great coarse masses that form lean ore deposits. Of the two, perhaps the magnetite is the later, as veins of this mineral penetrate the lean ore. It is probable, however, that the magnetite separated in two stages, of which one was nearly or quite contemporaneous with the great mass of the hornblende, and the other was distinctly later. Where the two minerals occur together in the lenses the hornblende is likely to occur on the border of the lens and the magnetite in the center; and where arms extend

[12] Unpublished manuscript by S. H. Hamilton, formerly mining geologist of the Cranberry mine.

into the surrounding quartz-feldspar mass the main portions of the lenses may be composed of magnetite or a mixture of magnetite and hornblende, and the extensions may consist entirely of hornblende.

In thin section under the microscope all the pegmatites, which were originally augite syenite pegmatites, show that they have been subjected to deformation. Their plagioclase, which is mainly andesine, is shattered and cracked, and its twinning lamellae are gently curved or are bent at sharp angles at cracks which cross them. Throughout the feldspar particles of epidote are common. They appear in individual crystals or as groups of grains, but the mineral is most abundant near contacts of the feldspar with hornblende. At such contacts the feldspar is entirely replaced by epidote, as it is also where the feldspar has been broken into small fragments. Between the feldspar grains is a mosaic of quartz and fresh, untwinned feldspar, with an occasional grain of microcline and in many places grains of epidote. The constituents of the mosaic commonly possess a parallel elongation. Here and there are areas in which a few large quartz grains are observable. These are perhaps the remnants of original quartz components of the pegmatite, as they are always divided into differently oriented sectors, all of which show wavy extinction, whereas the smaller components of the mosaic are homogeneous throughout and extinguish sharply. In some places, more particularly in the triangular patches of mosaic between several neighboring feldspars, there are small masses of calcite. As these show comparatively few twinning bars, they are inferred to be secondary.

The hornblende, which is present in nearly all specimens of the pegmatite that have been seen, is apparently all secondary. It occurs in large compact masses and in plates, fibers, and acicular crystals. Within many of the large compact masses there are remnants of a partly uralitized pyroxene which is slightly pleochroic in yellowish-green tints. Many of the pyroxene remnants, like the feldspars, are fractured, and into the fracture cracks quartz or quartz and epidote have been forced. The compact hornblende that is not demonstrably derived from pyroxene occurs in large crystals that have the sieve structure characteristic of minerals of metamorphic origin. Scattered through the hornblende here and there are the little regularly arranged platy inclusions characteristic of diallage in gabbros. The greater part of the hornblende, however, is a mass of small crystals and fibers intermingled with small grains of quartz, a few tiny grains of epidote, and little nests of calcite.

The gneisses that constitute so large a proportion of the vein matter are medium-grained schistose aggregates of epidotized feldspar, hornblende, magnetite, and a little quartz in which the pencil structure is prominent, or of fresh feldspar, quartz, and magnetite. There is no reason to suppose that the magnetite does not bear the same relation to the other components as the hornblende, or as any femic mineral in any gneiss with a structure that is original. The gneiss in the vein mass of the Cranberry vein (exclusive of that forming horses) is believed to be an igneous rock closely related to the pegmatite, and its structure is thought to be the result of crushing and recrystallization under movement in the plane of the vein.

The relation of the pegmatite to the coarse hornblende masses is difficult to determine. In some specimens the pegmatite appears to be older than the hornblende, but in most specimens it is later. It intrudes the hornblendite in distinct dikes and little stringers, all running in the same direction, forming a gneiss, and it also crosses little streaks of the hornblendite and surrounds little islands of this rock. The general aspect of specimens showing these relations is that of an injection gneiss.

The lean ore has been described as a mixture of hornblende and magnetite. Usually the two are uniformly intermixed, but in some of the ore the magnetite is scattered as tiny grains through the hornblende, and elsewhere it occurs as little streaks and lenses in the midst of a granular hornblende aggregate. Portions of the leaner ore are characterized by the presence of garnets. Ore of this kind is finely granular and is composed mainly of little grains and crystals of magnetite and red garnet, separated from one another by a little chlorite, pyroxene or hornblende, epidote, and tiny nests of calcite, in a fine-grained mosaic made up of quartz and calcite. The hornblende and epidote and much of the calcite occupy areas that were originally occupied by pyroxene, and in places the garnet forms a wide border around them. The relation of the garnetiferous ore to the other varieties is not certainly known, but this ore is said by the miners to be associated with pegmatite. As the ore becomes richer the magnetite becomes more and more abundant and the hornblende naturally less abundant until the richest ore of this type is a fine-grained aggregate of grains of magnetite 1 millimeter or less in diameter, with here and there a grain of hornblende, epidote, and quartz and little nests of calcite. A few white sugary quartz veins run through the mass, and it has a very obscure schistosity. In many places where the schistosity is a little more marked than elsewhere the difference appears to be due to the much greater abundance of magnetite in certain layers than in others—either as many little lenses embedded in sparse hornblende or as numerous grains scattered through the hornblende. The magnetite is not sharply separated from the surrounding hornblende, nor are the layers rich in magnetite sharply separated from those composed exclusively of hornblende. The portions rich in magnetite grade into those containing little, and in many hand specimens it is impossible to designate definite lines between them. The relations of the magnetite to the hornblende suggest strongly that a schistose hornblende rock has been impregnated by magnetite and that the result is a magnetite-hornblende gneiss analogous to the impregnation gneisses so common in areas of old rocks.

In ore of a second type an enrichment in iron has been brought about by a later contribution of magnetite in the form of veins that cut the lean ore. These veins range in width from a small fraction of an inch to several feet. With increase in their number and thickness the lean ore rapidly changes to a high-grade ore, the highest grade being that of the thickest veins. Some of these veins are wide enough to furnish fragments that can easily be separated by hand from the run of the mine and saved for a special grade of the highest quality. The material of these veins is usually a medium coarse-grained aggregate composed entirely of magnetite. The grains have average diameters of about a quarter of an inch, though many of them are much larger. They are black and have a brilliant luster, being thus distinctly different from the titaniferous magnetites, which have the color and luster of steel.

The most striking feature of thin sections made from ore and gangue is the granulation of the quartz and the feldspar. Many of the magnetite grains are broken and their parts separated. The amount of crushing suffered by the constituents of the vein is even greater than that suffered by the surrounding granite, to judge from the appearance of the thin sections. This conclusion is directly in opposition to Keith's view[13] that the deposit was made after the deformation of the region.

The minerals composing the ore and gangue of the Cranberry vein were thought by Keith to have been deposited long after the inclosing granite and after the deformation that produced its schistosity, for they "are only slightly crushed or rearranged, although they are the same varieties which in adjacent formations show the greatest metamorphism." The ore may "have replaced a preexisting mass of rock by solution and substitution of new minerals, or it may have been deposited from solution in open spaces in the inclosing formation."[14] It appears to Keith more probable that the ore replaced an igneous, diabase-like mass that intruded granite, although he does not say why other diabase-like masses in the granite were not similarly replaced. He concludes that because the magnetite deposits are later than the folding movements in the district, and because an adjacent gabbro, regarded by him as the Bakersville gabbro, is also later than these movements, and the magnetite bodies swing around the circumference of an area of the gabbro, "the magnetites are due

[13] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (No. 90), p. 8, 1903.
[14] Idem, p. 8.

to alterations begun by the gabbro intrusions." However, as there are no "later intrusions" of gabbro or diabase in Ashe County, where magnetites similar to the Cranberry magnetites occur, the ore in this region can not have been produced by the process outlined. Keith thought that the iron in Ashe County may have been dissolved from the Roan gneiss, through which the mineralizing solutions must have passed in more than one epoch.

The study by the writer of thin sections of the so-called Bakersville gabbro near Cranberry reveals a metamorphosed basic rock in which there has been a great deal of crushing. They show exactly the same features as the heavier layers in the Roan gneiss, which is pre-Cambrian.

The relations of pegmatite, gneiss, hornblendite, and magnetite in the Cranberry vein suggest that they were all formed by an intrusion that took place before the general deformation of the mountain region was concluded. The intrusive mass was apparently a magnetitic pyroxene pegmatite, followed later by one of pyroxene magnetite and finally by one of magnetite. According to this view the magnetites of North Carolina and the similar magnetites in eastern Tennessee originated in much the same way as those of New Jersey. In all three States intrusions of less siliceous ferriferous liquids, which formed pyroxene pegmatites and magnetites, followed those of the more siliceous magmas, which formed richly quartzose pegmatites. The intrusions in New Jersey are thought to have taken place in pre-Cambrian time, because no later pegmatites are known there. In North Carolina the severe deformation of the material of the deposits indicates that they were formed earlier than the end of Paleozoic time, and as no pegmatites are known to exist in the Paleozoic rocks, it is probable that they were formed in pre-Cambrian time. The source of the liquids is not known, but they might well have come from the magmas that furnished the gabbros, diorites, and other basic sills, in the Roan gneiss, unless this gneiss is distinctly older than the Cranberry granite, as believed by Keith. Or they may have come from magmas that later rose as Algonkian(?) volcanic material, forming the Linville metadiabase, Montezuma schist, Flattop schist, and metarhyolite of Keith.[15]

OTHER DEPOSITS IN THE CRANBERRY BELT.

The Cranberry vein is believed to extend southeast and northwest of the Cranberry mine for some distance. It has been traced continuously southeastward across Smoky Mountain for 3,800 feet from the mine and has been opened at three places by pits and tunnels and at several other places by trenches. Ore has been taken from two of these, known as Smoky No. 1 and Smoky No. 2 openings. Farther

[15] Op. cit., pp. 3, 4.

southeast the vein becomes more indefinite. Openings on the Lee Johnson place, 1 mile north of Vale and 4 miles southeast of Cranberry, indicate that it extends at least that far. Beyond this point Cambrian sediments cover the pre-Cambrian rocks and prevent further tracing of the belt. It is said that 2 carloads of ore were shipped from the Johnson place.

At no point southeast of Cranberry are there any known deposits that are comparable in size with that at Cranberry. A few carloads of ore may be furnished by lenses strung at intervals along the line, but no large mine is likely to be developed anywhere.

Northwest of Cranberry the vein has been traced 2½ miles in a general direction N. 35° W. to the State line and 2½ miles N. 65° W. to the Teegarden mine, near Shell Creek, Tenn. Beyond this point the vein has not been traced continuously. The Peg Leg mine is 1½ miles N. 65° W. of the Teegarden opening, on Doe River about 1 mile south of Roan Mountain station. Here the vein apparently takes a turn to the south, for no openings are known to have been found in it north of west of the Peg Leg opening. However, 2½ miles S. 60° W. are several openings of the Horse Shoe mine, and 3 miles farther in the same direction is a group of pits and other openings north of Magnetic City. Beyond Magnetic City the number of exposures and pits increases, but they are not limited to a single line. The exposures indicate much narrower veins and very small ore bodies. As the same associations of epidote, hornblende, and magnetite as at Cranberry are shown at all these openings, it has been assumed that they are all on a single vein or on a series of connected parallel veins that follow the structural trend of the country rock like the vein at Cranberry. At Cranberry the trend is northwest. Beyond Elk Park it begins to bend to the west and at Doe River more to the south. Between Magnetic City and Relief on Toe River the rock belts strike S. 30° W. Beyond Toe River in Yancey County no exposures of the vein are known, though a few scattered deposits have been found. Everywhere the vein or vein belt follows the rock structure in direction, as if the material composing it had been introduced into the old rocks along a shear zone in which the resistance was less than in other directions.

The principal openings in this line of deposits are at the old Cooper place, three-fourths mile south of Elk Park, from which a little ore was taken; the Ellers or Hardigraves Elk Park opening, three-fourths mile southwest of Elk Park, which are reported to have furnished about 3,000 tons of ore containing 42 per cent of iron; the Wilder mine, halfway between Elk Park, N. C., and Shell Creek, Tenn., and one-third mile south of the railroad right of way; the Red Rock mine, about half a mile west of the Wilder mine; the Teegarden and Ellis mines, three-fourths mile southeast of Shell Creek; the Peg Leg mine, 1 mile south of Roan Mountain station; the Horse Shoe mine, at the big bend in Doe River, 3 miles southwest of Roan Mountain station; and the Jenkins ore banks, on Greasy Creek near Magnetic City. Many of these openings furnished ore to local forges, and several of them, notably the Wilder, Teegarden, and Peg Leg, have sent ore at various times to the Cranberry furnace. At the Wilder mine about 5,000 tons was obtained before 1918 averaging 30.70 per cent of iron and 0.014 per cent of phosphorus, and at the Teegarden mine about 5,000 tons containing 36.36 per cent of iron and 0.0113 per cent of phosphorus.

At all these places the relations of the ore to the vein matter and of the vein to the country rock are the same as at Cranberry, and the character of the ore in all is similar. At the Wilder mine, however, the vein is folded and the vein matter contains a few large flakes of molybdenite. One of these flakes, found by S. H. Hamilton, measures about 2½ by 1½ inches. It occurs in the foliation planes of an epidote-hornblende gneiss that is believed to be a sheared pegmatite.

South of Magnetic City and at several other points to the north and east are numerous prospects that are not on the line passing through the deposits enumerated above. Some of them are apparently isolated, but others seem to be grouped along lines following the direction of the general structure. In all of them the conditions seem to be similar to those at the Cranberry mine except that the veins are small and consequently the inclosed ore lenses are likewise small. None of them give promise of becoming commercially important in the near future.

RESERVES IN THE CRANBERRY BELT.

Nowhere in North Carolina and Tennessee have the explorations in the magnetite been sufficiently thorough to warrant a statement as to the quantity of this ore in the ground. It is known that there are numerous deposits of good ore on what has been called the Cranberry belt, but as to the size of most of these deposits almost nothing is known. Probably all those in Mitchell County near Toe River are too small to be of importance as potential sources of ore.

