STATE OF TENNESSEE
DEPARTMENT OF EDUCATION
DIVISION OF GEOLOGY
Wilbur A. Nelson, State Geologist

BULLETIN 29

THE MAGNETIC IRON ORES

OF

EAST TENNESSEE

AND

WESTERN NORTH CAROLINA

By W. S. BAYLEY

Prepared in cooperation with the United States Geological Survey, the North Carolina Geological and Economic Survey and the State Geological Survey of Tennessee.

NASHVILLE, TENN.
1923

McQUIDDY PRINTING CO., NASHVILLE

CONTENTS

Foreword 10
Preface and summary 11
Chapter I.
General considerations 17
Magnetites and titaniferous magnetites 18
Composition and classification 18
Occurrence 20
Hematitic magnetities 22
Chapter II.
Historical review of literature 23
Chapter III.
The ores 35
General features 35
Magnetites 36
Chapter IV.
Siliceous magnetites 37
Character 37
Deposits in the mountain districts 37
Geology 37
Roan gneiss 39
Bakersville gabbro 41
Cranberry granite 44
Relations between Roan gneiss, Cranberry granite and other rocks 47
Ore veins 48
Vein-filling 48
The ore 52
The gangue 58
Pegmatite 62
Gneisses 64
Relations of the rocks in the vein-mass 66
Age 67
Origin 68
Utilization 69
Reserves 76
Chapter V.
Exploration 82
Preliminary statement 82
Instruments employed in exploration 82
The dial compass 82
The dip needle 88
The magnetometer 91
Sampling 92
Chapter VI.
Mines and prospects in siliceous magnetites 97
General features 97
Carter County, Tenn., and Avery and Mitchell counties, N. C. 97
The Cranberry belt 97
Cranberry mine 98
General description of mine and ore 98
Smoky No. 1 106

Smoky No. 2 108
Firmstone opening 112
Mine opening 112
Other openings in the Cranberry belt 117
Lee Johnson place 117
Cooper place 118
Ellers and Hardigraves Elk Park openings 118
Wilder mine 119
Greenlee and Ray and Tester property 122
Red Rock mine 122
Patrick mine 123
Teegarden and Ellis mines 123
Heupscup Ridge prospects 126
Peg Leg and Old Forge mines 126
Horse Shoe prospect 128
Julian prospect 129
Campbell prospect 129
Chestnut Ridge prospects 130
Magnetic City prospects 130
Deposits between Magnetic City and Toe River 131
Madison County, N. C. 132
Big Ivy mine 132

Chapter VII.
Mines and prospects in siliceous magnetites 134
Alleghany and Ashe counties, N. C. 134
General statements 134
Kirby opening 136
Deposits in the Poison Branch belt 139
General description 139
Pugh and Smith openings 139
Deposits on Helton Knob 140
Blevins openings 140
Red Hill openings 141
McClure's Knob deposits 142
Poison Branch mine 143
Openings between Silas and Piney creeks 145
Piney Creek opening 146
Francis and Henninger openings 147
Openings on Turkey Knob 148
Graybeal property 149
Waughbank property 153
Hampton Knob openings 153
Openings southwest of Hampton Knob 153
Openings southeast of Lansing 154
Deposits in the New River belt 155
General description 155
Openings in Alleghany County 155
Lunceford openings and Cox place 156
Brown openings 157
Ballou Home Place and Sand Bank openings 157
Reserves in Ashe County 160

Chapter VIII.
Mines and prospects in siliceous magnetites 161
Deposits in the Piedmont area of North Carolina 161
Preliminary statement 161
Origin 163
Reserves 165
Catawba and Lincoln counties, N. C. 166
General description 166
Deposits in the Catawba-Iron Station belt 166
Powell ore bank 168
Little Mountain deposits 168
Anderson Mountain openings 169
Morgan and Stonewall banks 169
Brevard and Big Ore banks 170
Deposits near Iron Station 172
Deposits in the Newton belt 172
Barringer mine 172
Forney and Killian mines 173
Exposures on Howards and Indian creeks 174
Deposits in the Eastern belt 175
Gaston County, N. C. 175
General statements 175
Deposits in the Eastern belt 176
Crowders Mountain deposits 176
Deposits in the Costner mine belt 177
Costner mine 177
Ellison mine 178
Ferguson mine 178
Fulenwider mine 180
Yellow Ridge mine 181

Chapter IX.
Marble magnetites 183
General character 183
Ashe Mining Company's mine 183
Chemical and mineralogical composition of ore 184
Association of minerals in the ore-mass 188
Pegmatite veins in the ore 191
The ore-body 192
Other marble-magnetite ores 194
Pit on Dr. Jones's property 194
Red Rock mine 194
Origin 195
Production and reserves 196

Chapter X.
Titaniferous magnetites 198
Characterization 198
Distribution 198
Composition 199
Origin 205
Utilization 207
Reserves 208

Chapter XI.
Mines and prospects in titaniferous magnetites 209
General statements 209
Deposits in the mountain districts 209
Ashe County, N. C. 209
Distribution 209
Smith place 210
McCarter place 215
Banguess place 215
Pennington opening 216
Alleghany County, N. C. 217
Avery and Mitchell counties, N. C. 217
Distribution 217
Senia deposit 218
Avery place 219
Grassy Bald of Roan Mountain 219
Jenkins prospect 220
Other deposits 221
Carter County, Tenn. 222
Lost Cove prospect 222
Other deposits 223
Yancey County, N. C. 223
Madison County, N. C. 224
Macon County, N. C. 225
Dobson Mountain 225
Other deposits 226
Chapter XII.
Mines and prospects in titaniferous magnetites 228
Deposits in the Piedmont area, North Carolina 228
Preliminary statement 228
Caldwell County, N. C. 228
Farthing place 228
Richlands Cove 229
Rockingham, Guilford and Davidson counties, N. C. 230
Tuscarora and Shaw belts 230
Tuscarora and Dannemora mines 234
Shaw mine 237
Apple plantation 238
Davie County, N. C. 238
Chapter XIII.
Hematitic magnetites 240
Deposits in North Carolina 240
Deposits in Tennessee and adjacent portions of Watauga County, N. C. 241
Deposits in the valley of Laurel Creek 241
Whitehead prospect 241
School House prospect 241
Deposits in Walnut and Beech mountains 242
Big Ridge openings 242
Explorations near Elk Mills 242
Deposits on Lunsford Branch 244
Scrawl Ridge openings 244
Lunsford prospect 244
Finney and Teegarden mine 245
Origin 251
Reserves 252

ILLUSTRATIONS

Plate			Page
I.		Map showing principal mines and explorations on and near the Cranberry belt, in Avery and Mitchell counties, N. C.	34
II.	(A)	Photomicrograph of Bakersville gabbro, near Cranberry, N. C.	43
	(B)	Photomicrograph of ore from Peg Leg mine, Carter County, Tenn.	43
III.		Polished surface of portion of vein-filling, Cranberry mine, Cranberry, N. C., showing interlayering of ore and gangue	49
IV.		Polished surface of portion of vein-filling, Cranberry mine, Cranberry, N. C., showing association of ore with hornblende	51
V.		Polished surfaces of two specimens of pegmatite and ore, from vein at Cranberry mine, Cranberry, N. C.	53
VI.	(A)	Photomicrograph of lean ore, Cranberry mine, Cranberry, N. C.	55
	(B)	Photomicrograph of schistose ore from Teegarden mine, near Shell Creek, Carter County, Tenn.	55
VII.	(A)	Photomicrograph of garnetiferous magnetite ore, from Smoky No. 1, Cranberry, N. C., in ordinary light	57
	(B)	Same as A, between crossed nicols	57
VIII.	(A)	View of pegmatite and ore in wall of open cut, Cranberry mine, Cranberry, N. C.	59
	(B)	View of younger pegmatite cutting across ore vein in Teegarden mine, near Shell Creek, Tenn.	59
IX.		Polished surface of pegmatite streaks in vein-filling, Cranberry mine, Cranberry, N. C.	61
X.	(A)	Photomicrograph of epidotized pegmatite vein-filling, Cranberry mine, Cranberry, N. C.	63
	(B)	Photomicrograph of pyroxene-magnetite pegmatite, Cranberry mine, Cranberry, N. C.	63
XI.	(A)	Photomicrograph in ordinary light of epidote-hornblende gneiss, vein-filling, Cranberry mine, Cranberry, N. C.	65
	(B)	Same as A, between crossed nicols	65
XII.		View of Cranberry mine, Cranberry, N. C.	99
XIII.		View toward Smoky Mountain, Cranberry, N. C.	101
XIV.		Cranberry Furnace, Johnson City, Tenn.	103
XV.		Map of surface, Cranberry mine, Cranberry, N. C., with projection of underground workings	105
XVI.		Plat of workings, Cranberry mine, Cranberry, N. C.	107
XVII.	(A)	View of Smoky No. 1 opening, showing hanging-wall granite, Cranberry, N. C.	109
	(B)	View of part of wall, open cut, Cranberry mine, illustrating irregular distribution of the ore	109
XVIII.	(A)	View of wall of open cut, Cranberry mine, Cranberry, N. C., showing irregular distribution of pegmatite in the vein-filling	113
	(B)	General view of wall of same cut, showing hanging-wall of foliated Cranberry granite	113
XIX.		Isodynamic chart of Wilder mine property, near Shell Creek, Carter County, Tenn.	121

XX. (A) Photomicrograph of magnetite ore, from Kirby exploration, Sturgill, Ashe County, N. C. 137
(B) Photomicrograph of hornblende granite 'horse' in Cranberry vein, showing epidotization of plagioclase 137
XXI. Polished surfaces of marble-magnetite ore from Ashe Mining Co.'s mine, Lansing, Ashe County, N. C. 185
XXII. (A) Photomicrograph of titaniferous magnetite, from Smith exploration, showing alteration of ore mineral into rutile 201
(B) Photomicrograph of silicates associated with titaniferous magnetite of Pennington exploration, Ashe County, N. C., showing probable pseudomorph after olivine 201
(C) Photomicrograph of titaniferous magnetite from Pennington exploration, Ashe County, N. C., showing presence of rutile in the ore mineral 201
(D) Polished surface of ore, Tuscarora mine, Guilford Co., N. C. 201
XXIII. (A) Photomicrograph of titaniferous magnetite from Smith exploration Ashe County, N. C., showing cracked magnetite 211
(B) Photomicrograph of another part of the same ore, showing rutile in magnetite 211

Figure — Page

1. Index map of western North Carolina and East Tennessee, showing positions of detail maps 20
2. Dial compass 83
3. Diagram illustrating horizontal deflection of compass needle caused by buried magnetic strip. (After Smyth) 84
4. Diagram illustrating effect of strike of magnetic strips upon needle of dial compass. (After Hotchkiss) 85
5. Dip needle 88
6. Contour map of dip needle deflections over a band of magnetic ore. (After Broderick) 89
7. Diagram illustrating effect of buried magnetic strip upon dip needle at different positions. (After Hotchkiss) 90
8. Diagram illustrating use of dial compass and dip needle to trace a magnetic line. (After Hotchkiss) 90
9. Magnetometer 91
10. Map showing isodynamic lines over a belt of magnetic formation in a rough country. (After Smyth) 92
11. Map of isodynamic lines over a series of magnetic lenses illustrating use as a guide for drilling. (After Hamilton) 94
12. Diagram to illustrate how the meandering of a drill hole may result in missing ore-body. (After Hamilton) 95
13. Map showing locations of magnetic iron ore deposits in Ashe County, North Carolina. (After Nitze) 134
14. Sketch map of openings at Poison Branch Mine, Ashe County, North Carolina. (After Nitze) 144
15. Map of portion of Ashe County, North Carolina, showing positions of the Graybeal property and the Ashe Mining Co.'s mine near Lansing 151
16. Map of explorations on Ballou and Calloway properties, Ashe County, North Carolina 158

Figure — Page

17. Map of iron ore deposits in Catawba, Lincoln, and Gaston counties, North Carolina. (After Kerr, Hanna and Nitze) 161
18. Ideal section illustrating shapes and positions of ore-bodies in Lincoln County, North Carolina. (After G. B. Hanna) 168
19. Map of openings at Big ore bank, Lincoln County, North Carolina. (After Bailey Willis) 170
20. Plan and section of Ashe Mining Co.'s mine at Lansing, Ashe County, North Carolina. (By Geo. W. Cooke) 186
21. Sketch of marble exposures at Intermont, Mitchell County, North Carolina 196
22. Sketch map of northern portion of iron-ore belt in Guilford and Rockingham counties, North Carolina. (After Lesley) 230
23. Sketch map of southern portion of iron-ore belt in Guilford and Rockingham counties, North Carolina. (After Lesley) 231
24. Openings at the Tuscarora Iron Works, Guilford County, North Carolina. (After Bailey Willis) 232
25. Plan and sections at Danemora mine, Rockingham County, North Carolina. (After Bailey Willis) 233
26. Map of explorations on Walnut Mountain, near Elk Mills, Carter County, Tennessee. (After Keith and Hamilton) 243
27. Diagrammatic cross section through Finney and Teegarden mine, Carter County, Tennessee 245
28. Photomicrograph of hematitic magnetite ore from Finney and Teegarden mine, Carter County, Tenn 247

FOREWORD

The present report, entitled "Magnetic Iron Ores of East Tennessee and Western North Carolina," represents a joint investigation of an important magnetic iron ore district lying partly in each State, and which has been carried on cooperatively by the North Carolina Geological and Economic Survey, the Tennessee Geological Survey, and the United States Geological Survey.

Professor W. S. Bayley, of the University of Illinois, was selected as the geologist to make the survey in these two States, and during the course of investigation he has had conferences with the State geologists of North Carolina and Tennessee and with E. F. Burchard, geologist of the United States Geological Survey in charge of iron.

The area covered by the investigation includes Carter County, Tennessee, and parts of Ashe, Allegheny, Avery and Mitchell counties, North Carolina.

The report also considers briefly deposits of magnetite in Catawba, Lincoln and Gaston counties, North Carolina. The topographical maps which have been used as bases of the geological maps accompanying this report were prepared from the topographic quadrangles of the United States Geological Survey and by special mapping of portions of the area.

The United States Bureau of Mines has made the tests in regard to method of separation of the magnetites, using for this purpose samples of ore from the Cranberry mine, Avery County, North Carolina, collected by Professor Bayley and Mr. Burchard.

The author has been very materially assisted by the owners of the various iron properties, and others interested in the general region, and the state geologists desire to make grateful acknowledgement at this time to all who assisted in various ways in facilitating the work of this investigation.

WILBUR A. NELSON,
State Geologist for Tennessee.

JOSEPH HYDE PRATT,
State Geologist for North Carolina.

Preface and Summary

The purpose of the study of the magnetic iron ores of East Tennessee and Western North Carolina was to learn, if possible, something of their value as a source of supply to furnaces in the South. It was undertaken at the suggestion of the State Geologist of North Carolina because the existence of the large deposit at Cranberry had led many persons to suppose that there might be other similarly large deposits in other portions of the mountain district. It was learned, however, soon after the beginning of the field work, that the most promising undeveloped deposits are in the extension of the Cranberry vein in Tennessee and that the topography of the region in which most of the magnetites occur is such as to make Johnson City, where there is already a modern blast-furnace, the natural outlet of the ores.

The furnace at Johnson City has utilized the ores of the Cranberry mine. It is desirable to learn whether or not there are other sources from which it may receive supplies. Rumors have been prevalent that there is an inexhaustible supply of iron ore in the area contributary to Johnson City. It is important to know whether the rumors are well founded or not. These considerations led to the cooperation of the Tennessee Geological Survey in the publication of the results of the study—and the outcome is the present bulletin. Throughout the course of the study the U. S. Geological Survey cooperated with the two State Surveys, paying a large share of the expenses of the field study.

Three[1] articles dealing with special phases of the subject, and a fourth[2] giving a summary of the entire study, have already been published.

The field work on which the report is based was done during parts of the summers of 1919, 1920, and 1921. In 1919 about seven weeks were devoted to the study of the magnetite deposits of Avery and Ashe counties, N. C., and that portion of Carter County, Tenn., contiguous to Avery County, and about two weeks to visiting the deposits in the Piedmont area of North Carolina. In 1920 the openings in the Cranberry belt of deposits extending westward from Cranberry into Carter County were again visited, about two weeks being spent in the study of critical areas, and a week in Ashe County making a topographic map of the region around Lansing and in the vicinity of the explorations on the North Fork of New River. In 1921 the region was revisited in company with Mr. E. F. Burchard of the U. S. Geological Survey. A number of the most important deposits were again examined and the Cranberry

[1]The magnetic ores of North Carolina—their origin: Econ. Geol., vol. 16, p. 142, 1921.
A magnetite-marble ore at Lansing, N. C.: Jour. Elisha Mitchell So., vol. 37, p. 138, 1922.
The occurrence of rutile in the titaniferous magnetites of Western North Carolina and Eastern Tennessee: Econ. Geol., vol. 18, p. 382, 1923.
[2]General features of the magnetic ores of Western North Carolina and Eastern Tennessee: U. S. Geol. Surv. Bull. 735-G, 1922.

mine was sampled for an experimental study of the susceptibility of its ore to magnetic separation methods. At the close of the season a day was spent examining the deposits of hematitic ores in Carter County between Shell Creek and Butler.

The writer wishes to express his appreciation of all the courtesies extended to him by the people with whom he was brought in contact during this work. Not only did the dwellers in the district respond willingly to all his requests for information, but in many cases they went out of their way to aid him in the search for the hidden mine holes and exposures. Special thanks are due to Mr. F. P. Howe, President, and to the general officers of the Cranberry Furnace Company and to Mr. S. H. Odom, Superintendent of the Cranberry mine, for information that could not have been secured elsewhere, and for the use of maps of the Cranberry mine, and to Mr. George Cooke, President of the Ashe Mining Company, who served as guide to many of the explorations and exposures in the neighborhood of Lansing. Grateful mention should also be made of Messrs. L. W. Fischel and L. J. Phipps, students of the University of North Carolina for their painstaking work on the map portions of Ashe County. The writer is also under obligation to Mr. S. H. Hamilton from whose report, now in the possession of the Tennessee State Geological Survey, he has taken the description of a few deposits which were not visited, and has copied the magnetic map of the Wilder Mine. Finally thanks are due in large measure to Col. Joseph Hyde Pratt, State Geologist of North Carolina and Mr. Wilbur A. Nelson, State Geologist of Tennessee, for their generous cooperation with him during the prosecution of the investigation.

The principal results of the study may be summarized as follows:

(*a*) The magnetic ores contributory to Johnson City and those in the Piedmont area of North Carolina are of three types, viz.: hematitic magnetites, titaniferous magnetites and non-titaniferous magnetites, all of which are in rocks of pre-Cambrian age.

The first group is composed of small deposits scattered over the mountain district of the two States. The largest and most characteristically developed are in the northeast portion of Carter County, Tenn., on Lunsford Branch between Butler and Shell Creek. They are associated with old volcanic rocks that may be classed with Keith's metarhyolites[1] which are thought to be of Algonkian Age. These are associated with chloritic schists that are probably metamorphised basic volcanics. Both acid and basic rocks are saturated with fluorite. Magnetite and hematite are so closely incorporated with the chloritic schists that it is thought iron emanations accompanied the basic magmas to their present positions, and formed the ores. It is possible that the presence of hematite is due to the presence of fluorine in the emanations.

[1]Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, Cranberry folio (No. 90), 1903.

At present the hematitic magnetites are not of practical importance as sources of iron-ore since the quantity available in the district is too small to warrant the expenditure of the funds necessary to place it on the railroad.

b. The titaniferous magnetites are present in the mountain district and in the Piedmont area. Some of the deposits are comparatively large, but most are too small to be of present value as sources of ore, even if they were acceptable to the furnace men. So long as there is a sufficient supply of non-titaniferous ore available there will be no demand for the titaniferous ore as a source of iron. In the future, when the supply of high-grade non-titaniferous ore is exhausted the titaniferous ores will unquestionably become of importance. At present it would be necessary to separate from them concentrates nearly free from titanium before they could be utilized in the blast-furnace in competition with non-titaniferous ores. This is possible in the case of some of them, but is so expensive that it is not practicable.

Singewald[1] had shown that for the most part the titanium in these ores is due to an intricate growth of some titanium mineral with magnetite. He supposed the titanium mineral to be ilmenite in such small plates and needles that it could not be separated by magnetic methods from the magnetite without such fine grinding that the cost of concentration would be prohibitive. Analyses of some of the titaniferous ores indicate that the titanium is not always present as ilmenite but that in some cases, at least, it occurs as an oxide and the study of thin sections show that much, if not all, of the titanium is present as rutile. However, the discovery of this fact does not modify Singewald's conclusion that the ores are unavailable at present as sources of iron. In one group of deposits—that on the Tuscacora and Shaw belts in Rockingham, Guilford and Davidson Counties, N. C., the intergrowth may be coarse enough to warrant an attempt at concentration, but the deposits are so far away from blast-furnaces that they are not now probable sources of ore.

In the field the titaniferous magnetites can usually be recognized by the fact that they are associated with basic rocks like gabbro. They are believed to consist mainly of segregations of ore minerals that were intruded into cooled portions of the same magma from which they were segregated.

c. The non-titaniferous magnetites are the most promising sources of ore for the North Carolina and East Tennessee furnaces. They are very low in phosphorus, sulphur, and titanium and consequently are utilized for making a very low-phosphorus iron. The ore that has not been concentrated by magnetic processes is comparatively low in iron, rarely reaching a content higher than 41 per cent. It is,

[1]Singewald, J. T., Jr., U. S. Bur. Mines Bull. 64, 1913.

however, susceptible to concentration, yielding a concentrate which may contain from 50 to 71 per cent of metal, depending upon the fineness to which the crude ore is ground and the strength of the magnets used in the process. (See page 69.)

It has been learned that there are some large deposits of ore of this kind in the Piedmont area of North Carolina and in the mountain district of North Carolina and Tennessee. Those in the Piedmont area are not of immediate economic importance because they are too far from furnaces. Most of those in the mountain district are within an area that should be contributory to Johnson City, but at present some of them particularly those in Ashe County, N. C., are unavailable because too far from the railroad. The largest deposits in the entire district, so far as we know, are on a belt passing through Cranberry in Avery County, N. C., and extending northwest into Carter County, Tenn. At Cranberry is the well-known Cranberry mine which has been furnishing ore to the blast-furnace at Johnson City for several decades. This is regarded as the type of all other non-titaniferous magnetites in the mountain district except one, at Lansing, Ashe County, which is in marble. The Cranberry vein is in a gneissoid granite.