The most promising portion of the belt is the stretch of about 10½ miles between Smoky Mountain, southeast of Cranberry, and the Horse Shoe mine, in Carter County, Tenn. It has been opened at thirteen or fourteen points, and at each opening some ore has been uncovered. Moreover, magnetic surveys indicate the presence of ore bodies between the openings. At the Horse Shoe, Peg Leg, Teegarden, and Wilder mines the deposits are probably large enough to be worked under present conditions, but in each place the ore is comparatively lean. Probably if an efficient concentrating plant to which the crude ore could be sent were within reach some of the other deposits might be exploited. Such a plant, if built, should be situated at Roan Mountain or Shell Creek, where all the ore that might be mined between Cranberry and the Teegarden mine could be sent to it by a down-grade haul on the railroad. A plant at Roan Mountain would also be conveniently situated with reference to any ore that might be obtained at the Peg Leg and Horse Shoe mines and in the intervening country.

It is impossible to estimate the amount of crude ore that would be contributary to such a plant, but if the average width of those portions of the deposits that would be worth concentrating is 15 feet, and if one-half the length of the belt is barren, the quantity of crude ore in the 5½ miles between the Cranberry and Peg Leg mines is 3,000,000 tons for every 100 feet of depth. As the width of the nearly pure magnetite exposed in the openings that have been made ranges from 4 to 20 feet, it is probable that the crude ore would yield about 75 per cent of commercial concentrate. On these assumptions 2,250,000 tons of concentrate would be obtained for every 100 feet of depth.

At the Cranberry mine the ore that has been removed was mainly in one large lens, but smaller portions of other lenses have also contributed to the product. As there is no reason for supposing that the lenses that have been worked are the only ones existing in the Cranberry vein, and as the theory of the origin of the vein and its contents suggests the existence of other lenses, it is assumed that such lenses occur both on the strike and the dip of the vein, and that they are uniformly distributed through its extent. The following estimate of the probable reserves in the vein is based on these assumptions.

In 1892 Nitze[16] estimated that the ore body had been opened and explored for a length of 875 feet, a breadth of 300 feet, and an average depth of 165 feet, representing approximately 1,600,000 yards of material, containing about 4,800,000 tons of ore material and 3,000,000 tons of "pure ore." Since 1882 only about 1,250,000 tons of ore has been shipped, though nearly the entire slice referred to has been mined except portions that were too lean to warrant the expense of removal and concentration. Moreover, the shipments include an additional quantity taken from the northwestern portion of the mine, which had not been developed at the time of Nitze's visit. It is evident that his estimate of 50 per cent (by volume) of ore in the slice was too large. The slice was clearly not all occupied by a single lens, and a fair estimate of the ore in the mine was impossible because insufficient exploratory work had been done. The same difficulties lie in the way of making a fair estimate to-day.

[16] Op. cit., p. 170.

An inspection of the mine plats will show that the ore has come from lenses limited partly by pinches in the vein and partly by the narrowing of the richer portion of the vein filling. There is no probability that the lenses terminate abruptly with depth. If the source of the ore was, as supposed, a subterranean magma, it is probable that the deposits extend downward for some distance. There should be ore below the present workings, and there is no reason to doubt that the quantity should be approximately the same per unit of mass as has been taken from the portions that have been worked out. If 1,500,000 tons of ore has been removed from the present workings, which are about 1,800 feet long, from a few feet to 200 feet wide, and about 550 feet high, and if 200,000 tons still remains in the upper levels, there is probably in an equal vertical distance of 550 feet below the present bottom of the mine a similar quantity (1,700,000 tons) in every 1,800 feet on the length of the vein. There is no evidence to show how far the vein extends with its present width either in a northwest or southeast direction, but magnetic observations made to the northwest indicate a number of swellings that represent lenses of ore. If the vein extends 1,800 feet northwestward beyond the present end of the mine with an average width of only half of that in the present workings, the quantity of ore that is still available above a depth of 550 feet below the present level is 3,600,000 tons, without considering that portion of the vein that extends southeast of Cranberry.

It is quite evident that the figures given above are of very little value as indicating the quantity of ore existing in the Cranberry vein except perhaps to emphasize the fact that the statements of enormous tonnages of ore existing in the mountains of North Carolina and Tennessee are grossly misleading.

OTHER RESERVES IN THE MOUNTAIN DISTRICT.

There is a great quantity of magnetite in the mountains, but it is so widely scattered in small deposits that but little of it is now available for commercial exploitation. In a few portions of the district large deposits occur, but their total magnitude is measured in millions and not in billions of tons. The smaller deposits constitute large reserves, but they are reserves that can not be drawn upon for many years.

DEPOSITS IN THE PIEDMONT AREA.

DISTRIBUTION AND GENERAL GEOLOGY.

Although the magnetite deposits in the Piedmont Plateau of North Carolina were known before those in the mountain district and had furnished ore to local forges during the War of the Revolution, none of them have been developed on as large a scale as the deposit at Cranberry, and for 30 years all of them have been abandoned. At several places explorations have been undertaken recently to test the size and quality of the deposits, but no favorable results were obtained. Some of the ore bodies are apparently large, but the poor quality of the ore and the distance of the deposits from the market prevent their development at present.

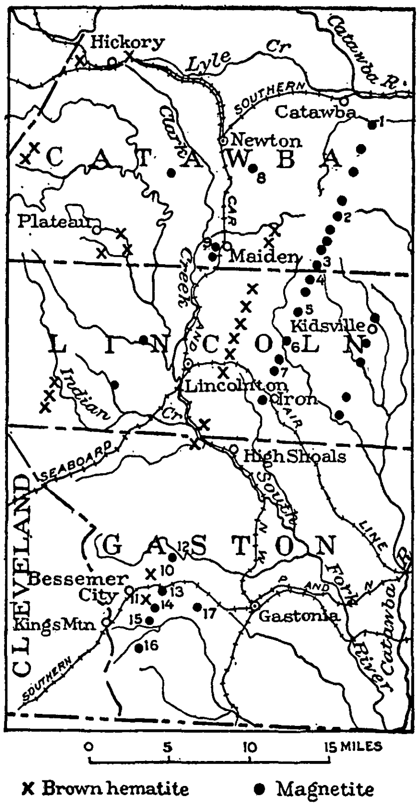

FIGURE 60.—Map showing location of principal iron-ore deposits in Catawba, Lincoln, and Gaston counties, N. C. (In part after Kerr, Hanna, and Nitze.) 1, Powell mine; 2, Abernethy mine; 3, Morrison mine; 4, Robinson mine; 5, Stonewall mine; 6, Brevard mine; 7, Big Ore bank; 8, Barringer mine; 9, Forney mine; 10, Ormond mine; 11, Little Mountain mine; 12, Costner mine; 13, Ellison mine; 14, Ferguson mine; 15, Fulenwider mine; 16, Yellow Ridge mine; 17, Crowder Mountain prospects.

Only the deposits in Catawba, Lincoln, and Gaston counties, N. C., are discussed here. (See fig. 60.) They comprise some of the most valuable deposits in the Piedmont district and are typical of the others.

The rocks with which the ores are associated are gneiss, schist, slate, limestone, quartzite, and granite, cut by dikes of granite, pegmatite, and diabase. The schists are in part very much sheared volcanic rocks and in part schistose sediments. These rocks occur in a number of approximately parallel belts crossing the State from northeast to southwest. They are not all of the same age, but their precise age relations have not yet been worked out. They are regarded by most geologists as pre-Cambrian. Keith and Sterrett[17] believe them to range in age from Archean to Triassic.

In a report on the gold and tin deposits in Lincoln and Gaston counties, near Kings Mountain, Graton[18] declares that a broad view of the field confirms the idea that many of the rocks associated with the ores are of sedimentary origin, as they reveal a stratigraphic succession characteristic of sedimentary formations.

[17] Keith, Arthur, and Sterrett, D. B., Tin resources of the Kings Mountain district, North Carolina and South Carolina: U. S. Geol. Survey Bull. 660, pp. 124–132, 1918.

[18] Graton, L. C., U. S. Geol. Survey Bull. 293, p. 26, 1906.

Impure quartzites, biotite and sericite schists, and partially marmorized limestones, representing original sandstones, conglomerates, shales, and limestones, are bedded with true sedimentary regularity. * * * From evidence furnished by the structure * * * a succession has been determined which is probably fairly correct. * * *

These strata are penetrated or separated by layers of amphibolite lying in parallel position. It seems probable that part of the amphibolite represents intercalated intrusions into the sediments, while part represents interstratified deposits of basaltic tuff or flows of basalt lava. Ancient bodies of granite, now converted into a more or less foliated gneiss, are likewise intercalated with the other rocks. More recent intrusions of granite, pegmatite, and diabase have also penetrated these strata.

The graphite and manganese deposits and some of the iron deposits are thought to be in beds that "represent localized deposits in bogs or swamps."

The beds were believed to lie in isoclinal folds with northeasterly axes and steeper dips on their southeast than on their northwest limbs. "Because of their comparatively small extent, the beds of iron and manganese ore and the conglomerate do not always form continuous outcrops and are [therefore] not always present on both sides of the fold."

The deposits of Catawba, Lincoln, and Gaston counties occur in distinct belts striking for long distances about N. 30° E., but the belts in Gaston County are offset with reference to those farther north and may not be continuous with them. The northern belts are separated from the southern belts by a stretch of country 12 miles or more in width from which no ore has been reported.

Hanna [19] mapped the area in 1888 (fig. 60), and Kerr [20] in 1875 declared that at that time the Lincoln County belts were the best known and best developed of all the iron-ore ranges in the State and had been the principal source of the domestic supply of iron for a hundred years.

At one time there were five furnaces and several Catalan forges working on the ores of the belt, and one of the furnaces had remained almost continuously in blast for more than 100 years. The iron made was regarded as excellent.[21]

CATAWBA AND LINCOLN COUNTIES, N. C.

Of the three belts of magnetite in Catawba and Lincoln counties, the one that contains the best ore bodies, which is the central one of the three, extends northeastward from Iron Station on the Seaboard Air Line Railway, a few miles east of Lincolnton, to a point near Catawba on the Southern Railway, a distance of about 20 miles. In the early part of last century this belt was more or less extensively developed throughout its extent. The large openings still visible at many points

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[19] Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geology of North Carolina, vol. 2, p. 155, Raleigh, 1888.

[20] Kerr, W. C., Report of the Geological Survey of North Carolina, vol. 1, p. 251, 1875.

[21] Kerr, W. C., and Hanna, G. B., op. cit., p. 167.

give evidence of the magnitude of some of the operations. Unfortunately, however, most of the work was done by means of open cuts, which are now so nearly filled that they furnish no possibility for study. About all that can be done at present is to examine the descriptions of the deposits that were written at the time they were being worked and interpret these descriptions in the light of present knowledge of similar deposits elsewhere.

In their report on the iron ores of North Carolina Kerr and Hanna [22] wrote with reference to the magnetites of this belt:

The beds are nearly vertical and dip sometimes to the east and sometimes to the west, but the westerly dips are by far the most frequent. For a considerable part of the belt in Lincoln County there are two parallel beds, the more westerly being the more productive, and the combined thickness being from 4 (rarely so low as 2) to 12 feet; the interval of 12 to 20 feet between them is occupied by talcose and chloritic schists, with a little ore in layers. The beds generally occur in lenticular masses or flat disks, which thicken at the middle and thin out toward the edges, having the same general dip as the bed; but they do not succeed one another in the same plane; their edges overlapping so as to throw up the upper edge of the lower disk behind the lower edge of the upper.

The deposits on this belt that were formerly worked, beginning with those to the north, were the Powell, Littlejohn, Abernathy, Mountain Creek, Deep Hollow, Tillman, and Morrison banks, in Catawba County, and the Robinson, Stonewall, Brevard, and Big Ore banks, in Lincoln County. Surface exposures and float are visible at several points between these old mines and at two points south of the Big Ore bank.

The deposits form an almost continuous straight line, bordered on the west by a low ridge of quartzite, beyond which, a little farther west, are two thin layers of white and blue marble separated by a layer of quartz. The layers or lenses of magnetite appear to be everywhere associated with talcose schists.

As the Big Ore bank was the largest of all the mines in this district a brief account of what is known of its geology is justifiable, though nothing can be added by the writer to the old descriptions. The principal openings are on both sides of the road between Macedonia Church and Derr, in the area mapped by the United States Geological Survey as the Hickory quadrangle. The series of openings, which include some immense holes, crosses the road about a quarter of a mile southeast of the road junction at Macedonia Church in a belt about 250 to 750 feet wide, striking N. 25° E. and extending from a point one-third mile north of the road southwestward for about 1¼ miles.

On the dumps were found a few pieces of rusty magnetite and fragments of a foliated rock composed of alternating layers of chlorite, mica schist, and fine-grained gneiss. A similar rock was

[22] Kerr, W. C., and Hanna, G. B., op. cit., p. 157.

seen in exposures at a little falls just west of the westernmost line of pits. About 250 feet west of the westernmost pits, north of the road, are exposures of coarse quartzite. Both the schist and the quartzite are apparently under the ore, the quartzite beneath the schist.

In the description of the mine in the Tenth Census report it is stated (p. 317) on the authority of an old miner that the ore

> lies in lenticular masses, which overlap each other, the southern end of one lying west of the northern end of the next. These ore bodies consist of alternate layers of magnetite and talcose schist and have a thickness of 8 to 20 feet, with a maximum length stated at 80 feet. The greatest thickness of any one stratum of clean ore is perhaps 2 feet; but such a layer is usually between two thinner ones of talcose schist impregnated with ore, so that the entire thickness would be mined out at once. As the strata stand nearly vertical there are apparently several parallel lines of ore bodies.

At the engine shaft the thickness of the mass of ore opened was 16 feet. This was mined in 1880–1882. The shaft was 100 feet deep, and according to Nitze[23] a crosscut at its bottom went through 60 feet of alternating schists and ore, as indicated by a sketch which was "drawn according to verbal statements obtained from Mr. J. E. Reinhardt, the last superintendent and manager of this mine." Three ore layers separated by layers of schist are shown in the sketch. Of the ore layers two consist of "gray ore," a schist through which is disseminated granular magnetite, and the third of "red ore," which is composed partly, perhaps, of martite.

Analyses of these two varieties are recorded by Nitze as follows:

Analyses of ore from Big Ore bank.

	Gray ore.	Red ore.
Silica (SiO_2)	6.19	1.07
Iron (Fe)	66.92	68.40
Sulphur (S)	.068	.069
Phosphorus (P)	.082	.072
Phosphorus ratio (P: Fe)	.124	.105

The complete analysis[24] of the soluble portion of a sample taken from the shaft at a depth of 40 feet gave:

Ferric oxide (Fe_2O_3)	73.67	Magnesia (MgO)	1.15
Alumina (Al_2O_3)	.62	Other	.86
Ferrous oxide (FeO)	8.68	Moisture	1.01
Manganese oxide (MnO)	.06		

If the determination of the FeO is correct, only 19.29 per cent of the Fe_2O_3 is required for the magnetite in the sample, and the remainder (54.38 per cent) must be present as hematite or martite. In

[23] Op. cit., p. 91.

[24] Tenth Census, vol. 15, p. 317, 1886.

this respect the ore is very different from the magnetites of the mountain district.

All the nontitaniferous magnetites in these two counties are like the ore at the Big Ore bank both in character and in associations, so far as these features are now observable.

The mines on the other two belts were never important. On the westernmost belt were the Barringer mine, east of Newton, and the Forney and Killian mines, southwest of Maiden. East of the Barringer mine the fields are full of fragments of a micaceous quartz schist, in which nothing but cracked and crushed interlocking quartz grains, large flakes of colorless muscovite, and an occasional particle of feldspar can be detected. No rocks are to be seen in the pits. Kerr[25] states that the ore was a compact or coarse granular magnetite in a nearly vertical vein and that there was practically no gangue. Several thousand tons of ore was taken from this mine during the Civil War. The other two mines present no significant features.

GASTON COUNTY, N. C.

Some of the ore veins of Lincoln County may extend southwestward into Gaston County, but some others disappear in their southwesterly extension and new ones not represented in the northern county take their place. As a matter of fact, a limestone belt and a belt of manganiferous slates in Gaston County are on the strike of similar belts in Lincoln County and are assumed to be their extensions. However, as there may well be several belts of both limestone and manganiferous slates in the district, it is possible that those in Gaston County are not the continuations of those to the north. This view is rendered the more probable by the fact that between the slates and limestones in Lincoln County there is only one belt of ore deposits, whereas between the slates and limestones in Gaston County there are three belts of deposits—one of magnetic ore and two of limonite. Moreover, there are three belts of magnetite in Lincoln County and only two in Gaston County, and there is a series of limonite deposits west of the limestone in Lincoln County and no evidence of such a belt in Gaston County. Until the geology of the district is mapped in detail the relation of the belts in the two counties can not be determined. When all the ore belts in both counties have been discovered, they may be found to be equal in number and it may be possible to correlate them, but at present it would seem better to consider the southern belts as being independent of the northern belts.

The easternmost belt of magnetites in Gaston County corresponds in position to the easternmost belt in Lincoln County and like that

[25] Op. cit., p. 253.

belt has been opened at only a few places, mainly on or near Crowders Mountain. Some of the ores are mixtures of magnetite and martite. It is probable that most of them are of local extent and of little promise as sources of ore.

In a footnote to his description of the Crowders Mountain ore beds Hanna [26] writes that

the iron ore is frequently seen in boulders, one of which was judged to weigh 200 tons. Most of the ore seemed to be layers of quartzite or schist, and often there is a transition from quartzite to ore, and vice versa, the extreme terms being a quartzose iron ore on the one hand and a ferruginous sandstone or quartzite on the other. Some of the ore beds were charged with pyroxene, while others showed the mammillary or cellular structure, originally due to its deposition as bog ore.

The last statement is evidently intended to apply to the limonites, but the correctness of the inference is doubtful, for if the sandstones associated with the ore have been metamorphosed to quartzite and to kyanite schist, as Hanna states, any bog ore interlaminated with the sandstones would have lost all of its original structure, particularly its cellular texture.

The principal belt of magnetite in Gaston County is that extending from the Costner mine, northeast of Bessemer City, to the Yellow Ridge mine, about a mile west of the south end of Crowders Mountain. No magnetite has been reported northeast of the Costner mine nor southwest of the Yellow Ridge mine, but between the two the vein has been traced almost continuously and has been worked at the Costner, Ellison, Ferguson, Fulenwider, and Yellow Ridge mines.

The Costner mine is now a series of nearly obliterated large pits, in the woods about 2½ miles northeast of Bessemer City. Very little is known about the occurrence of the ore, but Kerr [27] reports that one wall was a bed of crystalline limestone 12 feet thick. The ore was variously reported as a very dense, a metallic, and a subcrystalline magnetite in a vein from 10 to 20 feet thick. It is stated [28] that during the Civil War a shaft was sunk on the property to a depth of 115 feet. From this shaft two kinds of ore were obtained, but their relations to each other were not ascertained. Special mention is made of this mine because it is the only one in which the magnetite is believed to be associated with limestone. In all the others on the belt only talcose or actinolite schist and quartzite are known to be in contact with the ore bodies. None of the old descriptions are definite enough to convey a very clear idea of the manner of occurrence of the ore, and at present nothing can be learned from an inspection of the openings. It is stated that the quantity of sulphur present in the ore increases slowly with increasing depth.

[26] Kerr, W. C., and Hanna, G. B., op. cit., p. 166.
[27] Op. cit., p. 255.
[28] Tenth Census, vol. 15, p. 318, 1886.

At the Fulenwider mine, which is on the south side of Abernethy Creek about 3½ miles south of Bessemer City, one feature was noted that has not been reported elsewhere. It is stated by Hanna [29] that the ore is the characteristic gray magnetite in a "talcose and quartzose gangue." On the writer's visit to the site of the mine he found a number of small openings and several large ones west of the road crossing the creek and was told that there were several others on the east side of the road. All the openings are now fallen in, so that nothing of interest could be learned from them, but the fields in the vicinity of the pits are thickly covered with numerous large boulders of rusty magnetite. In the road are exposures of a very quartzose graywacke or a quartz schist that is cut by veins of quartz parallel to what appears to be bedding. The quartz is veinlike, and much of it is pure. In some places it contains narrow streaks of a fine-grained tourmaline aggregate; in others the quartz is fractured, and tourmaline occurs between the fragments. In a few places the quartz is unquestionably later than the tourmaline. It cuts the tourmaline aggregates in little veins and forms little nests in them in which the quartz exhibits comb structure. Apparently there were two periods of quartz intrusion, separated by a period during which tourmaline was introduced. The introduction of the tourmaline may have begun before the intrusion of quartz had ceased, so that the two may have been contemporaneous for a short time. Later the tourmaline was introduced in larger quantity. It replaced the earlier quartz until at many places the quartz entirely disappeared. The tourmaline layers seen on the road range in width from a small fraction of an inch to several inches, and in some places gradations can be traced from tourmaline to quartz in the same layer, the tourmaline becoming less and less abundant on the strike until it disappears. In a few places the tourmaline layers are swollen to a foot or more in width, and the expanded portions cut across layers of schist and quartz. Although there is no evidence that magnetite accompanied the tourmaline, nevertheless the presence of so much tourmaline near the ore and in the same kind of rock suggests that the two may be related genetically. There are no exposures of the ore near the pits, but the boulders of magnetite strewn over the ground look as if their source were a rock very like that exposed in the road. There is probably no doubt of the magmatic origin of the tourmaline and some of the vein quartz associated with it. If the magnetite is genetically related to the tourmaline, it too must be of magmatic origin—probably the result of hydrothermal processes.

The Yellow Ridge mine is on the west slope of the south end of Yellow Ridge about 1 mile northwest of the Pinnacle. The old

[29] Kerr, W. C., and Hanna, G. B., op. cit., pp. 161–162.

mine holes are in a field over which are strewn fragments of quartz and sandy quartzite. Most of the ore found on an old stock pile is a fine-grained porous sandy magnetite containing talc or some other fibrous mineral that gives rise to a crude schistosity. Much of it contains also some pyrite. A better quality of ore is composed of grains and crystals of magnetite embedded in hematite. Both types of ore resemble schist that had been impregnated with magnetite crystals. In the hematitic variety the schist remnants seem to have been replaced by hematite. According to Willis,[30] two deposits in talc schist were worked. The western deposit consisted of two layers of ore separated by a thin layer of talcose schist like that in which the deposit was embedded. The western ore layer was 20 feet thick and contained pyrite; the eastern layer was 10 feet thick and free from pyrite. The eastern deposit was found only in one pit, southeast of the pits showing the double deposit. This was only 6 feet wide but consisted of good ore free from pyrite.

The two following analyses of the ore are given by Willis; several others are added by Nitze.[31]

Analyses of ore from Yellow Ridge mine.

	1	2
Iron (Fe)	57.64	57.43
Sulphur (S)	.441	.101
Phosphorus (P)	.009	.010
Phosphorus ratio (P : Fe)	.016	.017

1. Sample from pile of pyritiferous ore.
2. Sample from pieces of pure ore.

ORIGIN OF THE PIEDMONT MAGNETITES.

The magnetic ores in the Piedmont area are apparently different in origin from those in the mountain district. They do not occur as lenses in distinct veins, like the ore at Cranberry, nor are they associated with epidotized pegmatites. On the contrary, they are almost everywhere associated with talcose schists and quartzites. Emmons[32] regarded them as igneous but noted their close association with quartzites.

Lesley,[33] referring to the titaniferous ores of the Tuscarora and Shaw belts, which he evidently regarded as having the same origin as the nontitaniferous magnetites, says:

> The beds were deposited like the rest of the rocks, in water; deposited in the same age with the rocks which hold them—are in fact rock deposits highly

[30] Tenth Census, vol. 15, p. 318, 1886.
[31] Op. cit., p. 107.
[32] Emmons, Ebenezer, Geological report of the midland counties of North Carolina, p. 113, 1856; quoted in Kerr, W. C., and Hanna, G. B., op. cit., pp. 156–157.
[33] Lesley, J. P., Note on the titaniferous iron ore belt near Greensboro, N. C.: Am. Philos. Soc. Proc., vol. 12, p. 139. 1871.

charged with iron, and they differ from the rest of the rocks only in this respect—that they are more highly charged with iron. In fact, all our primary (magnetic and other) iron beds obey this law.

The later students of the North Carolina ore have expressed no definite opinion as to the origin of the magnetites, but inferentially they have assumed that they were laid down with their inclosing rock as ferruginous beds. Thus Kerr[34] concludes that inasmuch as the Tuscarora and Shaw belts of titaniferous ores approach one another as they pass southward, "it is almost certain that the Shaw belt is the northwest outcrop of a synclinal basin 3 miles wide, and that the Tuscarora belt is the southeast outcrop," and Nitze[35] declares that "the application of the term 'veins' is essentially incorrect. They are rather ore beds or ore bodies."

No evidence is given by Emmons for concluding that the ores are igneous, and no evidence is cited by Kerr, Hanna, or Nitze to prove that they are sedimentary. The only reason suggested for concluding them to be sedimentary is that offered by Kerr to the effect that the ore belts in one locality appear to be on the opposite sides of a synclinal fold.

From the nature of the rocks associated with the ores it is evident that they constitute an interlaminated series, many of the layers of which—the limestones, slates, and quartzites—are sedimentary. With these are gneisses and schists that are believed to be sheared volcanic rocks. Some of the schists are amphibolites that are supposed to represent in part intrusions into the sediments and in part interstratified basalt flows or ash deposits. The ore is described as consisting of actinolitic, talcose, or chloritic schist saturated with magnetite. As actinolitic, talcose, and chloritic schists are common metamorphic products of basaltic rocks it is probable that the schists with which the ores are associated are old lava flows or tuff beds. If so, they must exist as layers with the sediments and are involved in any folding to which the series has been subjected. The inference that because they exist in folds they must be sedimentary is unwarranted.

As none of the ore has been seen in place by the writer his discussion of its origin must be based on the observations of others. Some of the ores are said to occur in beds and layers in the schists, others in irregular deposits "with overlaps and jumps, the ore giving out at one place and suddenly reappearing at another"; others in lenses composed of alternating layers of magnetic and talcose schists, in which the magnetite is in thin "strata" of clean ore and the talcose schists are impregnated with magnetite in small grains. At the Forney mine the ore has been described as being in "irregular pockets, scattered

[34] Op. cit., p. 241.
[35] Op. cit., p. 29.

very disorderly through the massive syenytic rock," which was probably an augite syenite.

The ore bodies at Crowders Mountain have been stated to occur in the quartz schist that forms the mountain, and Hanna reports that in many places there is a transition from a quartzose iron ore to a ferruginous sandstone or quartzite. At the Fulenwider mine there are exposures of talcose quartz schist cut by veins of quartz and tourmaline. (See p. 238.) Locally the tourmaline replaces the quartz of the veins. As the veins are parallel to the bedding of the quartz schist the result is a series of schists interlayered with seams of tourmaline, resembling the layers of ore in the quartz rocks elsewhere. At intervals the tourmaline layers, which are usually less than an inch thick, swell to a foot or more, forming rude lenses whose boundaries cut across the layers of schist and the quartz veins, just as the boundaries of some ore lenses cut across the schists in which they occur.

The talcose schist is probably a sheared igneous rock. Its composition suggests that it is igneous rather than sedimentary, and its nature is identical with that of similar schists elsewhere that are known to be sheared igneous masses. Its occurrence at a constant horizon in a series of sediments, always very near a heavy bed of quartzite, suggests that it was originally a lava flow, a sill, or more probably a tuff and not a dike; but this is about all that can be asserted as to its origin. Those who have seen the ore in place say that it is nearly everywhere associated with the schist. Consequently it may be justifiable to assume a genetic connection between them.

In a few places, however, magnetite occurs in quartzite or quartz schist, apparently replacing the quartz, and at one place tourmaline exhibits similar relations. In the schist the magnetite appears to be in distinct veins, as well as in lenses, and some of it is disseminated as crystals through the schist.