One of the principal objects of the study was to determine the origin of the Cranberry deposit so that some notion might be gained as to whether it extends beneath the present workings of the mine or is merely a superficial phenomenon. Since the ore was found to be closely associated with an epidotized pegmatite which was originally an augite syenite-pegmatite, it is believed to be deep-seated in origin and consequently may be expected to continue to depth with approximately the same character as in the developed portion of the vein.

The ore occurs in the vein as a series of lenses connected with one another by thin strips of ore. If the vein, as appears probable, is as rich in ore beneath the present bottom of the mine as above it, there is present in 1,800 feet of the vein and within a depth of 550 feet beneath the present lowest mine-level about 1,700,000 tons of ore of the same quality as that which has already been taken out.

The Cranberry vein continues without interruption for 5½ miles northwest of Cranberry into Carter County, Tennessee, and in it are lenses of ore which have been opened at the Wilder, Teegarden, Peg Leg and other mines. A conservative estimate of the ore existing in the vein between the Cranberry and Peg Leg mines is 2,250,000 tons for every 100 feet depth. (See pages 76 to 80.) It is not known how much of this ore might be mined and concentrated with profit, but it is probable that at a number of places the lenses are sufficiently large to warrant working, provided there were some provision made for their concentration at a point on the railroad within convenient reach of all the operations. Such a point is believed to be situated near Roan Mountain Station, to which the ore from any place on the vein might be transported by a down-grade haul.

So far as has been determined there are no other deposits within reasonable distance of Johnson City that are large enough to warrant the construction near them of concentrating plants. Nor are there any, except those on the Cranberry vein, that are near enough to Roan Mountain to deliver crude ore to a concentrating plant at that point at a cost that would yield a profit. There is an abundance of ore scattered through the mountains but it is in such small deposits as to be unavailable at the present price of ore.

In Ashe County there are several deposits of fair size, but they are so far from railroads that they would be expensive to operate. The deposits on New River contain at least 700,000 tons of merchantable ore and those near Lansing about 225,000 tons but the enormous tonnages that have been supposed to exist in this County have not been developed by exploration and are not suggested by surface indications.

d. The only deposit of economic importance in the mountain district that is not in gneissic rocks is that of the Ashe Mining Company at Lansing, Ashe County, which is in marble. The deposit is small and its content of iron is small, but because the gangue is marble the ore finds a ready sale. The ore consists of grains of magnetite in a white marble that contains in addition to magnetite small amounts of phlogopite, actinolite, and quartz. It is cut by veins of actinolite and dark hornblende and of a fine-grained aplitic rock, believed to correspond to the pegmatite at the Cranberry mine. The ore is thought to have an origin analogous to that of the Cranberry ore, *i. e.* to have been deposited by ferruginous materials accompanying pegmatitic intrusions. Marble ores are believed to be rare in the mountain district because marbles are rare among the pre-Cambrian rocks of the district.

e. Since the non-titaniferous magnetite deposits of the mountain district are found in the pre-Cambrian rocks of the district and are associated with pegmatites that are not known to penetrate the Cambrian rocks it is inferred that the ores are pre-Cambrian in age.

The non-titaniferous magnetites of the Piedmont area are all associated with gabbros and other basic rocks that are believed to be pre-Cambrian, and consequently, these ores are also inferred to be of pre-Cambrian age.

The titaniferous ores are thought to be genetically connected with peridotites of the same age as the peridotite rocks that are so common all along the east side of the Appalachian ranges. If these are pre-Cambrian the titaniferous ores are likewise pre-Cambrian.

The age of the hematitic magnetites is not known, but if the rocks associated with them are Algonian, as probably is the case, these ores are also pre-Cambrian.

The Magnetic Iron Ores of East Tennessee and Western North Carolina

By W. S. BAYLEY.

CHAPTER I.

GENERAL CONSIDERATIONS

The iron ores of East Tennessee and western North Carolina comprise magnetite, titaniferous magnetite (or mixtures of magnetite with ilmenite, or with rutile), brown hematite (limonite and goethite), and mixtures of magnetite with hematite or martite. Hematite also occurs but in such small quantities that it has never been mined. The brown hematite, magnetite and titaniferous magnetite have been mined and smelted, but in later years the titaniferous varieties have been completely neglected, because not adapted to modern blast-furnace practice. Until within a few years past the magnetite deposits furnished nearly all the ore, but recently the brown ores have become more and more important. Almost all of it came from North Carolina. Since 1900 the production[1] has been:

1922—	Magnetite	= 4,321	tons;	Brown ore	=12,958	tons.
1921—	"	=......	"	"	= 2,583	"
1920—	"	=44,482	"	"	=27,328	"
1919—	"	=43,483	"	"	=15,295	"
1918—	"	=60,593	"	"	=47,739	"
1917—	"	=55,353	"	"	=35,644	"
1916—	"	=60,043	"	"	= 4,263	"
1915—	"	=65,596	"	"	= 857	"
1914—	"	=57,607	"	"	=.....	"
1913—	"	=69,235	"	"	=.....	"
1912—	"	=68,322	"	"	=.....	"
1911—	"	=84,782	"	"	=.....	"
1910—	"	=65,278	"	"	=.....	"
1909—	"	=61,150	"	"	=.....	"
1908—	"	=48,522	"	"	=.....	"
1907—	"	=75,638	"	"	=.....	"
1906—	"	=56,057	"	"	=.....	"
1905—	"	=56,282	"	"	=.....	"
1904—	"	=64,347	"	"	=Some	
1903—	"	=82,851	"	"	=Some	
1902—	"	=34,336	"	"	= 3,500	tons.
1901—	"	= 2,020	"	"	= Little	
1900—	"	=20,479	"	"	= Little	

[1]Taken from the reports of the North Carolina Geol. and Econ. Survey and Min. Resources of the U. S.

Most of the brown ore produced since 1915 came from Madison and Cherokee counties in North Carolina, the greater portion from Cherokee County. In the earlier years of the century it was obtained mainly from Chatham and Johnston counties for the use of the furnace at Greensboro which was closed about 15 years ago. The magnetite came mainly from Cranberry in Avery County. A small quantity has been contributed by deposits at other localities from time to time, but this was obtained principally in the development of explorations and consequently was only an incident. Most of it was from deposits in Carter County, Tenn., where search was made for the western extension of the Cranberry vein.

In this report attention is directed mainly to the magnetites and magnetite-hematite ores of Carter County, Tenn., and to the magnetite ores of Ashe and Avery counties and the titaniferous magnetite of Guilford County, N. C. (See index map, Figure 1.) A few deposits in other portions of North Carolina are described only briefly, since at present they are of little importance. The deposits of Avery and Ashe counties, N. C., and Carter County, Tenn., are believed to offer more promising opportunities for successful development than those elsewhere, and therefore the time available for the field work was devoted almost exclusively to them. Information concerning deposits in other portions of North Carolina is gathered mainly from the literature.

The magnetic ores usually occur in areas of granites, gneisses and schists, but in Ashe County, N. C., a deposit of magnetite occurs in marble. In all, or nearly all cases, the magnetic ores are associated with pegmatites or aplites or with the alteration products of basic intrusives.

MAGNETITES AND TITANIFEROUS MAGNETITES

COMPOSITION AND CLASSIFICATION

The magnetic ores have already been referred to as comprising 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 first type are usually spoken of as magnetite and those of the second type as titaniferous magnetite or titaniferous iron ore. The titaniferous and non-titaniferous magnetites differ not only in the presence or absence of considerable quantities of titanium but also in the presence or absence of chromium. Both types are comparatively free from phosphorus and sulphur.

The difference in the two types is indicated by the following series of analyses, most of which were taken from the preliminary report of

H. B. C. Nitze[2] on the iron ores of North Carolina, published in 1893. The first 9 and the last 1 are of the non-titaniferous types. Most of them contain a little titanium but it is in such small quantities as to be negligible. The other 7 represent the titaniferous varieties. Most of the specimens analyzed were from deposits in Ashe County, but they are representative of the magnetic ores throughout the crystalline areas of both North Carolina and Tennessee.

Selected Analyses of North Carolina magnetic ores

	SiO_2	Fe	S	P	P ratio	TiO_2	Mn	Cr_2O_3
1	14.28	57.21	tr	.060	.105	.12	.16	none
2	5.27	64.64	115	.004	.006	.95	.19	
3	19.83	51.55	.137	.042	.081	.207		
4	32.06	37.14	071	.004	.010	.106		
5	32.59	36.41	200	.003	.008	.118		
6	28.60	37.30	.090	.014	.038	082		
7	20.36	45.06	130	.011	.024	.040		
8	3.20	65.40		.011	.016	.000	2.58	
9	6.85	63.55	tr	.009	.014	.060		
10	1.80	54.17				14.46	.96	.97
11	4.71	48.41	.089	.023	.048	13.74	.11	.34
12	1.31	55.06	tr	tr	tr	13.60	.70	.72
13	5.73	52.22	tr	tr	tr	12.96	.26	.390
14	9.90	46.81	.137	.025	.053	6.03		.630
15	6.35	57.66	.061	.008	.013	4.69		.505
16	4.75	52.23	.112	.021	.040	8.91		1.190
17	17.25	48.87	.057	.066	.135	.210		.000

1. Cranberry mine, Avery Co., N. C. Analyst: J. G. Fairchild, U. S. Geol. Surv.
2. Cranberry mine, 10th Census Report, vol. 15, p. 326, 1886.
3. Long Trench, Red Hill, Poison Branch belt. Nitze, North Carolina Geol. Surv., Bull. No. 1, p. 143, 1893.
4. Opening No. 2, Red Hill, Poison Branch belt. Idem, p. 144.
5. Opening No. 3, N. W. side, Red Hill, Poison Branch belt. Idem, p. 144.
6. Opening S. side of road, Poison Branch mine, Poison Branch belt. Idem, p. 150.
7. Lower portion of opening, N. side of road, Poison Branch mine, Poison Branch belt. Idem, p. 150.
8. Piney Creek opening, Poison Branch belt. Idem, p. 153.
9. Jos. Graybeal, main opening, Poison Branch belt. Idem, p. 155.
10. Shaw mine, Rockingham Co., Kerr and Hanna, Geol. of North Carolina, vol. 2, chap. 2, p. 150, 1888.
11. Dannemora mine, Rockingham Co., 10th Census Report, vol. 15, p. 311, 1886.
12. Sergeant shaft, Tuscarora mine, Guilford Co., Kerr and Hanna, Op. cit., p. 149.
13. Wm. Young, Titaniferous belt, or Helton Creek belt. (See page 215.)
14. McCarter opening, No. 4, north of road, Titaniferous belt. Nitze, Bull. No. 1, North Carolina Geol. Surv., Bull. No. 1, p. 157, 1893.
15. Bauguess Place, Titaniferous belt. Idem, p. 160.
16. Pennington's Place, Titaniferous belt. Idem, p. 160.
17. Kirby Place, Titaniferous belt. Idem, p. 160.

The most striking features of these analyses are the marked differences in the quantity of titanium dioxide (TiO_2) in numbers 10 to 16 as compared with the quantity shown in numbers 1 to 9 and in number 17. Aside from this, the difference is the more noticeable with respect to chromic oxide (Cr_2O_3). All the titaniferous ores contain this oxide, whereas none has been found in those in which titanium is present in less than 1 per cent of TiO_2. Moreover, there is another

[2] Nitze, H. B. C., Iron Ores of North Carolina: North Carolina Geol. Surv., Bull. No. 1, Raleigh, 1893.

distinction which is not evident from inspection of the analyses. The magnetites frequently contain comparatively large quantities of manganese whereas in the titaniferous ores this element is in small quantities only. Phosphorus is below the Bessemer limit in both kinds of ore except in a very few cases, in which it is slightly above the limit. Sulphur is always in small quantities. The titaniferous ores are not available for blast-furnace use only because of their high content of titanium.