The only possible conclusion as to the origin of this magnetite (if all of it originated in the same way) seems to be that the ore mineral is a result of hydrothermal processes, like those that gave rise to the tourmaline at the Fulenwider mine and to the later ore in the Cranberry vein. These processes at Cranberry produced the veinlike masses of rich ore cutting the lean ore and the strings of magnetite connecting the ore lenses. In the Piedmont area the solutions found easier access along the tuff beds than through the quartzites, and consequently the ore deposits are more numerous in the talcose schists than elsewhere. In some places the solutions contained boron and made tourmaline; in others they attacked the quartzite and replaced the quartz by magnetite; but usually the ore mineral was deposited in the tuff as distinct veins. Although marble is one of the members of the sedimentary series with which the ore is associated, the carbonate, so far as known, is not replaced anywhere, perhaps because the ore and the tuff deposit in which most of the ore occurs are both the result of the same igneous episode and the igneous action had ceased before the limestone had been deposited, though as the relative age of the talcose schist and the marble is not known this hypothesis has little value. However, the slight evidence available that bears on the origin of the ore appears to indicate that it was formed by igneous and probably hydrothermal action.

RESERVES IN THE PIEDMONT AREA.

Unsurmountable difficulties are encountered in an attempt to estimate the available tonnage of magnetic ore in the rocks of the Piedmont area. Undoubtedly there is an enormous quantity of ore in the aggregate, but it is not generally available for commercial use because only at a comparatively few points does it occur in ore bodies large enough to warrant exploitation. The Catawba and Iron Station belt, in Lincoln County, was once mined extensively, but at no point on it is there evidence of the existence of any large lens of ore. The ore is described as being in veins from 2 to 20 feet wide, interlayered with schist. In the old mines this material was taken out to water level, and then the mines were abandoned. There is unquestionably considerable ore beneath these old workings, but whether it is concentrated in sufficiently large deposits to be worked to advantage under present economic conditions is doubtful. Moreover, the descriptions of some of the deposits state that the ore is contaminated more or less with pyrite, and that this component increases with depth. Below the water level, where it has been protected from oxidation, it occurs in some places in large enough quantity to be seriously objectionable. One of the most promising of the old mines has been explored in recent years with a view to reopening it, but the quantity of pyrite found to exist in the ore at moderate depths below the present bottom of the mine was so great that the project was abandoned. Of course, it is possible that some of the deposits are free from pyrite and that their ore is of a desirable quality, even at considerable depth, but there is no deposit now known which is comparable in size with some of the deposits in the mountain district. The ore of any deposit now known can not be placed on the market without concentration. Unquestionably much of the ore will be placed on the market sometime, but probably not until the deposits in the mountain district have been thoroughly developed.

MAGNETITE-MARBLE ORE.

LANSING MINE.

The only magnetite-marble ore known in the district is in Ashe County, N. C., near Lansing, on the Norfolk & Western Railway

(Virginia-Carolina Railroad).[36] (See fig. 59.) It is the only productive mine in the county. This mine and that at Cranberry have furnished all the magnetite that has been mined in North Carolina during the last decade.

The mine, which is being worked by the Ashe Mining Co., consists of a tunnel and several raises near the base of a hill near Horse Creek about 1¼ miles southeast of Lansing station. The original opening, which dates back to 1828, was on top of the hill about 50 feet above the present tunnel. At its bottom a little marble ore was encountered, but most of the ore found was of the siliceous type.

The ore of the deposit now being worked is essentially a coarsely granular intermixture of carbonates and magnetite. The carbonates occur in large grains with perfect cleavage, constituting a white marble. The magnetite is in irregular slightly elongated grains scattered through the marble, producing an ill-defined schistosity, which is emphasized by the local accumulation of the magnetite grains in lenses whose long axes are parallel to the obscure schistosity of the matrix of marble and magnetite in which they lie. In a few places the rock is markedly schistose, owing to the elongation of the magnetite grains in a common direction and to the occurrence of many of them in plates, suggesting the plates of hematite in specular ores. Many of the elongate grains are sheared along cleavage planes and drawn out into lines or rows of sharp-edged particles. The carbonate grains associated with the magnetite show no similar elongation, but the schistosity is in places accentuated by the presence of calcite veins or layers running in the same direction as the lines of magnetite plates. Evidently the carbonates have been entirely recrystallized since the rock beds were deformed. Here and there through the rock are embedded small garnets, many of which are so altered as to give rise to light-brown stains.

Some of the marble-magnetite is too poor in iron to be regarded as an ore, but by rejecting this portion the remainder passes as an ore which, though possibly of low grade with respect to iron, is available to the furnace because practically all the material that is not iron is calcite or dolomite, which serves as a flux.

A typical lean ore in thin section shows coarse-grained aggregates of two colorless carbonates, of which one is calcite and the other probably dolomite, a few plates of phlogopite, and large irregular masses of magnetite. The mica is in streaks of plates extending in nearly straight lines through the section, with the individual plates lying between adjoining carbonate grains and more commonly near the magnetite. This mineral occurs in many large areas with very

[36] A more detailed discussion of this ore has been published in Elisha Mitchell Sci. Soc. Jour., vol. 37, p. 138, 1922.

ragged boundaries, the salients of which project considerable distances between the grains of carbonate or between contiguous twinning lamellae. Here and there a smaller grain appears to be inclosed in grains of what is regarded as dolomite; elsewhere the larger masses appear to inclose small grains of the carbonate. As the carbonate inclusions polarize uniformly with the large grains surrounding the magnetite, it is thought that the apparent inclusions are merely portions of projections that extend into the embayments of the magnetite and that they appear in the section as inclusions surrounded by magnetite simply because the section was cut through the boundary between magnetite and carbonate.

The richer ore differs from the poorer ore mainly in the larger size of the distributed magnetite grains and especially in the much greater size of the magnetite lenses, some of which are a foot or more in length and 5 or 6 inches in diameter.

A selected sample of the richest ore freed from adhering limestone was analyzed by J. G. Fairchild, of the United States Geological Survey, with the result shown below.

Chemical composition of magnetite from the Lansing mine.

SiO_2	2.33	P_2O_5	Tr.
Al_2O_3	2.38	SO_3	0.11
Fe_2O_3	60.42	H_2O-	.04
Cr_2O_3	.00	H_2O+	.83
FeO	24.80	S	.00
MnO	3.01	V_2O_3	.00
MgO	3.37	BaO	.00
CaO	1.14	SrO	.00
Na_2O	.26	F	.00
K_2O	Tr.		
TiO_2	Tr.		100.66
CO_2	1.97		

The magnetite is remarkably pure. It evidently contains a little manganese (though probably most of this element is in the marble) and is free from titanium. In these respects it closely resembles the magnetites in the Franklin limestone in New Jersey.[37]

The percentage of iron indicated by the analysis is 61.58 and that of manganese 2.33, but this analysis was made on a selected sample from which material other than magnetic had been removed as thoroughly as possible by careful hand picking. The ore sent to the Cranberry furnace is shipped as taken from the mine, without crushing and careful selection. This ore is therefore much lower in iron and indeed is considerably lower than the minimum limit for ordinary magnetic ore, but because of its extremely low phosphorus and high calcium it is acceptable.

[37] Bayley, W. S., New Jersey State Geologist Final Rept., vol. 7, p. 111, 1910.

Analyses of many carload lots made at the Cranberry furnace at Johnson City showed limits of 36.43 to 52.93 for iron and 0.0094 to 0.0114 for phosphorus.

A series of analyses[38] of seven cars received during the fall of 1919 gave the following results:

Iron.	Phosphorus.	Iron.	Phosphorus.
40.65	0.0062	40.65	0.0042
42.76	.0052	35.11	.0062
46.46	.0052	38.54	.0057
39.07	.0052		

The greater portion of the ore is a coarsely crystalline marble containing grains and lenses of magnetite. In many places, however, it contains veinlike layers of bright-green granular actinolite in a fine-grained aggregate, which, where shearing occurs, is changed to a mass of bright-green fibers. In many places magnetite is present in the granular aggregate, and this is noticeably more abundant near the contact of the green layer with the limestone. Indeed, not uncommonly there are distinct lenses of magnetite at the contacts of the two rocks, even though magnetite is not present elsewhere in association with the green rock, and here and there a continuous thin layer of magnetite separates the two for considerable distances. The actinolite band passes into the marble by a very gradual transition, the actinolite becoming less and less abundant until it forms a very small portion of the mass.

Around many of the lenses of magnetite in the marble are envelopes of actinolite, and in places veins of actinolite cut through the lenses. In these places the magnetite is cleaved, so that the lenses appear to be granular masses composed of elongate grains of the magnetite.

In other specimens veins of actinolite traverse masses of magnetite and marble, and sporadic garnets appear.

The suggestion furnished by the sections is that a mass of calcite and magnetite became shattered as the result of movement, and the cracks between the fragments were filled with actinolite formed by metamorphic processes during the course of this movement. At the same time some of the magnetite was cracked, and some calcite that was undergoing recrystallization was forced into the fractures.

In some places calcite veinlets were formed; in others actinolite veins. Because the actinolite was formed under differential pressure, its fibrosity is everywhere parallel. Probably the magnetite lenses are also secondary forms, though the magnetite itself was present prior to the deformation.

[38] Furnished by F. P. Howe, president Cranberry Furnace Co., Johnson City, Tenn.

There was evidently motion in the rock mass also after the actinolite was formed and after the magnetite was shattered, as it shows slickensides coated with acicular actinolite, in many places to a thickness of half an inch or more.

Here and there through the ore there is also considerable dark hornblende. It apparently is present in fairly large dikes in which hornblende, magnetite, and frequently garnet are intermingled. Where the hornblende occurs in dikes a foot or more wide their interiors consist of a coarse aggregate of black hornblende free from garnet. In many of the smaller dikes, on the other hand, the hornblende masses inclose small lenses of limestone, which have been almost completely changed to pink garnet.

In many places near the borders of the deposit and here and there within its mass are irregular aggregates of red garnet, black hornblende, magnetite, and carbonates, in which the garnet is predominant. The hornblende on the whole looks as if it were intrusive, and the garnet as if it were a contact product between hornblende and the carbonates. These aggregates are traversed by little veins of white calcite and colorless quartz and contain here and there nests of these minerals, which are unquestionably secondary.

Pyrite is not common anywhere in the ore. Some of its particles are plainly large skeleton cubes, poikilitically developed. In other words, they possess the sieve structure that is characteristic of minerals formed later than the rock in which they are found. Some of the pyrite apparently replaces calcite, and some replaces magnetite. It is believed that the pyrite was not a part of the original rock but was introduced subsequently.

In places epidotized pegmatites cut the hornblende masses. Those that cut the gneiss country rock are coarse grained, and large garnets occur near their contacts. The pegmatites that cut the hornblende masses in the ore are fine grained and aplitic, and garnet does not occur at their contacts but is confined to the contacts between the hornblende and the marble. It may be fair to assume that the hornblende masses are a part of the pegmatite, for upon this assumption the presence of garnets between them and the marble is easily explained as due to contact action. Moreover, the hornblende is an altered augite, and in the Cranberry area the pegmatites associated with the ore were originally of an augitic variety.

In this section the fine-grained veins are seen to be badly crushed pegmatites. Their quartz areas are aggregates of small quartz grains, and the former feldspar grains are now aggregates of small grains of very light yellow epidote. The contact of the veins and the hornblende masses is far from sharp. Here and there a streak of small pink garnets separates the two, but for most of the distance the epidote aggregate penetrates the hornblende mass and hornblende grains are embedded in the epidote. The hornblende mass consists mainly of large crystalloids of yellow-green hornblende with large nuclei composed mainly of partly amphibolized light-yellowish augite. In some grains the partly altered pyroxene comprises three-fourths of the area of the grain, and around it is a zone of compact green-yellow hornblende with sharp projections extending from the more compact portion. Extinctions of 24° against the cleavage in the surrounding zone and of 45° in the nucleus are characteristic.

The relations of the pegmatite, hornblende, and marble, together with the presence of garnets and of streaks of magnetite near the borders of the hornblende, are suggestive of contact action. In the old Waughbank mine the ore was of the same character as that in the Cranberry mine. There is very little pegmatite in the Lansing mine, unless it is represented by the hornblende streaks and the fine-grained veins described above, but pegmatite occurs abundantly in the old Waughbank openings. The hornblende streaks in the Lansing mine may well have been very basic phases of augitic pegmatite, which added iron and perhaps silica to the limestone and brought about contact action by which garnets, phlogopite, and actinolite were produced.

The ore body of the Lansing mine is reached by a tunnel running into the base of the hill just above the level of Horse Creek for 150 feet in a direction N. 40° E. The tunnel is in the footwall, which is a light-gray, thoroughly crushed mica gneiss. Between this gneiss and the ore body is a thin layer of gray mica schist, which may readily be a result of shearing of the gneiss along the contact. Immediately above the ore is another thin sheet of a similar schist, and above this a light-gray fine-grained gneiss that may be a part of the Cranberry granite mass.

The ore body appears to be very irregular in shape. In general it strikes about N. 35° E., as the tunnel, which runs N. 40° E. in the footwall, strikes the ore at its end. The dip of the ore body is about 40° SE. In a portion of its course the dip and strike are regular, indicating a width of only 4 feet, and in some places the ore is cut out entirely by what appear to be great fragments of the country rock or by small faults. Near the present end of the tunnel the ore body is chimney-like. It was encountered in an old hole on the surface above the tunnel and was followed downward in a small steeply pitching shoot into the present ore body, where it expands into a sheet having the dip and strike of the surrounding gneiss.

On the borders of the ore body are selvages of garnet and hornblende several feet thick. Within these selvages the ore is fairly uniform in character, varying only in the proportions of magnetite and carbonate present. Here and there near its edges are pockets of loose magnetite, especially near the footwall, where the sparse carbonate cement in lenses of granular magnetite may have been dissolved by percolating water. The pyrite that has already been mentioned is confined almost exclusively to the borders of the ore body and to the vicinity of little veins of hornblende that cut through it. The pyrite is apparently most abundant where shearing has taken place. As it is entirely absent from the main mass of the ore body it has no bad effect upon the ore. Through the ore are small veinlike masses of coarse black hornblende or of hornblende and magnetite, all running parallel to the schistosity of the ore, which is parallel to the general strike of the ore body, and thus accentuating the structure. Some of the limestone also contains streaks of magnetite that very strongly suggest little dikes. These streaks are rarely more than $1\frac{1}{2}$ inches wide. Their walls are nowhere sharp, the magnetite layers passing into the marble by gradations and the carbonate grains becoming more and more abundant toward the marble side of the contact until finally the rock becomes essentially a nearly pure marble.

OTHER MAGNETITE-MARBLE ORES.

The only other point at which the conditions appear to be similar to those at the Ashe Mining Co.'s mine is a few yards north of Dr. Jones's residence, about a third of a mile northeast of the railroad station at Lansing and three-quarters of a mile N. 20° E. of the Ashe Mining Co.'s mine. Here a pit was started at a place where there was much magnetite in the soil. At a depth of 25 feet a piece of limestone was encountered in the midst of the gneiss, with manganese ore on opposite sides. The hole is now filled, but on the old dump, which has almost entirely disappeared, a fragment of actinolitic rock was found that is unquestionably a metamorphosed limestone consisting of calcite, actinolite, and tremolite.

ORIGIN.

If the theory with regard to the origin of the Cranberry ore is correct (see p. 227) and the magnetite in this deposit is due to deposition from ascending hot liquids and gases brought upward by augitic pegmatites, then it seems probable that the marble ore is likewise the result of pegmatitic solutions. Old limestones were metamorphosed by solutions that produced garnet and the greater part of the actinolite from the constituents of the limestone and added components from which were made dark hornblende and magnetite. The distribution of the components of the ore is such as would occur if they were produced by hot solutions emanating from dikes of pegmatite. No distinct dikes of pegmatite are to be seen cutting the limestone ore, but such dikes are believed to be represented by the small veins of epidote that traverse the ore, by aggregates of epidote and magnetite and of hornblende and magnetite that appear as streaks in it, and by the lenses of dark hornblende that occur here and there. The epidote is believed to represent the feldspar of the pegmatites, as all gradations between pegmatites in which the feldspar is only slightly epidotized and those in which all the feldspar has been replaced by epidote are common in the Cranberry area. At Lansing very little of the pegmatite magma reached the position of that portion of the ore body now being worked, but the gases and liquids traveled along the contacts between the limestone and the gneiss, penetrated the limestone near the contacts, and caused the deposition of the garnet and magnetite which have been described as forming a selvage on the borders of the ore body. The limestone was a part of the schist series at the time the pegmatite was intruded.

The magnetite-marble ores are rare because the limestone beds themselves are rare. The best-known occurrence is in a cut on the Carolina, Clinchfield & Ohio Railway at Intermont, about 4 miles south of Toecane. Here the limestone is a coarse white marble associated with gneiss and pegmatite. It is mapped by Keith[39] as being in the Carolina gneiss—a series of micaceous and garnetiferous schists and micaceous, garnetiferous, and kyanitic gneisses which are believed to be the oldest rocks in the region.

The marble appears to be in fragments separated by gneiss and pegmatite. At the south end of the cut near its bottom the marble is in contact with the pegmatite and with gneiss, and at both contacts it shows the effect of contact action. At the contact with the pegmatite the contact zone is about 1½ inches wide and is composed of two layers, the inner one of which is characterized by the presence of plates of tremolite and more scanty plates of wollastonite. The tremolite is generally fresh and colorless, but the wollastonite is traversed by many cracks in which have been deposited fibers of a light-green micaceous mineral, with a slight pleochroism in greenish and yellowish tones. Some tremolite flakes are tinged with green and are very slightly pleochroic, thus approaching actinolite in character. The outer layer consists exclusively of a light-gray platy tremolite arranged with its long directions perpendicular to the contact. This tremolite strongly resembles the mineral at the Lansing mine that has been called actinolite. Whether the two minerals are actually the same or are different is of little importance. Their presence indicates that the pegmatite added material to the limestone in both places. The irregular distribution of the limestone, parts of which

[39] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Mount Mitchell folio (No. 124), p. 2, economic-geology map, 1905.

are almost completely surrounded by silicate rocks, suggests an explanation of the irregular distribution of the ore at Lansing. The limestone bed was broken into fragments, as at the occurrence on the railroad, and the marble ore naturally has a similar distribution.

RESERVES.

Because of the irregular manner of distribution of the limestone in the schists at the Lansing locality it is impossible to estimate with any probability of correctness the quantity of ore that may be expected. If the limestone is shattered, as it is near Toecane, it may terminate within a few feet of the present workings, or it may extend beyond them for a long distance. In either event it is probable that the limestone ore may be replaced by silicate ore such as was found in the old Waughbank opening, above the present mine, and this ore may be valuable or worthless, according to the width of the vein. The limestone ore is merchantable even if its iron content is as low as 35 per cent. The silicate ore must carry much more iron before it will be accepted at the furnace, and therefore most of it must be concentrated.

TITANIFEROUS MAGNETITES.[40]

GENERAL CHARACTER.

Scattered throughout the district in which the magnetitic ores exist are deposits of magnetic ores that contain notable quantities of titanium. They are abundant in the mountainous portions of North Carolina, less abundant in the Piedmont area, and, so far as known, least abundant in the mountains of Tennessee. Formerly they supplied ore for forges in North Carolina, but they are now abandoned. Some of them are large and at one time were the source of much of the iron that was smelted in the South.

The titaniferous ores differ from the nontitaniferous varieties in occurring as veins cutting through gneiss and schist. They are accompanied by no pegmatites, no great masses of hornblende, and no epidotic rocks. They occur not as lenses or small veins composed largely of other substances but as clean-cut veins with very little gangue. The gneisses with which they are most intimately associated are usually dark basic rocks, which generally contain talc, serpentine, or other similar fibrous minerals. Like the nontitaniferous magnetites, the titaniferous varieties are found in lines or belts conforming to the structural trends of the country rock, but the belts are not as definite as those of the nontitaniferous ores, the deposits of which are much more numerous.

[40] For a more comprehensive discussion of these ores see a forthcoming bulletin of the Tennessee Geological Survey.

On analysis the titaniferous ores show a wide range in content of titanium. Some contain as little as 4.5 per cent TiO_2 to 65 per cent Fe, and others as much as 39 per cent TiO_2 to 25.76 per cent Fe. In addition to these two constituents, all specimens that have been carefully examined have shown the presence also of small quantities of Cr_2O_3. Manganese is absent or present in only very small quantities. A few type analyses are given below:

Analyses of titaniferous magnetites.

	1	2	3	4
Silica (SiO_2)	1.31	4.71	9.90	4.75
Iron (Fe)	55.06	48.41	46.81	52.23
Sulphur (S)	Trace.	.089	.137	.112
Phosphorus (P)	Trace.	.023	.025	.021
Phosphorus ratio (P:Fe)	Trace.	.048	.053	.040
Titanium dioxide (TiO_2)	13.60	13.74	6.03	8.91
Manganese (Mn)	.70	.11	....	....
Chromic oxide (Cr_2O_3)	.72	.34	.63	1.19

1. Sergeant shaft, Tuscarora mine, Guilford County, N. C. Kerr, W. C., and Hanna, G. B., op. cit., p. 149.
2. Dannemora mine, Rockingham County, N. C. Tenth Census, vol. 15, p. 311, 1886.
3. McCarter opening, Ashe County, N. C. Nitze, H. B. C., North Carolina Geol. Survey Bull. 1, p. 157.
4. Bauguess place, Ashe County. Idem, p. 160.

DEPOSITS IN THE MOUNTAIN DISTRICT.

ASHE COUNTY, N. C.

One of the belts of these ores is to be found in Ashe County, N. C. (See map, fig. 59.) It is about 2 miles long, extending from a point near the Virginia State line, at the headwaters of Little Helton Creek, southwestward nearly to the mouth of Wallens Creek. There are six or seven groups of openings in this belt, but in none of them can the relation of the ore to the surrounding rocks be seen. Nitze, however, examined most of them when first opened and has briefly described them.[40]

Most of the openings are small, and none of them give any evidence of deposits large enough to be of economic value. The largest are on the Smith place, half a mile east of Little Helton Creek and half a mile south of the State line; on the McCarter place (now also the property of Mr. Smith), about a quarter of a mile farther west; and on the Pennington place, near Wallens Creek. At each place is a comparatively wide vein of granular magnetite apparently associated with a basic rock that varies somewhat at the different localities. At the Smith place the ore consists of shattered grains of an opaque mineral like magnetite and of this mineral intergrown with reddish-yellow rutile in a mass of weakly polarizing fibrous material, in which are to be seen many elliptical areas outlined by magnetite dust, as if representing former olivine crystals that have been completely decomposed into serpentinous substances. Most of the

[41] Nitze, H. B. C., op. cit., p. 158.

opaque mineral exhibits no signs of alteration. Some of it, however, appears to have suffered almost complete change to rutile. In grains that seem slightly altered the rutile occurs in irregular patches through the apparently unaltered mineral and in a narrow zone around its borders. In other grains the interior patches coalesce into elongate masses that lie parallel. Many of these show crystal terminations, but some are merely aggregates of grains. By extreme alteration the particle becomes an interlayered aggregate of wide rutile plates and narrow magnetite plates.

The grains that have thus changed may have been ilmenite originally, and those that have not changed may be magnetite, as the contact between the altered and the unaltered grains is rather sharp. That the whole mass of the ferriferous mineral in the rock is not as rich in titanium as the altered grains might suggest is indicated by the fact that the total TiO_2 content of the ore is only one-ninth that of the Fe_3O_4.

At the old McCarter place the ore is associated with a biotitic chlorite-actinolite schist composed of fractured remnants of plagioclase, pyroxene, etc., embedded in a mixture of fibrous minerals, among which serpentine is prominent. The ore is likewise greatly shattered. The magnetite occurs in sliced grains, and the slices are slightly displaced. Many of them contain irregular patches of rutile. Mr. Fairchild reports that a sample of the ore had the following composition:

Analysis of ore from old McCarter place.

Silica (SiO_2)	5.73	Titanium dioxide (TiO_2)	12.96
Alumina (Al_2O_3)	1.70	Phosphorus pentoxide (P_2O_5)	Tr.
Ferric oxide (Fe_2O_3)	45.51	Sulphur (S)	Tr.
Chromic oxide (Cr_2O_3)	.39	Water above 100° C	2.81
Ferrous oxide (FeO)	26.20	Water below 100° C	.06
Manganese oxide (MnO)	.34		
Magnesia (MgO)	3.99		99.69

The ore contains also traces of lime, soda, and potash, but no carbon dioxide, vanadium oxide, baryta, strontia, or fluorine.

At the Pennington place also the ore shows the presence of rutile when examined microscopically. Grains of magnetite and others composed of interlayered magnetite and rutile are embedded in a mass of light-green fibers and plates lying in a weakly polarizing aggregate that has probably originated from some basic rock.

ALLEGHANY COUNTY, N. C.

Deposits of titaniferous ore in which the ore mineral is associated with steatite and asbestos occur in Alleghany County, and they have been described by Nitze.[42]

[42] Nitze, H. B. C., op. cit., pp. 125–126.

AVERY AND MITCHELL COUNTIES, N. C., AND NEIGHBORING PORTION OF TENNESSEE.

A line of deposits in Avery and Mitchell counties, N. C., and the adjacent part of Tennessee is described by Nitze as beginning at the mouth of Roaring Creek, 7 miles a little west of south of Cranberry, running north and northwest over Grassy Bald Ridge, turning toward the south, and continuing southwestward to the Yancey County line at Toe River. (See fig. 58.) On this line are a dozen or so small deposits that exhibit no peculiar characteristics. At the mouth of Roaring Creek, however, there is one that is worthy of notice. Here a small strip of massive dunite that is sheared in places to a chlorite-talc schist is traversed by a narrow stockwork of tiny veins of magnetic ore. The country rock is the Roan gneiss. The other deposits are evidently small and unimportant. Nearly all are in the Roan gneiss, but in some places the rock immediately associated with the ore mineral is fibrous.

OTHER DEPOSITS IN NORTH CAROLINA.

Madison and Yancey counties also contain deposits of titaniferous ores that are remarkable for their high content of titanium. Nitze [43] refers to a nearly vertical bed, from 6 to 10 feet across, at a point 6 miles north of Burnsville, on the south side of Mine Fork in Yancey County, that contains 11.90 per cent of TiO_2, and Kerr and Hanna [44] refer to another in Madison County, near Ivy Creek and near the public road between Burnsville and Asheville, that contains 37.88 per cent of TiO_2. Hanna's analysis of this ore showed 37.06 per cent of FeO and 11.03 per cent of Fe_2O_3. On the assumption that all the FeO that is not in magnetite is present in ilmenite, there is still an excess of about 2.5 per cent of TiO_2, which must be in rutile.

Deposits of titaniferous ores are indicated by float in Macon, Clay, and other mountain counties in North Carolina, but no explorations have been made in them.

OTHER DEPOSITS IN EASTERN TENNESSEE.

Three or four fairly large explorations have been made in deposits of titaniferous ore in Carter County, Tenn., but none of them have developed any considerable bodies of ore except perhaps that in Lost Cove. Mr. Hamilton, in the manuscript report already referred to, states that on the west side of the ridge between Burbank and Lost Cove magnetic float is common. At one point a pit uncovered large pieces of magnetic ore that have the purplish steel color and brilliant luster that are associated with magnetite or ilmenite mixed with

[43] Nitze, H. B. C., op. cit., p. 187.

[44] Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geology of North Carolina, vol. 2, p. 181, Raleigh, 1888.

rutile. Mr. Hamilton also states that though the ore is in the areas of Cranberry granite mapped by Keith, it is most intimately associated with a black gneiss.

A partial analysis of this ore by Dr. Hinds, of the Tennesse Geological Survey, gave the following figures:

Partial analysis of ore from Lost Cove, Tenn.