FIGURE 1. Index map of East Tennessee and Western North Carolina, showing positions of detail maps.

OCCURRENCE

The magnetites and the titaniferous iron ores are alike in general appearance and in their occurrence as lenses and veins in gneisses, schists and other crystalline rocks. Those in the mountain district are associated with Archean country rocks. The country rocks associated with the deposits in the Piedmont area are quartzites, marbles, micaceous schist, and slates that may be of Cambrian age, and gneisses and old

volcanic lavas and tuffs which are younger than Archean, but probably older than Cambrian.[3]

Nitze[4] in his discussion of the magnetitic ores described them as occurring in belts, inferring that they are distributed along continuous lines. This inference may be correct in a broad way, *i. e.*, the deposits are usually in zones parallel to the general structure of the region, but in a narrower sense they are in short discontinuous lines or series of parallel lines that may be close together in some places and widely apart in others. In Ashe County, for instance, Nitze designates several belts of non-titaniferous magnetites and one belt of titaniferous varieties. In the titaniferous belt, because of its position, he is compelled to place the Kirby mine, which, however, contains only a trace of titanium and no chromium. Moreover the Kirby ore is associated with rocks that are different from those associated with the titaniferous magnetites in the same belt, and are like those associated with the ore at Cranberry, which, as is well-known, is also non-titaniferous. In Avery County he designates as a belt of titaniferous ores a series of deposits of different kinds, which are so distributed that a line joining them crosses the structure of the country.

In some places the deposits are actually in line with one another, where they are situated along a zone of weakness in the country rock, usually a zone along which the schistosity is more pronounced than elsewhere. In other places they are in schistose zones but not in the same plane. In these places the zone itself consists of a series of planes along which marked schistosity has taken place, but the loci of maximum weakness are not always in the same plane. In these zones the deposits may be 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. In still other places, so far as now known, the deposits are isolated.

In some instances the zones within which the deposits are distributed may cross the country for many miles; in other instances, they are short. But even in the case of 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 when observed carefully to be on parallel lines.

[3] Keith, Arthur, and Sterrett, Douglas B., The resources of the Kings Mountain district, North Carolina and South Carolina, U. S. Geol. Surv., Bull. 660, p. 126, 1918.

[4] Nitze, H. B. C., Iron ores of North Carolina, N. C. Geol. Surv., Bull. No. 1, p. 230, Raleigh, 1893.

HEMATITIC MAGNETITES

The ores that are mixtures of magnetite and hematite are limited to a small area in Carter County, Tennessee, where they occur as layers between gneisses and chloritic schists, 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, nor so far as is known has any of it 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 promising ore of this type is an extremely fine grained, obscurely layered and slightly schistose specular ore that resembles in appearance some of the more massive specular ores of the Marquette district. Others are flinty hematities.

Analyses of two specimens show that they are low in phosphorus and free from titanium, and that their iron is present in widely varying proportions of hematite and magnetite.

Partial analyses of hematitic magnetite ore, Carter County, Tennessee

	Teegarden mine	Keystone Ridge
Silica (SiO_2)	21.94	14.86
Alumina (Al_2O_3)	1.26	.....
Ferric iron (Fe_2O_3)	54.76	82.84
Ferrous iron (FeO)	21.52	1.40
Phosphorus pentoxide (P_2O_5)	.026	.....
Other constituents	.53	.....
	100.036	99.10

The first analysis indicates a mixture of about 6.5 per cent of hematite and 70 per cent of magnetite, and the second a mixture of 79.8 per cent of hematite and 4.4 per cent of magnetite.

CHAPTER II.

HISTORICAL REVIEW OF LITERATURE

Before 1827 iron ores had been worked in Lincoln county, N. C., presumably for local forges, for in the first geological report of the first State Geologist[5] of North Carolina we read,

"Compared with the other regions of the globe, the eastern section of the continent of North America is, with a single exception, not rich in the metallic ores. With the most important and valuable of all, the ores of iron it abounds. . . . So far as we can judge from observations hitherto made, the mines of iron and coal, with the lead mines of the Missouri, are to constitute the principal mineral wealth of the United States. . . . . as the county of Lincoln was the first to embark in the iron manufacture, so it is probable that she will maintain the standing she has acquired. The superior excellence of the ores from which the metal is extracted . . warrants this conclusion. Nor is the demand just at present, greater than this single county might supply, because of the high cost of labor in America and the very trifling expense of transporting such an article as iron across the Atlantic."

Dr. Gerard Troost, State Geologist of Tennessee in 1837 in his fourth report, speaks of the Cranberry ore deposit as follows:

"The iron ore of the primordial formation is generally that kind which is called magnetic iron ore. Immense quantities of this ore are found in the northeastern parts of the United States. And not to speak of the vast deposits of this ore in similar formations in Washington County, Missouri, which have formed these fifty years one of the wonders of the west, nor those of Elba, which produced most of the iron used by the Romans, and the mines of which are yet considered as inexhaustible; I must mention one situated near the limit which separates the State of Tennessee from North Carolina, at the foot of the Roan Mountain, in Carter county. It seems to be an extensive vein of rich magnetic iron ore, similar to that of some parts of Sweden, and is accompanied with the same minerals as the Swedish ore, namely, a variety of pyroxene (salite or malacolite)."

Again in 1854 the existence of iron ores in parts of North Carolina was referred to by Whitney[6], but the ores were not discussed. He stated that iron ores could be found in the metamorphic rocks in the western part of the State, but declared that they were too remote to be of much consequence to the iron manufacturer. They were considered of importance only locally, as the Census of 1850 had reported but 400 tons of the metal produced in the entire State.

A few years later, however, Emmons[7] began to emphasize the value of the ores and recommended the construction of a national foundry at Deep River. The Deep River deposits are titaniferous magnetites that

[5]Mitchell, Elisha, Report on the geology of North Carolina, part III., pp. 25-26, November, 1827.

[6]Whitney, J. D., Metallic wealth of the United States, p. 474, Philadelphia, 1854.

[7]Emmons, E., Geol. report of the midland counties of North Carolina, pp. 112-128, Raleigh, 1856.
National Foundry.—Deep River, N. C. Raleigh, 1859. Also Min. Mag. ser. 1, vol. 10, pp. 281-288, 1858.
A national foundry in North Carolina: De Bow's Review, vol. 24, pp. 403-409, 1858.

are of no economic importance at the present time, so that it is unnecessary to refer to them further in this place. They will be discussed later in connection with the character and origin of the titaniferous ores.

Emmons recognized 3 belts of ore in the midland counties, of which the western one passes 6 or 7 miles east of Lincolnton and extends to King's Mountain in Gaston County. The ore was described as being in talcose slate between quartzite and gneiss belts. It was declared to be in flat lenses which lie obliquely in the slate, one lens succeeding another along the strike in such a manner that each "laps on to the west side of another flattened oval mass, which lies behind the first." The deposits in Lincoln County were reported to have been worked for a long time for local forges. All the ore was believed to be in veins of igneous origin in the sediments which were regarded as the oldest in the State. The author surmised that not all the deposits had been found but he thought there were no inducements for further search since the ore already known "is in sufficient quantity to serve all uses."

The other two belts are east of the Lincoln County belt, outside of the area discussed in this bulletin.

In the Iron Manufacturer's Guide[8], published 3 years later, Lesley mentions the existence of the same 3 belts of ore in the State, of which the one that passes east of Lincolnton is described in some detail. He states his view as to the sequence of the beds associated with the ores and declares them to be Taconic. He indirectly refers to the ores of Cherokee County and elsewhere, since he states that bloomeries supplied by these ores had been working with them for many years.

During the next ten years several[9] other references to the iron ores of the State were made in published articles, but none of them contributed any new information as to their quality or abundance.

The first systematic account of the North Carolina ores was given by Kerr[10], who discussed the ore deposits by districts, describing them in considerable detail, illustrating his descriptions by many figures and maps, and quoting many analyses. Many of the mines described are, however, east of the areas discussed in this report and these, therefore, need not be referred to here.

The ore in the belt passing through Catawba, Lincoln and Gaston counties was reported to consist of talcose, chloritic, quartzitic or actinolitic schists impregnated with granular magnetite and hematite, and lying near a quartzite, which Emmons had declared to be a marker for

[8]Lesley, J. Peter, Iron Manufacturer's Guide, pp. 449, 451-452, N. Y., 1859.

[9]Sergeant, J. D., The titaniferous iron mines of North Carolina: Eng. and Min. Jour., vol. 11, p. 130, 1871.
Colton, H. E., Mines in North Carolina: Eng. and Min. Jour., vol. 11., p. 323, 1871.
Genth, F. A., Mineral resources of North Carolina: Jour. Frank. Inst., vol. 62, Dec. 1871.
Lesley, J. P., Note on the titaniferous iron belt near Greensboro, N. C.: Am. Philos. Soc. Proc., vol. 12, pp. 139-158, 1873.

[10]Kerr, W. C., Report of the Geol. Survey of North Carolina, vol. 1. Physical geography, resume, Econ. Geol., pp. 217-271, Raleigh, 1875.

the ore deposits. The belt contains, according to Kerr, two parallel "beds," the westerly being the more productive, with 12 feet to 20 feet of talcose or chloritic slates between them.

The belt is said to divide itself into two groups of beds, the northern in Lincoln county, and the southern in Gaston county. The principal deposits in both groups were described in some detail, and attention was called to the great size of some of them.

That portion of the belt in Gaston County was stated to be similar to the portion in Lincoln County, but the ore contains a little more hematite and usually has a red streak. The belt is double, as it is further north, but the two parts are much farther separated.

Other deposits of magnetite were mentioned as existing in Lincoln and Gaston counties, but as most of them are not in the belts recognized by the author they were simply referred to.

The Cranberry ore-bank, however, was briefly described. The country rocks around the deposit were stated to be hornblende slate and syenite, and gray gneisses and gneissoid slates. At that time the mine had not been opened, the ore being taken from the loose masses scattered through the soil over the vein. Prof. Chandler is quoted as stating that it was the best iron ore he had ever analysed. In regard to quantity Kerr believed it "exceeds the great deposits of Missouri and Michigan and at least equals anything in the Champlain region (page 266.)" He gave no details about the vein, merely declaring that "the epidote is not entirely confined to a single stratum, or part of the bed, being mixed to some extent with the pyroxenic rocky gangue which most abounds toward the western side of the vein." (Page 266.)

Other ore beds like those at Cranberry were reported to exist to the northwest, west, southwest, and southeast of the Cranberry bed, many of them like the Cranberry deposit; but most of them were known only by their outcrops and no definite information as to their size was available.

Important magnetite deposits were said to occur, also, in Ashe County—the best known being on Horse Creek, at Hampton's and at Graybill's, and the largest on Helton Creek. The veins were stated to be in gneiss and syenite and their gangue to be pyroxene and epidote. From the Helton Creek deposit, according to the author, a coarse-grained, pure magnetite had been taken during a long period. One vein is 9 feet wide and another 18 feet wide. Other deposits occur in the district but they are known only by hand specimens.