Silica (SiO_2)	4.80	Titanium dioxide (TiO_2)	17.20
Alumina (Al_2O_3)	3.28	Phosphorus (P)	Tr.
Iron (Fe)	51.74		

D. F. Farrar, the present chemist of the Tennessee Survey, reports also a trace of chromic oxide. A second specimen from the same place was reported by Dr. Hinds to contain 10.50 per cent of titanium dioxide.

Float occurs also at the Cordell and Montgomery properties, 2 miles northeast of Shell Creek, associated with a gabbroitic rock in an area of granite which is mapped by Keith as Beach granite. Specimens of this have been found by Dr. Hinds to contain 8.00 per cent of titanium dioxide.

Although very little has been learned about the Tennessee titaniferous ores, it appears probable that they are in every respect like similar ores in North Carolina and that their origin is the same. At present they are of no economic importance.

DEPOSITS IN THE PIEDMONT AREA.

In Caldwell, Rockingham, Guilford, and Davidson counties, in the western part of the Piedmont area in North Carolina, there are a number of deposits of titaniferous iron ore, some of which contributed comparatively large supplies to the old forges. At Richlands Cove, on Yadkin River 16 miles north of Lenoir, is a compact, slightly magnetic ore body 45 feet thick, distributed through a talcose chlorite schist.[45] A sample of the pure ore gave the following result:

Partial analysis of ore from Richlands Cove, N. C.

Silica (SiO_2)	7.55	Phosphorus (P)	1.40
Iron (Fe)	28.24	Titanium dioxide (TiO_2)	41.21
Sulphur (S)	.013		

indicating an excess of titanium dioxide over the amount necessary to combine with all the iron to make ilmenite.

Singewald [46] says that the ore consists chiefly of small particles of ilmenite in a matrix made up mainly of fibrous and scaly aggregates of

[45] Nitze, H. B. C., op. cit., p. 120.

[46] Singewald, J. T., jr., The titaniferous iron ores in the United States: U. S. Bur. of Mines Bull. 64, p. 84, 1913.

chlorite, serpentine, and talc, but Hess,[47] in 1906, had noted that it contains magnetite, ilmenite, and rutile.

The largest zone[48] of titaniferous magnetites in the State extends from the headwaters of Abbots Creek, in Davidson County, across the southwest corner of Forsyth County and entirely across Guilford County to Haw River, in Rockingham County, a distance of 30 miles. It consists of two parallel belts 3 miles apart throughout their greatest distance but approaching until, as believed, they unite in Rockingham County. The ore bodies consist of strings of lens-shaped masses, continually enlarging and contracting in thickness, from a few inches to 8 feet. Some of the ores contain granular corundum, in one or two places in so great quantities that they become true emery. Lesley thought that the ore-bearing layers were deposited at the same time as the rocks that hold them, as they differ from the other rocks of the series only in being more highly charged with iron. The ore beds vary in number at different places and are irregular in position in the nonferriferous rocks, but Singewald,[49] who visited the Guilford County deposits in connection with his work on the utilization of the titaniferous magnetites, found that the ore bodies are segregations within small gabbro masses. At the Tuscarora mine, he says, the rock immediately associated with the ore is an olivine gabbro with a diabasic texture, and the gangue of the ore is a mass of chlorite and small quantities of material so greatly decomposed as to make it undeterminable.

The Tuscarora mine, 1 mile north of Friendship, was the principal opening on the southeastern belt. The ore is traceable for a mile in a direction N. 77° E., and the vein has a dip of about 70° a little east of south. There were two ore beds, one 12 feet thick, that were cut by a shaft 109 feet deep.

The Dannemora mine[50] was 20 miles farther northeast. It was in operation as late as 1880 in an ore deposit 125 feet long, 80 feet wide on the incline, and 12 feet thick. Other lenses of approximately the same size were later found to the northwest and southeast of the main one. The ore was accompanied by chlorite and mica.

Analyses of samples taken from several points on the belt are given as follows:

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[47] Hess, F. L., U. S. Geol. Survey Mineral Resources, 1906, p. 530, 1907.

[48] Kerr, W. C., Report of the geological survey of North Carolina, vol. 1, pp. 236–250, 1875. Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geology of North Carolina, vol. 2, pp. 143–154, 1888. Willis, Bailey, Tenth Census, vol. 15, p. 308, 1886. Nitze, H. B. C., op. cit., pp. 60–68.

[49] Op. cit., pp. 86–87.

[50] Willis, Bailey, Tenth Census, vol. 15, pp. 308–311, 1886.

Analyses of ores from deposits on Tuscarora belt.

	1	2	3	4	5	6	7	8
Silica (SiO_2)	1.31	4.70	0.76	0.40	1.30	12.75	1.30	26.80
Iron (Fe)	55.06	48.31	57.68	59.03	56.41	41.95	67.60	21.63
Alumina (Al_2O_3)	4.26	8.66	1.68	1.06	2.54	5.17	.55	8.87
Sulphur (S)	Tr.	.089						
Phosphorus (P)	Tr.	.023						
Titanium dioxide (TiO_2)	13.60	13.71	13.52	11.95	12.35	15.35	1.27	16.20
Chromic oxide (Cr_2O_3)	.72	.34	.46	1.07	1.10	1.25	1.43	.43
Manganese oxide (MnO), Cobalt oxide (CoO)	.96	.11	.81	1.02	1.10	1.25	.93	1.55
Magnesia (MgO)	2.33	2.96	2.79	1.99	2.41	4.14	.75	10.30
Lime (CaO)	.60	1.42	.45	.24	.51	.90	.14	1.40
Water (H_2O)	.18	.98		.38	.79	1.36		3.55

1. Sargent shaft, Tuscarora mine, Guilford County. The iron was reported as Fe_3O_4=76.04. Genth, F. A., Geology of North Carolina, vol. 1, p. 245, 1875.
2. Dannemora mine, Rockingham County. Tenth Census, vol. 15, p. 311, 1886.
3. K. R. Swain's, Davidson County. Iron reported as Fe_3O_4=79.53. Genth, F. A., op. cit., p. 245.
4. Granular ore, Elisha Charles, Guilford County. Iron reported as Fe_3O_4=81.89. Idem.
5. John Clark, Guilford County. Iron reported as Fe_3O_4=77.90. Idem.
6. Soft micaceous ore, Mrs. McCuiston, Guilford County. Iron reported as Fe_3O_4=57.93. Idem.
7. Magnetic portion of No. 6. Iron reported as Fe_3O_4=93.63. Idem.
8. Nonmagnetic portion of No. 6. Iron reported as Fe_3O_4=30.90. Idem.

From a comparison of analyses 6, 7, and 8 it will be seen that as early as 1875 it was learned that most of the titanium dioxide could be eliminated from this ore by careful magnetic cobbing. In 1913 Singewald[51] repeated the experiment more carefully and reached a result that was not quite so satisfactory. His figures are as follows:

Results of cobbing ore from Tuscarora belt.

	Yield of concentrate (per cent).	Fe (per cent).	TiO_2 (per cent).
Ore		58.07	12.82
Concentrate, ore crushed to 0.3 millimeter	71.5	67.76	4.25
Tailings, ore crushed to 0.3 millimeter	28.5	33.76	34.32
Concentrate, ore crushed to 0.15 millimeter	70.1	68.41	3.64

A complete analysis of the Dannemora ore was made by the chemists of the Tenth Census.[52] The analysis yielded:

Analysis of Dannemora ore.

Ferric oxide (Fe_2O_3)	43.05	Phosphorus (P)	0.023
Ferrous oxide (FeO)	23.51	Titanium dioxide (TiO_2)	13.71
Sulphur (S)	.089		

If all the ferric oxide is present in magnetite there must also be 19.4 per cent of the ferrous oxide in this component, leaving only 4.1 per cent to supply the chlorite and other ferrous silicates and any ilmenite that might be present.

An insoluble residue constituted 28 per cent of the assay and had the following composition:

[51] Op. cit., p. 22.
[52] Tenth Census, vol. 15, p. 311, 1886.

Composition of insoluble residue from Dannemora ore.

Silica (SiO_2)	4.70	Soda (Na_2O)	0.05
Alumina (Al_2O_3)	9.75	Phosphorus pentoxide (P_2O_5)	.045
Lime (CaO)	.56	Titanium dioxide (TiO_2)	11.82
Magnesia (MgO)	.72		
Potash (K_2O)	.03		27.675

There was no iron in the insoluble component, consequently almost all the titanium dioxide in the ore must be in the form of an oxide, probably rutile. The large quantity of alumina present may represent corundum, which is known to be associated with the titaniferous ore farther northeast, or some of it may be in spinel, a small amount of which occurs in the Tuscarora ore.

Singewald did not study the ore of the Dannemora mine, but he made a rather thorough metallographic examination of that of the Tuscarora mine, which he stated to consist of about 20 to 40 per cent of ilmenite intergrown with magnetite in plates sufficiently large to be separable by crushing and magnetic concentration.

Examination of thin sections makes it evident that, as in the Dannemora ore, much of the 13.6 per cent of titanium dioxide in the Tuscarora ore must be in the form of rutile, for the sections show the presence of many grains of red-brown rutile embedded in an opaque mineral and to a less extent in interstitial light-green hornblende between the ore particles. The particles of rutile bear the same relation to the opaque ore, which is presumably magnetite, as the light and dark minerals shown in Singewald's photographic illustration of a polished specimen of the ore.[53] The rutile in the ore occupies the position corresponding to the light portions of the illustration. It usually occurs in streaks about 1 millimeter long and 0.12 millimeter wide, or in sharp-edged rhomboidal or wedge-shape grains measuring about 0.7 by 0.3 millimeter in diameter, but occurs also as very irregularly outlined pieces, as narrow rods, and as little dustlike particles scattered irregularly through the magnetite. It is reddish brown, rather strongly pleochroic in yellowish and brown tints, and clouded toward the center with reddish opaque substances that suggest red-stained leucoxene, or perhaps limonite. In the centers of several of the rutile bodies are little masses of a green spinel having very irregular shapes.

Thus the Tuscarora ore resembles very closely the ore of the titaniferous deposits in the mountain district, in all of which most of the titanium dioxide must be in the form of rutile.

On the Shaw belt, which is 3 miles northwest of that on which the Tuscarora and Dannemora mines are situated, three or four distinct and parallel deposits were opened, the widest of which measured 6

[53] Op. cit., pl. 2, C.

feet in width where solid. Some pits on the property were worked in Revolutionary times, but the main openings were made in the seventies. The ore of the Shaw mine contained 14.46 per cent of titanium dioxide.

One other deposit in Rockingham County is of special interest because of its suggestiveness. Its exact location is not certainly known, and no description of the association of the ore is available. However, two samples from this deposit were analyzed by Genth. One was a granular reddish ore resembling a reddish-brown garnet and the other a grayish granular ore in which minute grains of yellowish or brownish-white corundum were visible.

Analyses of ore from Rockingham County, N. C.

	Reddish ore.	Gray ore.		Reddish ore.	Gray ore.
Silica (SiO_2)	1.39	0.98	Magnesia (MgO)	0.68	3.27
Magnetite (Fe_3O_4)	42.77	46.29	Lime (CaO)	.84	.91
Alumina (Al_2O_3)	52.24	44.86	Titanium dioxide (TiO_2)	.78	2.42
Manganese oxide (MnO) / Cobalt oxide (CoO)	1.00	1.27	Chromic oxide (Cr_2O_3)	.30	Tr.

There is no definite statement that the ore is associated directly with basic rocks, but its high content of alumina indicates that it contains so much corundum as to suggest that it may well be genetically related to the corundum-bearing peridotites that have been studied by Pratt and Lewis.[54]

COMPOSITION.

From the descriptions of the ores given in the preceding pages it appears that some of them may be mixtures of magnetite and ilmenite in various proportions. Others are now mixtures of magnetite and rutile, though originally they may have been ilmenite. Some of the ores that are richest in titanium exhibit no magnetism when subjected to the influence of an ordinary horseshoe magnet and may be mixtures of rutile and ilmenite. Singewald[55] has concluded, as the result of his metallographic studies of the titaniferous ores of North Carolina, that some of them are pure ilmenite and others are intergrowths of magnetite and ilmenite. The study of thin sections, however, shows that some of the titaniferous ores contain large quantities of rutile. Singewald[56] has called attention to the fact that Seligman, Cathrein, and Mügge have described intergrowths of rutile in magnetite. Cathrein found the rutile to exist as minute

[54] Pratt, J. H., and Lewis, J. V., Corundum and the peridotites of western North Carolina: North Carolina Geol. Survey, vol. 1, 1905.

[55] Singewald, J. T., jr., The titaniferous iron ores in the United States: U. S. Bur. Mines Bull. 64, pp. 80–93, 1913.

[56] Op. cit., pp. 24, 27.

microlites arranged parallel to the three edges of an octahedral face and intersecting one another at angles of 60°, but they were so small that the magnetite appeared wholly homogeneous even when highly magnified, and the microlites were revealed only when the magnetite had been dissolved from the mass by hydrochloric acid. In the few sections of the North Carolina ores that have been examined microscopically the rutile does not occur in minute needles but is for the most part in broad yellowish-brown translucent masses, some of which are wider than the opaque magnetite or ilmenite between them, as if the rutile had formed along definite planes and had gradually replaced the magnetite or ilmenite on both sides,[57] until in some places only a narrow layer of the opaque mineral is now left between neighboring layers of the brownish rutile. That the opaque mineral is magnetite rather than ilmenite is indicated by the strong magnetism of the ore. It is possible that the material of the ore grains was once an intergrowth of magnetite and ilmenite and that the present interlayering of magnetite and rutile is the result of some sort of metamorphism of the ilmenite.

In the Tuscarora ore, however, the rutile is apparently original, as many of its particles, which are completely embedded in the ore minerals, show crystal outlines.[58] Moreover, in a few places similar crystals are embedded in the amphibole that lies between the ore grains. It seems necessary to conclude that this rutile was one of the first minerals to solidify, being preceded only by the spinel that occupies the centers of many of its grains.

Chromic oxide has been found in all the titaniferous ores of the district studied whenever it has been sought in the analyses. On the other hand, it is absent from ore containing only small quantities of titanium. In the titaniferous ores the chromium is evidently in the magnetite rather than in distinct particles of chromite, for when a specimen of ore from the Tuscarora belt was subjected to the influence of a magnet most of the chromium went with the magnetic portion.

After Kemp[59] had studied the Adirondack ores he concluded that vanadium is a characteristic component of the titaniferous magnetites, and that these are the only varieties that contain more than a trace of this metal. In view of this conclusion it is interesting to note that none of the titaniferous magnetites in either North Caro-

[57] The appearance is very similar to that of the polished surface of the Tuscarora ore illustrated by Singewald (op. cit., pl. 7, A), who describes the light-colored bars as ilmenite.

[58] Since this statement was written Mr. Hess has called the attention of the writer to a crystal of rutile from Shooting Creek, in Clay County, that is an intergrowth of a large proportion of rutile and a small proportion of ilmenite.

[59] Kemp, J. F., The titaniferous iron ores of the Adirondacks: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 390, 1899.

lina or Tennessee, so far as is known, contain even a trace of vanadium. In three analyses vanadium was sought with negative results.

The high alumina shown in many of the analyses may be due in some of the ores to corundum and in others to spinel.

ORIGIN.

From a consideration of the scanty facts known concerning the association of the titaniferous ores, it seems probable that their origin is due to the presence of dikes and lenses of olivine gabbro or more basic rocks (dunite and peridotite) in the schist. Only at Senia, on Roaring Creek (p. 253), is there direct evidence of the existence of dunite with the ores, but at several of the old mines the ores are associated with certain talcose, chloritic, and serpentinous schists that may have been derived from olivine rocks, and at one place the rock immediately associated with the ore is an olivine gabbro or a hornblende schist that may well be a metamorphosed gabbro.

The universal presence of notable quantities of chromium in the titaniferous ores and the absence of this metal from the nontitaniferous magnetites indicate a difference in origin. This is further indicated by the universal presence of epidote in the nontitaniferous ores and its absence from the titaniferous ores. The nontitaniferous ores are plainly related to pegmatites. The titaniferous ores are not so related, or at any rate pegmatites have not been found with them. The titaniferous ores appear to be associated with basic rocks, which elsewhere in the State comprise dunite, amphibolite, and olivine gabbro.[60] These peridotitic rocks when well developed contain corundum, spinel, chromite, and in some places rutile.[61] The ores always contain titanium, chromium, and spinel and are in some places associated with corundum (p. 255). It appears probable that the titaniferous magnetites are connected genetically with apophyses from the dunite and peridotite magmas that have intruded the schists along their foliation planes in the form of narrow veins or flat lenses. The ore veins are portions of these rocks rich in ferruginous material. The ores correspond in this respect to ores of the same kind that are associated with gabbro in the Adirondacks or with rocks closely related to dunite in Rhode Island and elsewhere and that have been generally regarded as magmatic segregations. In North Carolina, however, some of the ores are apparently in distinct dikes or in parallel-walled veins, and these may have been deposited by hydrothermal processes. At Senia the ore is distinctly later than the dunite in which it occurs, and in the sections of the Smith and Pennington ores the ore minerals are younger than the silicates asso-

[60] Pratt, J. H., and Lewis, J. V., North Carolina Geol. Survey, vol. 1, pp. 369–384, 1905.
[61] Idem, pp. 277, 279, 280.

ciated with them. Consequently they can not have been deposited by segregation from a magma the greater portion of which was still liquid but must have been intruded between the solidified components of the magma.

UTILIZATION.

Singewald[62] has shown that for the most part the titanium in titaniferous magnetic ores is due to an intergrowth of some titanium mineral with magnetite so intimate that their separation is not practicable on a commercial scale. In North Carolina only the ores of the Tuscarora belt might possibly furnish concentrates sufficiently low in titanium to be acceptable to the furnace men to mix with titanium-free ore. But very little is known of the size of the deposits.

No examination was made by Singewald of any of the titaniferous ores of Ashe, Mitchell, and Avery counties, but the study of thin sections of these ores by the writer indicates that their titanium content is due largely to the presence of rutile. This might be separated from the magnetite by magnetic concentration after pulverization, if there were any incentive to make the attempt. However, none of the deposits in any of these counties are large enough to warrant the installation of concentrating machinery so long as the numerous non-titaniferous deposits remain undeveloped.

MAGNETITE-HEMATITE ORES.

DISTRIBUTION AND CHARACTER.

At several localities in North Carolina and in Carter County, Tenn., there are deposits of iron ore that consist of mixtures of magnetite and hematite in widely different proportions. In some deposits the mixture is so nearly pure hematite that it is only weakly attracted by a small magnet. In others the magnet attracts the ore almost as strongly as it attracts the more common magnetites. As most of the deposits are small, they have not received much attention from prospectors.

Nitze[63] refers to several deposits of this kind in Watauga County, N. C., and several near the boundary between Mitchell County, N. C., and Unicoi County, Tenn., but gives no description of their manner of occurrence. He also mentions the fact that the Watauga County belt probably extends into Carter County, Tenn. Martite schists have been described[64] as occurring in the neighborhood of Boone and near the crest of the Blue Ridge as far northeast as the Virginia

[62] Singewald, J. T., jr., U. S. Bur. Mines Bull. 64, 1913.
[63] Nitze, H. B. C., op. cit., pp. 164–168.
[64] Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geology of North Carolina, Vol. 2, p. 176, Raleigh, 1888.

line. The only specimen seen from any of the occurrences in this belt shows a network of hematite veins forming a zone 2 inches wide in a white fine-grained rock that resembles in general appearance a crushed rhyolite, like the rhyolites associated with the ore at the Finney & Teegarden mine, near Lunsford Branch. (See below.)

Reference has also been made in another place (p. 235) to the occurrence of martite with magnetite in ores from deposits in the Piedmont Plateau, but these ores are more closely related to the siliceous magnetites than to the magnetite-hematite ores.

According to Nitze's account a deposit of red specular hematite was uncovered in several small openings on Bald Mountain, near the headwaters of Spring Creek, in Mitchell County. The ore is said to be fine grained and compact, and its wall rock to be "an arenaceous slate striking N. 25° E." Nothing is known of the size of the deposit, but it is stated that the belt of ore has been traced southwestward for 7 miles to Toe River.

The most valuable ores of this type occur near the north border of the area in Watauga and Carter counties that is shown on the maps of the Cranberry and Roan Mountain quadrangles as being underlain by Beech granite, either in the Beech granite or in the Cranberry granite, which adjoins it. (See map, fig. 61.) The Beech granite is characterized by Keith[65] as a white or pink porphyritic biotite granite that is intrusive in the Cranberry granite. It is regarded as the youngest of the Archean rocks of the district but like all the other rocks of this age has been so metamorphosed that it has now become markedly schistose.

Nitze reports a short belt of the magnetite-hematite ores on the south side of Beech Mountain, in the valley of Elk Creek, where it appears as a "bed" between "slaty, gneissoid walls." The ore is very siliceous, and the bed strikes east and dips north. It is believed to be of no commercial value.

Another belt of ores occurs on the southeast side of White Rocks Mountain at the headwaters of Laurel Creek, near the road from Shell Creek to Elk Mills, but nowhere is there any evidence of the presence of large ore bodies, nor are the exposures of such a character as to yield any information in regard to the manner of occurrence of the ore. Specimens appear to be composed almost wholly of magnetite. The only specimen from the locality that has been seen is a titaniferous magnetite containing 8.0 per cent of titanium dioxide. It is reported by Mr. Hamilton[66] to be associated with a gabbro. (See also p. 254.)

Farther down the valley, however, about 5 miles a little south of east of Hampton, on the crest of Keystone Ridge, is the Whitehead

[65] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (No. 90), p. 3, 1903.
[66] Hamilton, S. H., unpublished report to the Tennessee Geological Survey.

prospect, in Cranberry granite. This prospect exposed 4 feet of flinty hematite between a wall of the usual granite and one of a red flinty rock in which only red feldspar and a mixture of magnetite and hematite or martite are visible. Other specimens from this

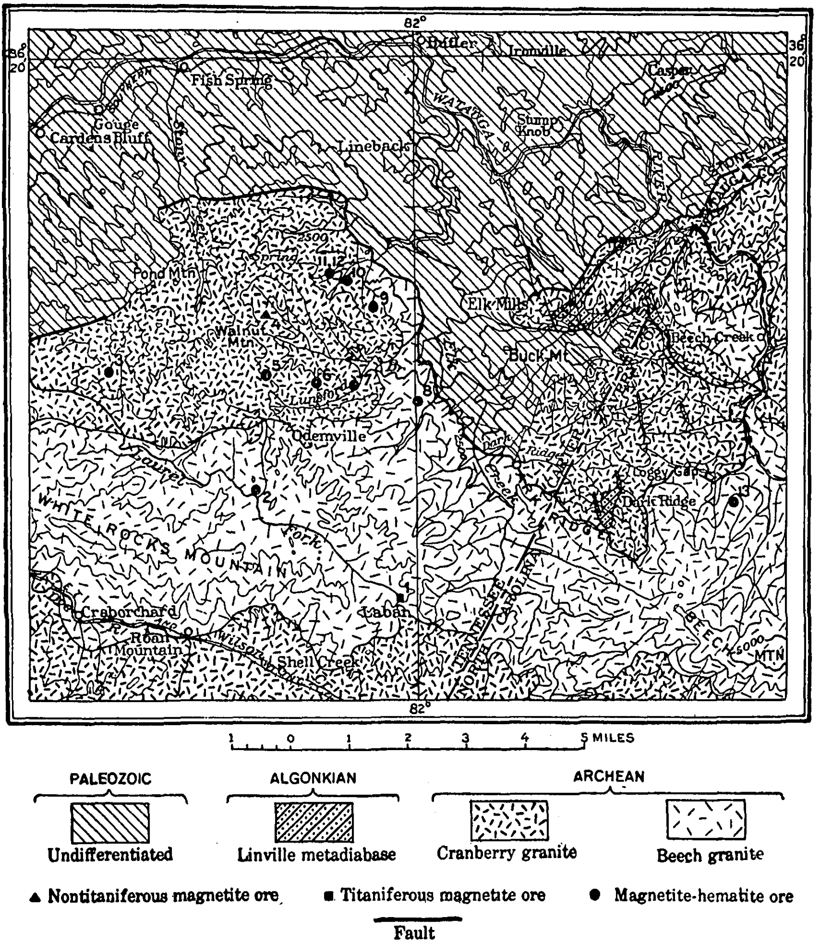

FIGURE 61.—Map showing location of prospects between Shell Creek and Butler, Tenn., and in adjacent portion of North Carolina. (In part after S. H. Hamilton.) 1, Montgomery and Cordell explorations; 2, School House prospect; 3, Keystone Ridge or Whitehead prospect; 4, Miller prospect; 5, Dr. Smith exploration; 6, Finney & Teegarden mine; 7, Lunsford prospect; 8, G. W. Stout exploration; 9, May's Ridge exploration; 10, Rabbit Station; 11, Black Bear prospect; 12, Black's prospect; 13, Big Ridge exploration.

prospect are extremely fine-grained homogeneous steely or flinty blue-gray hematites.

About 6 miles farther east and a little south of the Whitehead place is the School House prospect, where a very small amount of work has shown an ore composed of magnetite and martite crystals and a little interstitial quartz. This ore, according to Mr. Hamilton, from whose notes many of the descriptions of the magnetite-hematite ores are taken, is associated with a dark rock resembling a diorite. A sample of this ore analyzed by Dr. J. I. N. Hinds, of the Tennessee Geological Survey, yielded 62.72 per cent of iron and no phosphorus or titanium.

The most extensive explorations in this general area were made in its northern part on the east and south slopes of Walnut Mountain and on Big Ridge,[67] a northern spur of Beech Mountain, about 2 miles southeast of the mouth of Beech Creek.

The ore at Big Ridge is a "partially magnetic specular hematite" in a "slate and hornblende gneiss." It occurs as a bed 1½ to 4 feet thick, made up of many streaks from half an inch to 1 inch thick. It has a variable strike between west and northwest and a dip of 45°–90° N. or NE.

The explorations on Walnut Mountain were once important, but most of them are now so fallen in that nothing can be seen in the old pits. The ore on Mays Ridge is reported by Nitze to be "of considerable thickness" and to be of good quality. Four analyses made by J. C. Guild, of Chattanooga, are quoted by Nitze as showing the following ranges: Silica (SiO_2), 7.15–16.93 per cent; iron (Fe), 48.82–63.63 per cent; phosphorus (P), 0.006–0.054 per cent; phosphorus ratio (P:Fe), 0.010–0.095 per cent.

The other explorations in this vicinity uncovered similar ore. At Rabbit Station it appears in a bed of low dip striking about due east. Above and below it are thin layers of schist, and beyond these is the prevailing gneiss of the region, which is mapped by Keith as Cranberry granite. The schist selvage is a thoroughly crushed granite in which all the feldspar has been changed to micaceous alteration products and in which small garnets have been developed. At the Black Bear prospect, on the ridge west of Rabbit Station, the ore is a granular mixture of magnetite, a little hematite, quartz, and feldspar. The one specimen seen resembles in appearance a magnetitic pegmatite in which some of the magnetite has passed over into martite.[68]

None of the openings on the east slope of Walnut Mountain are of significance either as indicating deposits of economic importance or as affording opportunities for gaining information as to the origin of the ores. The meager descriptions of the deposits suggest that their ores and their associations at these places are like those of the deposits on Lunsford Branch described beyond and that, in all likelihood, the method of origin in both localities was the same.

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[67] Nitze, H. B. C., op. cit., pp. 165–166.

[68] Specimens of these ores were collected by Mr. Hamilton to illustrate his report to the Tennessee Geological Survey.

Lunsford Branch flows between White Rocks Mountain and Walnut Mountain. At several points in its valley ore deposits are known to occur, more particularly on its south side. Some of these have been explored by trenches and pits, and at two or three places the Virginia Iron, Coal & Coke Co. has made large open cuts, driven tunnels, and sunk a few shafts in the hope of finding sufficient ore to warrant mining operations. The result was disappointing, and the work was soon abandoned.