The titaniferous ores of Guilford County were described in great detail, much of the description being taken from a report made by Dr. J. P. Lesley for the North Carolina Centre Iron and Mining Company. In this report Lesley refers to the origin of the ores and reaches a conclusion which is opposed to that of Emmons, who regarded them as igneous veins. (See page 24.) Lesley declares (page 241) that:

"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 charged with iron; and they differ from the rest of the rocks only this respect: that they are *more highly charged with iron*. In fact all our primary (magnetic and other) iron ore beds obey this law. They are merely certain strata consisting more or less completely of peroxide of iron, with more or less intermixture of sand and mud, which when crystalized, fall into the shape of feldspar, hornblende, mica, quartz, &c., &c."

The author states that magnetite and titaniferous iron ores were known to occur also in Madison County, but they were not examined.

Within the next few years S. T. Abert[11] in a report to the Chief of Engineers, U. S. Army, made mention of the existence of iron ores in Gaston, Lincoln and Catawba counties and a writer who signed himself N[12] called attention to the construction of a railroad from Johnson City, Tenn., to Cranberry in order to tap the ore at Cranberry for the use of furnaces in Tennessee. He estimated that not more than 50,000 tons had been taken from all the lenses in the vicinity of the village, and advised further exploration. He also noted the presence of other deposits southwest of Cranberry and of a titaniferous ore on Rocky Creek.

In 1883 and 1884 Smock[13] again mentioned the existenceof magnetite in western North Carolina, and in the earlier year the Handbook[14] of the State of North Carolina contained a summary of the State's iron resources. Most of the statements in these articles are repetitions of those published in Kerr's report.

In the Mineral Resources of the United States for the following year, however, J. M. Swank[15] made precise mention of the ore-bank at Cranberry, which he declared had been worked for 100 years to supply bloomeries in the neighborhood. At the time he wrote preparations were being made to ship the ore to distant points and to smelt it in a small charcoal furnace that had been built at the mines. The ore was said to possess "superior adaptability to the manufacture of steel." Several analyses appear in the report, but they are useful at the present time only in showing that the character of the ore produced has remained uniform for 40 years.

[11]Abert, S. T., Examination of Catawba River from South Carolina line to Old Fort, North Carolina. U. S. Army, Chief of Engineers, Report for 1876, pt. 1, pp. 367-376, Appendix O, 1876.
[12]N., Magnetic iron ores of the Unaka Mountains, North Carolina and Tennessee: Eng. and Min. Jour., vol. 25, pp. 272-273, 293-294, 1878.
[13]Smock, J. C., U. S. Geol. Surv., Min. Resources for 1882, p. 715, 1883.
Smock, J. C., Geologico-geographical distribution of the iron ores of the Eastern U. S.: Am. Inst. Min. Eng. Trans., vol. 12, pp. 130-144, 1884; and Eng. and Min. Jour., vol. 37, pp. 217-218, 230-232, 1884.
[14]Handbook of the State of North Carolina, exhibiting its resources and industries. Prepared under the direction of the Board of Agriculture, Raleigh, 1883.
[15]U. S. Geol. Surv., Min. Resources, 1883-1884, pp. 277-278, 1885.

A series of analyses are also appended to an article by Porter[16] on the iron ores and coals of Alabama, Georgia and Tennessee, and some of them are of samples of magnetites collected in North Carolina, among them samples of Cranberry ore and of a titaniferous ore from Roan Mountain. Unfortunately there are no precise locations for most of the samples. While Porter regarded the Cranberry occurrence to be "a great bed" he believed that there are equally large ones in Ashe County and perhaps elsewhere.

Two years later Swank[17] again referred to the "celebrated Cranberry ore" as being well adapted to the manufacture of steel by the acid process, and stated that similar ores occur elsewhere in the western part of the State, and John Birkinbine[18] referred briefly to the Cranberry deposit and to various veins of magnetite elsewhere and quoted analyses by Britton and McCreath of the Cranberry ore and of an average of 23 samples of limonites from the southwestern part of the State.

About this same time appeared the Census Report [19] on the Mining Industries of the United States during the Census Year beginning July 1, 1886. In this report brief descriptions of all the mines in North Carolina and analyses of their ores are given. This report will be referred to repeatedly in the present discussion, partly because it gives us the earliest details we have of the mines and partly because it contains the most complete analyses of the ores that had been published at that time. As it was written when the magnetites were being explored most vigorously it contains much information which would have been lost if not preserved in its pages, because many of the deposits then exposed to sight have since been covered by debris and are no longer available for study.

A few references were made to the ores during the next two years but they added very little to the information given us by Kerr and Willis.

During the course of a trip across the State, Britton[20] visited the Cranberry mine, which he reported to be in rocks that are probably of the same age as those in which the New Jersey ores are found. The ore is described as being in a bed at least 100 feet thick, and as being self-fluxing, probably in consequence of the presence in it of much dark-colored pyroxene. With it is associated some epidote and insignificant amounts of white quartz and calcite, and bands of feldspathic rock. The strata are said to be much contorted.

In the following year were published the notes of a lecture delivered by John Birkinbine[21] on the iron ore resources of the country in which

[16]Porter, J. B., The iron ores and coals of Alabama, Georgia and Tennessee. Iron ores of North Carolina: Am. Inst. Min. Eng. Trans., vol. 15, pp. 190-191, 206, 1886.
[17]U. S. Geol. Surv., Min. Resources, 1886, p. 36, 1887.
[18]Idem., pp. 82-83.
[19]Willis, Bailey, Notes on samples of iron ore collected in North Carolina: 10th Census U. S., vol. 15, pp. 301-329, 1886.
[20]Britton, N. L., Geol. notes in Western Virginia, North Carolina and Eastern Tennessee: N. Y. Acad. Sci. Trans., vol. 5, pp. 215-223, 1887.

he referred to the existence of magnetites in North Carolina and the fact that the first discovery of iron ores in what is now the United States was made in this State in 1885.

The first fairly complete account of the State's iron ores is to be found in the report of Kerr and Hanna[22], published in 1888. In this volume of 359 pages, 64 are devoted to the iron ores. The deposits are discussed by districts as in the first report (see page 24), and each mine that was open at the time the field work was done is described in detail; and in the cases of all important mines the descriptions are illustrated by maps. The character of the ore in each mine is also carefully described with the aid of many illustrations and numerous analyses.

The general discussion of the deposits is identical with that in the earlier report except that Hanna is inclined to think that the ore was not deposited with the original sediments (compare page 26), but was later formed by some metamorphic process. The greatest advance over the earlier report is in the discussion of the individual mines. Each of these is described by name and the manner of occurrence of the ore in many of them is illustrated by figures, some of which are reproduced in the pages following. Many of the descriptions are also quoted in part, so that they will not be referred to at greater length in this place. Numerous analyses enrich the descriptions and render them all the more valuable, since they were in many cases made on fresher samples than it is possible to secure at present. Many of them, however, are reprinted from Kerr's earlier report.

Brief reference is made to large deposits of magnetite in Ashe County, but no detailed description of them is given.

No other descriptions of the ores of North Carolina are met with until the publication of Nitze's report in 1893, but references to them are found in several articles. Whitfield[23] gave a partial analysis of the Cranberry ore. T. S. Hunt[24] referred to the ores of North Carolina in his general description of the iron ores of the United States, and J. M. Swank[25] in his "History of the Manufacture of Iron in All Ages," but both of these writers merely mentioned the Cranberry and some other deposits. Hunt regarded the Cranberry ores and other magnetites in the extreme western part of the State as belonging in his Laurentian series, and believed that the ores and the gneisses with which they are associated were deposited from a great ocean.

[21]Birkinbine, John, The iron ores of the United States: Jour. Franklin Inst., vol. 126, Phila., pp. 196, 198, 1888.

[22]Kerr, W. C., and Hanna, G. B., Ores of North Carolina: Geol. of North Carolina, vol. 2, chap. 2, pp. 125-187, Raleigh, 1888.

[23]Whitfield, J. E., U. S. Geol. Surv., Bull. 60, p. 168, 1890.

[24]Am. Inst. Min. Eng. Trans., vol. 19, pp. 3-17, 1890, and Eng. and Min. Jour., vol. 50, pp. 600-601, 622-623, 1890.

[25]Swank, J. M., Phila. Am. Iron & Steel Assoc., pp. 272-275, 1892.

In 1892 H. B. C. Nitze[26] gave a preliminary account of his work on the iron ores of Ashe County in which he described the main deposits and quoted a few analyses. In the following year he [27] published an advance summary of a study of all the iron ores in the State, and in the same year appeared his full report.[28]

In Nitze's report is given a description of all the iron ore mines and all the undeveloped iron ore deposits within the State. At the time the report was being written access was possible to many deposits that have since been covered so that its pages must furnish us much information that is not elsewhere obtainable. There is very little in the report that was not covered in the reports of Kerr and Hanna and of Bailey Willis, except with reference to the development of the mines, and the composition of the ores. Many new analyses are published and there are given a few geological notes. For the first time the Cherokee County limonites and the Ashe County magnetites are described in detail and their geology outlined. An attempt is made to show that the ores in the crystalline rocks occur in belts that are apparently regarded as representing definite horizons. In Ashe County, for instance, the magnetites are grouped in (1) the Ballou, or River, belt, (2) the Red Hill, or Poison Branch belt, and (3) the Titaniferous belt. There is no general discussion of the origin of the ores, but here and there occur remarks as to the possible origin of individual deposits; but these, as a rule, are taken from Willis's article in the report of the Tenth Census. Repeated reference will be made to Nitze's bulletin in the succeeding pages.

Nothing of importance was contributed to the subject under discussion between 1893 and the appearance, between 1903 and 1907, of Keith's series of folios on the quadrangles in western North Carolina and neighboring portions of Tennessee and Kentucky. References had been made to the iron ores of North Carolina by various writers, but these references were merely interpretations of statements in Nitze's bulletin. Phillips[29] in an article in which he briefly discusses the magnetic concentration of North Carolina magnetites questions the practicability of concentrating them with profit and states that he doubts the value of any of the ores except those in the extreme western part of the State.

In the volume "North Carolina and its Resources"[30] a brief account of the iron ore resources is given, but the material was taken almost without modification, except condensation, from Nitze's bulletin.

[26]Nitze, H. B. C., The magnetic iron ores of Ashe Co., N. C.: Am. Inst. Min. Eng. Trans., vol. 21, pp. 260-280, 1892.

[27]N. C. Geol. Surv., First Biennial Report, 1891-1892, Raleigh, pp. 25-26, 1893.

[28]Nitze, H. B. C., Iron ores of North Carolina: N. C. Geol. Surv., Bull. No. 1, pp. 239, Raleigh, 1893.

[29]Phillips, W. B., North Carolina iron ores and magnetic concentration: Eng. and Min. Jour., vol. 57, p. 490, 1894.

[30]North Carolina and its resources: State Board of Agriculture, Winston, pp. 87-98, 1896.

The serious study of the details of the geology of the magnetite ores began with the appearance of the Federal geologists on the scene, when they undertook to map the quadrangles in which the ore bodies occur.

Keith, as the result of his work in mapping several of the quadrangles in the western part of the State, obtained a general knowledge of the many magnetite deposits occurring in the crystalline rocks and incidentally developed the first precise views that have been published with reference to the origin of the great deposit at Cranberry. These views he gave briefly in the text of the Cranberry folio[31], and again in a special article in a bulletin [32] of the Federal Survey. He described the Cranberry deposit as being one of a series reaching from near Old Fields on the North Toe River, northwestward, through Cranberry to Shell Creek in Tennessee. The line of outcrops lies in the Cranberry granite, and extends in a direction which is nearly parallel to the boundary of the granite with the older Roan gneiss. The ore is said to occur "as a series of lenticular bodies of magnetite in a gangue of hornblende, pyroxene, epidote, with a little feldspar and quartz, and a few unimportant minerals. The ore and gangue occur as a series of great lenses dipping toward the southwest at angles of 45°—50° about parallel to the planes of schistosity in the gneiss (schistose Cranberry granite). The ore is found in the gangue in the shape of smaller lenses, dipping southwest from 40° to 60°." They vary from a few inches to 50 feet in thickness and are from 2 to 5 times as long. Sometimes the lenses have sharp limits, but usually the ore and gangue grade into one another. Moreover ore is sprinkled through the gangue and more or less gangue is scattered through the ore.