The westernmost openings in this series are at the Miller prospect, on Scrawl Ridge of Walnut Mountain, about three-quarters of a mile up the valley of Scrawl Branch. The country rock, which is mapped as Cranberry granite, is a crushed quartz syenite, composed of about 20.7 per cent of quartz, 47.1 per cent of orthoclase, 9.8 per cent of albite, 3.9 per cent of anorthite, 17.2 per cent of hornblende, and 1.3 per cent of apatite. With this are masses of crushed dioritic rocks which in some places contain large quantities of magnetite in irregular grains and crystal particles grouped between hornblende grains, as if it had been introduced after the rock had suffered much crushing. As some of the larger grains are fractured, it is evident that the magnetite was introduced before the deformation had ceased. Farther up the hollow the Virginia Iron, Coal & Coke Co. undertook a few other explorations and found a mineralized zone of crushed diorite charged with magnetite and cut by veinlets of epidote and quartz.[69] The descriptions suggest occurrences like that of the ore at Cranberry, except that the deposits are probably comparatively lean. They are unlike other deposits in this district and are more properly to be classed with the magnetites.

The best-known openings in the valley of Lunsford Branch are the Finney & Teegarden mine and the Lunsford prospect. The latter is a tunnel about 1½ miles east of the mouth of Scrawl Hollow, between Lunsford Branch and the road on its north side. The tunnel is reported to have entered the hill for about 50 feet and to have cut good ore like that at the Finney & Teegarden mine. Nothing of interest can now be seen at the prospect except a little ore dump, on which the fragments consist of a slightly banded granular mixture of magnetite, perhaps a little martite, a very little pyrite, and many small round particles of quartz. Their structure is that of a crushed rock into which iron oxides have been forced. According to Keith's mapping the prospect is in the Cranberry granite, but a section on the road just above the tunnel shows a series of parallel layers of much crushed quartz syenite, fine-grained gray rocks, and crushed dioritic rocks. The fine-grained rocks resemble granulitized felsites. Scattered through them are particles of quartz and feldspar

[69] From notes of S. H. Hamilton, in unpublished report to Tennessee Geological Survey.

a trifle larger than the grains of the matrix in which they lie. This matrix is an extremely fine grained aggregate of quartz, plagioclase, orthoclase, tiny flakes of green hornblende and biotite, granules of epidote, and wisps of muscovite. The constituent grains are elongate in the same direction, and many of them are flattened. The whole mass is silicified so that the original structure is unrecognizable. In the coarse phases the fragmental character of most of the larger components is pronounced. Some of them, however, are crushed into shreds. These phases of the rock are distinctly schistose. The groundmass of all phases is so fine grained and its constituents are so thoroughly crushed that it is impossible to decide whether it is

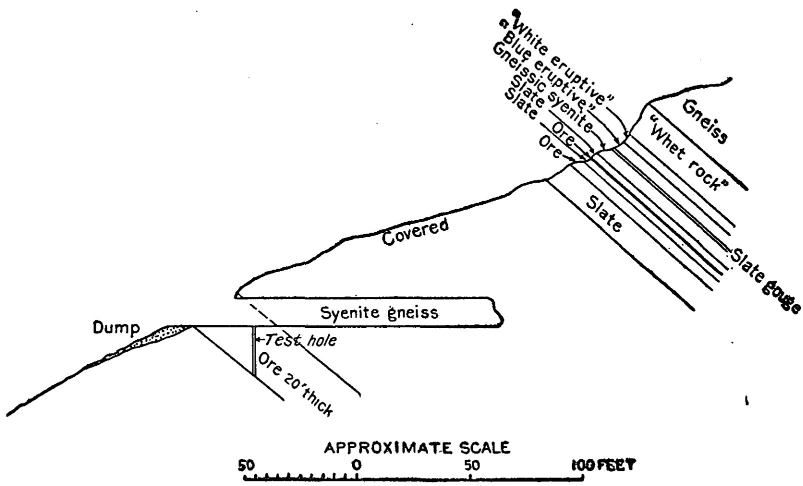

FIGURE 62.—Diagrammatic north-south section through Finney & Teegarden mine, in valley of Lunsford Branch, Carter County, Tenn. (By S. H. Hamilton.)

a crushed volcanic rock like a rhyolite or is composed of the débris of a crushed granite or quartz syenite.

At the Finney & Teegarden mine the opportunities for studying the relations of the ore to the associated rocks are fairly good. The mine is between the Miller and Lunsford prospects, about 1 mile west of the latter, on the south side of the main stream of Lunsford Branch. In 1912 two open cuts were made here by the Virginia Iron, Coal & Coke Co., a tunnel was driven into the hill from the western cut, and a vertical drill hole was put down at the mouth of the tunnel.

The country rock is a quartz syenite like that at the Miller and Lunsford prospects but very much more thoroughly crushed and therefore more schistose. Interlayered with this is a series of light-gray or white massive and slaty rocks, chlorite schist, and black magnetic ore, striking about S. 60° W. and dipping about 35° SE., into the hill. (See fig. 62.) The chlorite schist is in comparatively narrow layers bordering the ore, the two apparently grading into one another. The ore layers, of which two have been uncovered, are about 5 feet and 30 feet thick, but each is further divided into thinner layers by chlorite-slate sheets a few inches thick. Some of the ore is strongly magnetic, coarsely crystallized, and homogeneous and is broken into cubical masses by joint planes; but most of it is a fine-grained grayish-black mass of irregular grains and minute octahedrons with a very little quartz in the interstices between them. In most of the ore the structure is sugary, with a slight suggestion of banding. In other specimens there is a slight schistosity, and the hand specimens resemble a fine-grained specular ore. In many places through the ore are shear zones marked by chlorite slickensides, and commonly little lenses of chlorite are embedded in it. Where such lenses occur there is usually a slickensided joint extending from the lens.

Analyses by Dr. Hinds of two specimens of the ore from this mine yielded the following results:

Analyses of ore from Finney & Teegarden mine.

	Dump.	"Best ore."		Dump.	"Best ore."
Silica (SiO_2)	13.51	19.94	Soda (Na_2O)	Tr.	....
Alumina (Al_2O_3)	3.52	.24	Potash (K_2O)	0.00	0.00
Magnetite (Fe_3O_4)	82.30	53.13	Phosphorus pentoxide (P_2O_5)	.00	.00
Ferric oxide (Fe_2O_3)	....	26.20	Water (H_2O)	.60	.20
Lime (CaO)	Tr.	.00			
Magnesia (MgO)	Tr.	.00		99.93	99.71

No titanium dioxide was present.

Thin sections of the "best ore" show opaque crystals and groups of crystals in a matrix of small interlocking grains of quartz, in which there are a few small clumps of hornblende or chlorite and a few other fibrous minerals. The quartz grains usually show undulous extinction, and the general arrangement of the ore crystals and groups of crystals is roughly parallel.

The magnetite-chlorite schist on the upper side of the ore is very much slickensided and obscurely layered, like a fine-grained slate. Under the microscope the alternating layers are seen to differ in containing chlorite and fibrous green hornblende. The chlorite layers contain in addition a few grains and crystals of magnetite, a very little interstitial quartz, and a little interstitial fluorite. The chlorite is elongated in a parallel direction, and the particles of magnetite are arranged in lines in the same direction. In the hornblende layers the hornblende forms a meshwork of small fibers. Magnetite is present in much greater amount than in the chlorite layers, and its grains are elongate perpendicular to the layering. The schistosity of these layers is due to lenses of quartz and of colorless fluorite which are arranged parallel to the banding. The rock is apparently a sheared basic igneous rock into which magnetite and fluorite have been injected. According to Mr. Hamilton, a "blue slate" lies 20 feet above the ore. It is like the schist just described but is so thoroughly sheared and slickensided that it is fissile. The slate is thinly banded in dark and light layers; the darker layers are like the chlorite schists that are in contact with the ore, and the lighter layers consist of comparatively large fragments of granulated quartz in a mosaic of finely crushed quartz lenses, separated from one another by thin seams of chlorite or hornblende. Through this mass are thin lenses rich in fibers of a brightly polarizing light-green mineral that may be kaolinite. The rock is so completely crushed and sheared that no hints of its original structure remain.

Between the slaty rocks and the gneissic country rock are layers of white and gray, extremely fine grained rocks that closely resemble in appearance slightly schistose felsites. All of them are imperfectly slickensided, and all are distinctly jointed. Mr. Hamilton has named the three most easily distinguished phases "blue eruptive," "white eruptive," and "whet rock." Analyses of two of these phases show that they are alkali rhyolites. The analysis of the "white rock" was made by Dr. Hinds and that of the "whet rock" by Mr. D. F. Farrar, of the Tennessee Geological Survey.

Analyses of "white eruptive" and "whet rock" from vicinity of Finney & Teegarden mine.

	White rock.	Whet rock.		White rock.	Whet rock.
Silica (SiO_2)	73.78	76.60	Soda (Na_2O)	1.45	4.09
Alumina (Al_2O_3)	13.96	11.98	Potash (K_2O)	5.58	2.20
Ferric oxide (Fe_2O_3)	.80	.27	Phosphorus pentoxide (P_2O_5)	.53	.017
Ferrous oxide (FeO)	1.30	2.72	Water (H_2O) above 100° C.	.50	.70
Magnesia (MgO)	....	.36			
Lime (CaO)	2.08	.52		99.98	99.46

The calculated norm of the "white rock" is 39.66 per cent of quartz, 33.36 per cent of orthoclase, 12.58 per cent of albite, 6.95 per cent of anorthite, 2.75 per cent of corundum, 1.72 per cent of hypersthene, 1.34 per cent of apatite, and 1.16 per cent of magnetite—or very nearly like that of some rhyolites. Fluorine was not determined in the specimen of the white rock analyzed by Dr. Hinds, but Mr. Farrar made a special search for it in another specimen from the same locality and found 2.19 per cent.

The least schistose of these rocks is an interlocking aggregate of plagioclase, orthoclase, and quartz grains with average diameters of about 0.4 millimeter forming a matrix around a few larger feldspars that are mainly plagioclase. Tiny masses of fluorite fill the interstices between the grains of the matrix. A few of the fluorite particles are arranged in lines, as if forming tiny veins, but the greater part of the fluorite is distributed uniformly through the section. The only dark components are irregular masses of magnetite that are probably original, as many of them are bordered by small flakes of biotite. The whole section is besprinkled with dust particles which under high powers are resolved into tiny plates of amphibole, glass inclusions, and little colorless prisms too small to be identified. The rock is probably a dike rock closely related to a quartz andesite.

The more schistose layers differ from the rock last mentioned in being much more acidic. Their matrix is very similar, but they contain in addition to large grains of feldspar many large grains of quartz and lenses of quartz mosaic that were once simple quartz grains or perhaps quartz phenocrysts. All the components exhibit the effect of strain. The quartz is granulated, the feldspar is cracked, and the fibrous constituents, which are mainly amphibole, muscovite, or kaolinite, are all arranged with their elongation parallel to that of the quartz lenses. Quartz and feldspars compose the greater part of the matrix, and all the grains appear as if they were crushed fragments. Fluorite is invariably present as a filling of interstices. These rocks might well have been acidic volcanic or dike rocks, like aplites, that have been sheared and later filled with fluorite.

ORIGIN.

There is not much evidence as to the source of the ore layers, but as the iron oxides are closely associated with the chlorite and rhyolitic layers, and as the ore and chloritic rock grade into one another, it is reasonable to suppose that the ore and layered rocks are genetically connected. The general occurrence of fluorite in the layered rocks suggests the presence of an emanation of fluorine or fluorides from a subterranean magma. This emanation may have risen after the intrusion of the rhyolite and andesite into the country rock, and it may have been accompanied or immediately preceded by intrusions of more basic material than the earlier ones, giving rise to what are now the chlorite schists and the "blue slates." With these came the iron oxides in the form of magnetite, some of which was later changed to martite, or it is even conceivable that some of the oxides were magnetite and others hematite, as in a few places hematite alone is known to occur in veins cutting the schistose country rock. Clarke [70] calls attention to the fact that ferric oxide can crystallize from magmas as hematite only where ferrous compounds are either absent or present in very subordinate amounts, for ferrous oxide unites with ferric oxide to form magnetite. Magnetite therefore appears more com-

[70] Clarke, F. W., The data of geochemistry, 4th ed.: U. S. Geol. Survey Bull. 695, p. 342, 1920.

monly in rocks rich in ferromagnesian minerals, and hematite appears chiefly in more acidic, alkaline rocks like rhyolites and andesites. It is possible that in the deposits here considered the proportion of ferrous oxide in the product of the emanations was influenced in some way by the presence of fluorine or fluorides in the magma, because at Cranberry and other places in the mountains there is no evidence that the magmas that produced the pegmatites, which are also acidic, contained fluorine, and the iron is in the form of magnetite.

Because the associations of the more common magnetites, like those at Cranberry, are different from those at the Finney & Teegarden mine, it is inferred that the sources of the two kinds of ore were different. Both are thought to be of magmatic origin, but the Cranberry ore is believed to have been brought into its present position by pegmatites and the emanations accompanying them, and the ore of the Finney & Teegarden mine to have been brought up by basic phases of the magmas, the earlier intrusions of which were the rhyolites. The advent of the magmas was followed by emanations of iron compounds and fluorite. In both localities the intrusions followed zones of weakness in the country rock, and in both the intrusive masses were folded with the country rock by later deformation.

RESERVES.

There is very little evidence upon which to base an assertion as to the economic value of the magnetite-hematite ore. Most of the deposits seen are too small to warrant consideration as sources of ore. Those on the belt in the valley of Lunsford Branch are the largest known, but they are so inconveniently situated with respect to transportation that it will be a long time before they can be worked profitably. So far as can now be judged, without a great deal of additional exploration, the quantity of ore in the belt is not sufficient to warrant the building of a branch from the railroads at Butler or Shell Creek. The ore is of good quality, but it is not likely that more than 65,000 tons of merchantable grade will be available within 500 feet of the surface for each 1,000 feet of the length of the belt.