The minerals composing the ore and gangue were thought to have been deposited long after the enclosing granite had solidified and indeed later than the deformation that produced its schistosity, since, as he supposed, they "are only slightly crushed or rearranged, although they are the same varieties which, in adjacent formations, show the greatest metamorphism." The ore deposit therefore was believed to be secondary. "It may have replaced a pre-existing 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." The latter result was regarded as unlikely because of the great size of the deposit. It appeared more probable that the ore replaced an igneous, diabase-like mass that intruded the granite. Because diabases elsewhere in the region, though much altered by metamorphosing processes, have not produced ores, the author thought that water charged with mineralizing agents "dissolved and perhaps added to the rock minerals and redeposited them in favorable places, either in the old or in new chemical combinations." The places of deposits were plainly controlled by the schistosity of the granite. In the granite are small veins and stringers of magnetite that may represent deposition from the mineralizing solutions where there was no readily alterable rock, and at other places the gangue minerals and even magnetite are developed in the mass of the red granite along more or less mashed zones. "These perhaps represent the places where alteration was most active; that is to say, the actual channels through which the mineralizing solutions passed."

[31]Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, Cranberry folio (No. 90), p. 8, 1903.
[32]Keith, Arthur, Iron ore deposits of the Cranberry district, North Carolina-Tennessee: U. S. Geol. Surv., Bull. 213, pp. 243, 246, 1903.

Since the magnetite deposits were believed to be younger than the folding movements in the district and the Bakersville gabbro also younger than these movements, and since the magnetite bodies swing around the circumference of areas believed to be underlain by the gabbro in the granite and in the Roan gneiss west and southwest of Cranbery the author was led to suggest that "the magnetites are due to alterations begun by the gabbro intrusions." However, since there are no gabbro intrusions in Ashe County the magnetites in the Ashe County area cannot have been produced by this process. The author thought the iron in this area may have been dissolved from the Roan gneiss through which mineralizing solutions must have passed in more than one epoch.

There is a band of titaniferous magnetite deposits south of the Cranberry belt of non-titaniferous magnetite and parallel with it. "In as much as the two belts are in close proximity and each is extensive without overlapping the other, their depositing solutions were probably active at different times. Still another period of mineralization left its record in the pegmatite veins and lenses so common in this region. These, however, were crushed and distorted during the folding of the strata, and thus are so much older than the magnetite deposits that they can have no origin in common."

In the Asheville folio[33] the author calls attention to the presence of veins of magnetite in granite, mica gneiss, hornblende gneiss, and hornblende-mica gneiss, and states that in most places the ore is associated with a gangue of hornblende, epidote and quartz, as at Cranberry. It is worthy of notice that the magnetite deposits are not limited to the granite areas, as was intimated to be the case in the text of the Cranberry folio.

The magnetites in the Mount Mitchell[34] quadrangle are nearly all titaniferous, but the author does not presume to offer any suggestions as to their origin.

Two years later, in 1907, the three folios on the Nantahala, Pisgah and Roan Mountain quadrangles appeared. In these Keith[35] makes

[33]Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, Asheville folio (No. 116), pp. 9-10, 1905.
[34]Keith, Arthur, U. S. Geol. Sur. Geol. Atlas, Mount Mitchell folio (No. 124), p. 8, 1905
[35]Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, folios 143, 147 and 151, 1907.

in general the same statements with reference to the ores as were made in the earlier folios.

The magnetite deposits in the Roan Mountain quadrangle are described as being in the Cranberry granite near its contact with the Roan gneiss[36]. The statements as to the origin of the ores are the same as in the case of the Cranberry deposit. No special reference is made to the titaniferous varieties.

Two items appeared in 1907, at about the time the last of Keith's folios was issued. In one Eckel[37] remarked that the iron ores of North Carolina are of interest as of possible future use, but, he says, they are not "serious factors in the industry of to-day." He further states that "though deposits of brown hematite are known to occur at various points in North and South Carolina the ores to which attention must be paid in future are the magnetic ores of the western part of both States." Hess[38] in the same volume, calls attention to the richness of some of the North Carolina magnetites in titanium and refers to the deposit north of Lenoir as being composed of menaccanite, magnetite and rutile, stating that it has been used in the manufacture of ferro-titanium. (See page 229.)

Five years later, in 1912, Pratt[39] during the course of a rapid trip through Ashe County examined a number of the old mines and mine openings in the county and published the results of some of his observations. He found the magnetites to be in lenses some of which may continue for long distances along the strike and dip. Others are smaller lenses in series. These are separated from each other by country rock or are connected with each other by thin seams of ore. Some deposits may be so small as to be of no commercial value, while others may be of great size. They lie in hornblende gneisses and schists and in micaceous schists, and are conformable with the country rock in strike and dip.

The deposits are grouped in the three belts of Nitze. These Pratt calls the River belt, the Poison Branch belt and the Helton Creek belt. The most important deposits on each belt are described in some detail, but there are no statements made as to the possible origin of the ores. The details of the descriptions are referred to in the discussions of the various deposits in the body of this report. (pp. 134 to 160.)

The author does not refer to the titaniferous ores of the county.

Finally in 1913 appeared Singewald's[40] report on the titaniferous ores in the United States, in which some of the North Carolina occurrences are discussed with reference to their titanium content. It was inferred from a study by metallographic methods that in most cases the titanium is present as ilmenite, which is intergrown with magnetite, often so intimately that the two minerals cannot be separated by mechanical means at a cost that will allow the purified ore to compete commercially with non-titaniferous magnetite. Later study of thin sections have shown that the titanium is mostly present as rutile instead of ilmenite. In the case of the Guilford County ore, however, observations indicated that the titanium mineral is in very coarse intergrowths, and experiments showed the possibility of the magnetic separation of a product containing such a low content of titanium as to warrant its use in mixtures with titanium-free ores.

Recently several papers by the present writer dealt with the origin of the Cranberry magnetite[41], of the marble-magnetite ore[42] at Lansing, N. C., and of the titaniferous magnetites[43] in the western part of the State, and a fourth paper[44] described briefly the various types of magnetic ores in western North Carolina and East Tennessee. Since most of the material of these papers appears also in the present report, it is unnecessary to refer to them further.

[36]Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, Roan Mountain folio (No. 151), p. 10, 1907.

[37]Eckel, E. C., Iron ores—North Carolina: U. S. Geol. Surv. Mineral Resources, 1906, p.88, 1907.

[38]Ibid., p. 530.

[39]Pratt, J. H., The mining industry in North Carolina during 1911 and 1912, N. C. Geol. and Econ. Survey, Economic Paper No. 34, pp. 64-73, Raleigh, 1914.

[40]Singewald, Jos. T. Jr., The titaniferous iron ores in the United States, their composition and economic value: U. S. Bureau of Mines, Bull. 64, pp. 35, 80, 93, 1913.

[41]Bayley, W. S., The magnetite ores of North Carolina—their origin: Econ. Geol., vol. 16, No. 2, p. 142, 1921.

[42]Bayley, W. S., A magnetite-marble ore at Lansing, N. C.: Jour. Elisha Mitchell So., vol. 37, Nos. 3 and 4, p. 138, 1922.

[43]Bayley, W. S., The occurrence of rutile in the titaniferous magnetite of Western North Carolina and Eastern Tennessee: Economic Geology, vol. 18, No. 4, p. 382, 1923.

[44]Bayley, W. S., General features of the magnetite ores of Western North Carolina and Eastern Tennessee: U. S. Geol Surv., Bull. 735-G, 1922.

PLATE I.

Map showing principal mines and prospects on and near the Cranberry belt, in Carter County, Tennessee, and Avery and Mitchell counties, North Carolina. Geology from Keith's 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, [illegible] 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.

CHAPTER III.

THE ORES

GENERAL FEATURES

The magnetic ores of the district under discussion, as has already deen stated, consist of three kinds: (1) those in which the ore component is magnetite; (2) those in which it is a mixture of magnetite and some mineral containing titanium, and (3) those in which it is a mixture of magnetite and hematite. At present only the non-titaniferous magnetites are of economic importance, although at once time the titaniferous ores were mined and formed the main supply for some of the forges in North Carolina. It was believed that they might furnish the principal source of iron for the eastern United States. However, with the introduction of modern methods of smelting, the value of the titaniferous ores diminished until in the latter portion of the last century all the openings into the deposits of these ores were abandoned. The magnetite-hematite ores have never been exploited. So far as is now known, their deposits are comparatively small and they are so far from railroads that the cost of getting them to the furnaces is prohibitive. Nevertheless, since the titaniferous and the hematitic ores constitute reserves of potential value, it is desirable to discuss them in some detail.

Both the magnetites and the titaniferous magnetites are alike in general appearance and in their occurrence as lenses and veins in gneisses, schists and other crystalline rocks. Those in the mountain districts are associated with Archean country rocks. The country rocks associated with the deposits in the Piedmont area are quartzites, marbles, micaceous schists, slates, gneisses, and old volcanic lavas and tuffs which are younger than Archean, but probably older than Cambrian.

Nitze[45] in his discussion of the magnetitic ores in North Carolina described them as occurring in belts, inferring that they are distributed along continuous lines. This inference may be correct in a broad way, i. e., the deposits are usually in zones parallel to the general structure of the region, but in a narrower sense they are in short discontinuous lines or series of parallel lines that may be close together in some places and widely apart in others.

In some places the deposits are actually in line with one another, when they are situated along a zone of weakness in the country rock, usually a zone along which the schistosity is more pronounced than elsewhere. (See Plate I and Figures 13, 16 and 17.) In other places they are in schistose zones but not in the same plane. In these places the zone itself consists of a series of planes along which marked schistosity has taken place, but the loci of maximum weakness are not always

[45] Nitze, H. B. C., Iron ores of North Carolina: N. C. Geol. Surv. Bull. No. 1, pp. 239, Raleigh, 1893.

in the same plane. The deposits may be 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 projection of their strikes are parallel.

The magnetite-hematite ores are not so well known as the magnetites and the titaniferous ore, and their method of occurrence has not been so carefully studied. They consist of mixtures of magnetite and hematite in widely different proportions. They vary in appearance from flinty, purple, dense, vein-like masses to fine granular and micaceous aggregates, resembling the specular hematites of the Lake Superior region, that seem to lie in beds, interlayered with igneous rocks that are believed to be Algonkian volcanics.

MAGNETITES

The magnetite ores include those magnetic iron ores in which titanium is present in such small quantity as to give practically no trouble in the blast furnace. They occur as lenses or veins in the old crystalline rocks of the Mountain district in North Carolina and East Tennessee and of the Piedmont district in North Carolina. (See Plate I and Figures 13, 16 and 17.) Though associated with large quantities of hornblende, they are not accompanied by basic intrusives as is the case with the titaniferous types, but are rather characterized by the presence near them of pegmatites.

The magnetite deposits have furnished most of the ore that has been mined in North Carolina. Some of them were worked as early as 1802 for use in Catalan forges. The famous Cranberry ore which is a non-titaniferous magnetite produces iron exceptionally low in phosphorus, and for this reason supplies a demand that cannot be as well supplied by metal from any other source. All the magnetites in the district fall within the Bessemer limit and most of them well below it.

All the magnetites, as has been said, occur in old crystalline rocks. Most of them are in granites and crystalline schists. These are referred to as the siliceous type. Those in the Piedmont district are in crystalline schists associated with quartzites. These also are of the siliceous type. One deposit in Ashe County, and perhaps several others, is in marble. This is referred to as a marble-magnetite ore.

The first type is the usual one for the district. It consists essentially of a mixture of hornblende and magnetite, often cut by small veins of nearly pure magnetite, or of a mixture of magnetite, hornblende and epidote, which occurs in a more or less distinct vein following the obscure schistosity of granitic rocks or the more evident structure of schists.

The second type consists of granules and small lenses of magnetite in a white marble. It is represented by a few deposits near Lansing, one of which is being worked by the only active mine in the county.

CHAPTER IV.

SILICEOUS MAGNETITES

CHARACTER

Under the name siliceous magnetites are included those non-titaniferous magnetic ores that occur associated with siliceous rocks to distinguish them from those that are associated with marble. They constitute by far the greater portion of the iron ores that are in the pre-Cambrian areas, and those of greatest value per unit, since they are nearly free from phosphorus and sulphur. Unfortunately most of them are found in comparatively small deposits and the magnetite in them is so intimately mixed with silicates that some form of beneficiation must be applied to them before they are fit for the furnace. As taken from the ground they are low in iron, except in a few cases, but when concentrated they furnish an ore that is in great demand for special purposes.

Because of their differences in character and associations the deposits in the Mountain district and in the Piedmont Plateau are discussed separately. The most striking difference in the two groups of deposits is the association of epidotized pegmatites with the mountain magnetites and of talcose schists with those occurring in the Piedmont area.

DEPOSITS IN THE MOUNTAIN DISTRICTS

GEOLOGY

The rocks of the Mountain district are crystalline schists, gneisses and igneous rocks sharply infolded with conglomerates, shales, sandstones, limestones, and one layer of amygdaloidal basalt. These in places, are metamorphosed to slates, quartzites, marbles and various sandy schists. The sediments are believed to be of Cambrian and Ordovician age. They are intersected here and there by diabase dikes. (See Plate I.) The schists, gneisses and granites are pre-Cambrian.

Since the ore veins are not known to occur in the Cambrian or Ordovician rocks, attention need be directed only to those of pre-Cambrian age.

Keith[46], who has mapped nearly all of the area with which we are concerned, concludes that the sequence of the pre-Cambrian formations in the Cranberry area is as follows:

[46]Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry (No. 90), Asheville (No. 116), Greeneville (No. 118), Mount Mitchell (No. 124), and Roan Mountain (No. 151), folios, 1903-1907.

Generalized table of pre-Cambrian rocks in the Cranberry area

CAMBRIAN

ALGONKIAN

Metarhyolite	Grayish metarhyolite and rhyolite porphyry.
Flattop schist	Gray and black schist, proably altered andesitic rocks.
Montezuma schist	Blue and green epidotic schist, probably altered basalt, and amygdaloidal basalt.
Linville metadiabase	Altered greenish diabase and gabbro.

ARCHEAN

Igneous Rocks

Beech granite	Coarse, reddish or porphyritic light granite.
Blowing Rock gneiss	Chiefly dark, coarse, porphyritic gneiss.
Cranberry granite	Mainly granite and granite-gneiss.
Soapstone, serpentine and dunite	Soapstone and serpentine altered from peridotite and pyroxenite.
Roan gneiss	Chiefly hornblende gneiss and diorite.

Metamorphic rocks of unknown origin

Carolina gneiss	Mica gneiss and mica schist, of unknown origin. Includes also other gneisses and schists and various igneous rocks and small lenses of marble.

In addition there are small areas underlain by gabbroitic rocks which Keith regards as Triassic, but which, for reasons that will be disclosed later (pages 41 to 44), are now considered as a portion of the Roan gneiss series or perhaps as equivalent to the meta-gabbro which Keith[a] has differentiated from the Roan gneiss on the map of the Asheville quadrangle, but which he thinks "was probably formed at about the same age as, or perhaps slightly later than, the Roan gneiss."

In the other quadrangles the variety and succession of formations is very much the same as in the Cranberry quadrangle, except that in some of them a few more granites have been differentiated and given distinct names.

These rocks are folded into a complicated series of sharp anticlines and sÿnclines, the outcrops of which cover irregularly shaped areas with a strong tendency to a NE.-SW. elongation. In many places the formations appear on the surface as narrow parallel bands more or less curving, but having a general NE.-SW. trend. (Compare map, Plate I.) In other places the granites and the Roan gneiss occupy broad areas, but they enclose narrow bands of other formations which have the usual trend.

[a]Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, Asheville folio (No. 116), p. 3.

In addition to folding, faulting is also an important structural feature of the pre-Cambrian rocks, though it is not as apparent as in the Cambrian and Ordovician sediments where disturbance of the known orderly alternation of beds is easily detected. Faults can be easily recognized when they occur at the contacts of the pre-Cambrian and the Cambrian areas, but within the pre-Cambrian areas they can be seen only under very favorable conditions. The fault planes strike in the same direction as the folds, i. e., usually NE., and dip to the southeast.

All of the pre-Cambrian rocks are also strongly schistose, as the result of movements developed during the folding and faulting of the district. The strike of this schistosity is approximately parallel to the strike of the fold in which the rocks are involved, being straight where the axis of the fold is straight and curved where the axis is curved. For the most part the strike is to the northeast, which is the strike of the most numerous folds, and the direction of the trend of the narrow areas of the different rocks exposed on the surface. Where the folds curve, the strips of exposed rock also curve and their strikes curve correspondingly. Since the schistose planes are planes of weakness in the rocks exhibiting schistosity, it is plain that intrusions into them of any kind, whether of dikes or veins, will tend to follow these planes rather than cut across them, provided the intrusion was made after the schistosity was produced. It is for this reason, probably, that all, or nearly all, the ore veins of the district follow the schistosity of the rock in which they occur, and extend in the direction of the structure of the country.

The only two formations that need further descriptions than the brief ones given in the table above are the Roan gneiss and the Cranberry granite. Both formations are complex in that they consist of a series of rocks rather than a single rock. The members of each formation, however, resemble each other much more than they do any of the members of the other formations. The Cranberry granite is a series of light colored acid gneisses and the Roan gneiss a series of dark colored basic gneisses.

ROAN GNEISS

The Roan gneiss, according to Keith, "consists of a great series of beds of hornblende gneiss, hornblende schist, and diorite with some interbedded mica schist and mica gneiss. The hornblendic beds are dark greenish or black in color, and the micaceous beds are dark gray." The micaceous beds range in thickness from a few inches to 50 or 60 feet and they are abundant near contacts with the Carolina gneiss, where their presence is explained as due either to intrusion of the Carolina gneiss by dikes of the magma that produced the beds of the Roan gneiss, or to the infolding of layers of the former with the latter.

The hornblendic members of the series range from an inch or two to thousands of feet in thickness. Hornblende schist makes up a large part of the series. It consists almost entirely of hornblende with a very little biotite, feldspar and quartz, and is interbanded with the hornblende gneiss, which is said to differ from the schist in being interlayered with sheets of quartz and feldspar. Beds of coarse diorite or gabbro are also common at some places, and these are also interlayered with the schists and gneisses. It is probable that the formation was originally a series of interlayered gabbros, diorites and perhaps other intermediate and basic rocks which became metamorphosed by deformation processes and had produced in them a complete recrystallization of their components into new ones. Garnet was a common product of this process, so that many of the gneisses, schists and more massive, dioritic beds are now full of little crystals of this mineral. Excellent exposures of the series are to be seen on the Carolina, Clinchfield and Ohio Railroad between Forbes and Toecane and in the cuts on the East Tennessee and Western North Carolina Railroad one mile south of Cranberry.

About three-quarters of a mile east of Forbes in Mitchell County, N. C., is a cut through a diabasic rock that weathers to great nodules. Beyond this to the east are black gneisses and beyond these are exposures of a fine grained purplish-black, very slightly schistose rock that appears to be a sill in the more schistose gneisses.

The diabasic rock now consists of large broken plagioclase crystals, enlarged at their ends by the addition of new feldspar, lying in a matrix of calcite, serpentine, amphibole, biotite, chlorite, epidote, quartz, magnetite, and here and there remnants of pyroxene. The grouping and distribution of these secondary minerals suggest an origin from an olivine diabase.

The purplish-black sill in the gneisses is very much like the sill-like mass on Roaring Creek (page 218), which is also mapped by Keith (in the Roan Mountain folio No. 151) as Roan gneiss. The rock is composed mainly of a medium-grained granular aggregate of fresh and compact green hornblende, fresh striated and unstriated feldspar, quartz and lenses of granular garnet. Scattered among these are comparatively large flakes of reddish-brown biotite, numerous small grains of magnetite and large and small nests of calcite. The larger grains exhibit a slight tendency to elongation in a common direction. The small grains, however, are not noticeably elongated, but they are often grouped into little lenses that have a common orientation, causing the rock's schistosity. This is particularly noticeable in the case of the garnet, which is in very much elongated lenses composed of many little round grains of colorless garnet, numerous grains of quartz, small particles of magnetite and a few flakes of biotite. Little nests of calcite are scattered throughout the rock, but they are larger and more abundant near the garnets than elsewhere. Thin sections of the gneisses differ from those of the more massive layers in containing much more quartz and often much more brown biotite.

The interlayering of the massive and schistose beds is well exhibited in the railroad cut south of Cranberry. Here there are hornblende schists, amphibolites, garnetiferous hornblende gneisses and massive gabbroitic rocks. The schistose rocks consist of green amphibole, plagioclase, brown biotite and quartz in widely varying proportions together with small quantities of epidote, sphene, apatite and ilmenite. Garnet is abundant in some specimens and is entirely absent from others. It is nearly always present where the rock shows evidence of being crushed. Nearly all plagioclase grains are granulated on their edges, or are shattered, and many grains show curved twinning striations. New feldspar in small grains is often found with granular green hornblende making a groundmass in which remnants of the original feldspars are embedded. In some specimens the diabasic texture can be recognized, even in distinct schists. In other specimens the entire rock is made up of small granules of amphibole, feldspars and quartz. All the amphibole-plagioclase schists and granites are believed to be sheared diorites, diabases, or gabbros.

A few schists are now composed of green amphibole, quartz and fresh untwinned feldspar and others of reddish-brown or green biotite, quartz and feldspar. In some of the biotite schists the biotite is in large flakes as in an ordinary biotite schist and in others is limited to the crush debris between quartz and feldspar. In the crush debris it occurs as comparatively small wisps. It was evidently a metamorphic mineral formed while the rock was being crushed. The original form of the richly micaceous schist is not known. It may have been a mica diorite.

BAKERSVILLE GABBRO

The "Bakersville gabbro" which is mapped as occupying a small area south of Cranberry is described by Keith[48] as being in a rudely lenticular mass lying along the foliation planes of the Roan gneiss. He states that it exhibits no evidence of dynamic metamorphism, although the surrounding rocks are all metamorphosed, in many places to an extreme degree. Consequently, he concludes, it must have been intruded into the Roan gneiss after the last deformation of the region and therefore must be younger than the end of Paleozoic time. Since it is thought to be similar in general character to the Triassic diabases and gabbros of the Piedmont Plateau area, he assigns it to this age. However, in the text of the Asheville folio[49], he describes a "very basic rock

[48]Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, Cranberry folio (No. 90), p. 5, 1903.
[49]Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, Asheville folio (No. 16), p. 3, 1904.

of the same general appearance as the massive portions of the Roan gneiss, but . . much less schistose and gneissoid," which in places is speckled with garnets, and states that it "was probably formed at about the same age as, or perhaps slightly later than the Roan gneiss." He designates it as a "metagabbro." The Bakersville gabbro is identical with the "metagabbro" in general appearance, and if the latter is pre-Cambrian in age, the former is also. The "Bakersville gabbro", according to Keith, is a dense, dark rock which on weathered surfaces has a reddish-brown or rusty appearance. Its texture is said to be massive and granular in most specimens, but to be ophitic in a few. Plagioclase occurs sparingly in porphyritic crystals and garnet is common.

All the varieties of the Bakersville gabbro described by Keith as occurring in the area south of Cranberry were observed by the writer and in addition several others. One was a porphyritic variety with numerous phenocrysts of plagioclase an inch in length. In some places fine-grained black schists are interleaved with the more massive metagabbros. In some places the lower portions of the massive layers grade into schistose phases, but it was not certain that the schists were made from the massive phases by shearing.

In the field the massive beds showed no evidence of having been subjected to dynamic metamorphism, in spite of the fact that there had been developed in them great quantities of garnet. When, however, their thin sections are viewed under the microscope it is very apparent that none of them have escaped metamorphism. All are full of metamorphic minerals and all exhibit more or less clearly signs of crushing. In some of them there remain a few remnants of augite in the midst of an aggregate of grains of green hornblende, but in most there is no trace of pyroxene remaining. The rocks now consist of plagioclase, green hornblende, and a little quartz, biotite, sphene, epidote, ilmenite or magnetite and calcite. In some specimens is a little tourmaline and in others some corundum.

The plagioclase is fractured and in some instances its twinning bars are curved and numerous grains show a wavy extinction. Frequently the edges of crystals are granulated and in some cases what were originally phenocrysts of plagioclase are now aggregates of striated and unstriated feldspar grains, a few grains of quartz, a few or many wisps of brown biotite and an occasional crystal of garnet. The hornblende is in masses of small, closely crowded granules, in some places intermingled with granules of quartz and unstriated feldspar, and in others cemented by feldspathic material which, in the section, is continuous over comparatively large areas. In most cases the hornblendic and feldspathic portions of the sections suggest a diabasic texture, but in other cases the original texture appears to have been granitic.

Most specimens contain also garnet in addition to the minerals already mention d. In some the garnets are in the form of crystals

PLATE II.

(A)

(B)

(A) Photomicrograph of Bakersville gabbro, near Cranberry, N. C. Area enclosed in dotted line is garnet. Black is magnetite and gray hornblende. The smaller white areas are fresh feldspar and quartz, the larger white areas in upper part are epidotized plagioclase. Ordinary light. X50.

(B) Photomicrograph of ore from Peg Leg mine, Carter County, Tenn. Black is magnetite and gray pyroxene with some uralite. The white areas in the magnetite are holes, those in the pyroxene are granular quartz. Ordinary light. X30.

of the same size as the other rock constituents and are scattered irregularly among them, but in most specimens they are in large grains many times larger than any other component except the feldspar phenocrysts. (Plate II, *A*.) All the garnets have the sieve structure which is indicative of metamorphic origin. In some specimens brown biotite is abundant and amphibole is present. In these quartz is more common than in the hornblendic phases.

In nearly all sections there can be detected crush zones, in which all the components are in small grains forming a schistose mosaic containing more biotite than is present elsewhere in the sections.

An analysis of a non-garnetiferous variety with a diabasic texture from Cranberry Creek, made by Dr. J. I. D. Hinds of the Tennessee Geological Survey, gave:

Analysis of "Bakersville gabbro" from near Cranberry, N. C.

Silica (SiO_2)	46.80
Alumina (Al_2O_3)	16.65
Ferric oxide (Fe_2O_3)	13.52
Ferrous oxide (FeO)	5.04
Magnesia (MgO)	4.01
Lime (CaO)	8.32
Soda (Na_2O)	2.86
Potash (K_2O)	.80
Phosphorus pentoxide (P_2O_5)	1.41
Water above 110°	.50
	99.91

This corresponds to a hessose in the chemical classification. It is a metadiabase in the more familiar classification. Other specimens would give other results, but all the massive beds in the series would probably be proven by analysis to have the chemical compositions of gabbros, diorites or diabases.

From the microscopic study of sections it has been learned that all of the massive rocks in the "Bakersville gabbro" area are similar to the massive beds in the Roan gneiss series. They have suffered the same kind of alteration as the beds in the Roan gneiss and have suffered the same degree of metamorphism. They cannot be regarded as unmetamorphosed Triassic rocks. They must be regarded as a part of the Roan gneiss series, and probably as equivalent to Keith's metagabbro of the Asheville area.

CRANBERRY GRANITE

Keith[49] writes that the Cranberry granite formation "consists of granite of varying texture and color, and of schists and granitoid gneisses derived from the granite. Included in the formation are small or local beds of schistose basalt, diorite, hornblende schist and pegmatite . . . The granite is an igneous rock composed of quartz and orthoclase and plagioclase feldspar with biotite, muscovite and occasionally hornblende as additional minerals." It is described as varying from a fine, even-grained mass to a coarse porphyritic phase. It suffered great changes during the deformation of the region which resulted in the production of schists and gneisses with a fairly uniform dip over large areas. "The results varied in extent from rocks with no change . . . to those completely altered into siliceous schists and gneisses . . . Thin parallel layers and striations composed of different minerals are of frequent occurrence, and the most extreme schists bear no resemblance to the original rock."

[49] Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, Cranberry folio (No. 90), p. 3, 1903.

Detailed examination of the Cranberry granite in the area around Cranberry proves conclusively that the formation is complex. Its greater part consists of granite, gneiss and schists like those described by Keith, but in addition there are present other schistose members which cannot be regarded as sheared phases of the granite.

The ore vein at the southeasternmost opening of Smoky Mountain (Smoky No. 1) at Cranberry is in Cranberry granite. On the hanging, or southwest wall, the granite is platy and is foliated with layers of hornblende gneiss and with others of a fine-grained light-colored gneiss that looks almost like a flow rhyolite. The whole is puckered and folded. (Plate XVI, *A*.) As the distance from the contact with the vein increases the inter-foliated gneisses apparently become less abundant and the light-colored, coarse-grained granite becomes more homogeneous and less schistose, though it still exhibits schistosity several hundred yards from the contact. Certain ledges, however, show a porphyritic granite which in many places is sheared to an augen-gneiss. The foot-wall rock is not visible, but it is known that it also consists of Cranberry granite.

The fine-grained, thinly banded light-gray rock near the contact that has been referred to as resembling a rhyolite, when studied in thin section is found to be schistose and minutely contorted. It is so thoroughly crushed that little of its original structure remains. It consists now of streaks of a very fine mosaic of elongated quartz, orthoclase and epidote grains with here and there little wisps of muscovite which curve around comparatively large fragments of plagioclase, mainly oligoclase, that suggest shattered phenocrysts. In some instances the large feldspar fragments are crushed into numerous small ones forming an aggregate of the same form as the original fragment. Orthoclase is present in small quantity in the enveloping mosaic and to some extent as larger fragments, but it seems to have suffered more decomposition than the plagioclase and is difficult to identify.

Specimens taken from points farther from the contact are not so thoroughly crushed. The epidote is confined to grains of plagioclase, and is not a component of the mosaic enveloping the feldspar. The mosaic is here mainly quartz and feldspars with a few flakes of biotite.

Still farther from the contact the feldspar is in larger fragments, some of which appear to be phenocrysts that have been merely abraded on their corners. Many of these have been enlarged by the addition of microcline, and some of the same mineral has apparently developed in the crush mosaic of feldspar and quartz. Biotite is a little more abundant in the sections examined, but is not common. Epidote is absent, except in an occasional nest of grains in certain streaks through the mosaic where the crushing has been especially thorough.

Throughout all the sections there has been considerable regeneration of feldspar and quartz. Fresh microcline and fresh plagioclase are quite common in the interstices between the elongate grains of the mosaic and fresh clear microcline not only surrounds the large cloudy plagioclase fragments, enlarging them, but it also saturates their masses.

These rocks are very much like specimens of the lighter colored phases of the Cranberry granite elsewhere. For instance at the top of Smoky Mountain, southeast of the Smoky No. 1 opening, light and dark gneisses are interlayered. In thin section the lighter rock is seen to be crushed in the same manner as the rock near the opening. There are large fragments of orthoclase and plagioclase, and lenses with plagioclase nuclei, surrounded by a mosaic of quartz and feldspar with an occasional biotite flake, running through which are streaks of muscovite fibers and of a fine quartz mosaic. Epidote in grains and short prisms and in nests of grains are scattered through the mosaic, and in many instances the larger quartzes of this mosaic exhibit strain shadows. In other places the light-colored gneisses resemble crushed rhyolite. They all contain a little magnetite in small grains and more or less epidote which has evidently been derived from plagioclase. The epidote that is in nests is probably the alteration product of grains of plagioclase that are in their original position; the grains and short prisms are particles that have been intermingled with other components of the mosaic by movements in the rock mass.

Some of the layers are entirely different from the fine-grained varieties that have been described, though nearly all show that they have been crushed and sheared. In most cases these processes have resulted in a fine-grained and banded schist retaining very little evidence of its original structure. In other cases the crushing is less complete and the rock is now a coarse-grained gneiss. Such a rock occurs on the road running south of Shell Creek, Tenn., where there is a coarse-grained biotite gneiss streaked with pegmatite. Under the microscope this rock is seen to have been subjected to strong stresses, as almost every grain of its quartz exhibits strain shadows. Orthoclase, microcline, oligoclase, and other undetermined plagioclase are abundant.

Quartz is subordinate. The dark components are brown mica, partially changed to light-green amphibole, and a small quantity of additional green amphibole that appears to have been derived from a more compact amphibole or from pyroxene.

The Cranberry granite is evidently a crushed and sheared complex of acid feldspathic rocks varying in composition to some extent, though perhaps not widely. Their layering may be an original structure or, as is more probable, it may be a secondary result of shearing. In some cases the alternation of darker and lighter layers is due to the intrusion of feldspathic veins, perhaps pegmatites, along their schistose planes, but in other cases it seems to be the result of shearing in a nearly homogeneous rock.

With the light-colored layers, which constitute by far the larger part of Keith's Cranberry granite, are also much more basic layers. Most of these are regarded by Keith as portions of the Roan gneiss which have been intruded into the Cranberry granite, since they are much more common near the borders of the granite areas than in their interiors. The few specimens seen by the writer have suffered less profound crushing than have the specimens of the granite that have been studied, but this may not be a general fact. In the very few thin sections examined the dark layers, while now very largely amphibolites or hornblende schists nearly all retain traces of a gabbroitic or a diabasic structure.

Farther south, near the crest of Smoky Mountain the formation consists of coarse-grained and fine-grained light rocks and fine-grained dark rocks interlayered, with here and there layers of coarse pegmatite. Some of the fine-grained light rocks are very much like the rhyolite referred to above in the description of the hanging at Smoky No. 1. Although only small exposures can be seen, nevertheless the impression is unescapable that what Keith calls the Cranberry granite is an intrusive in a series of basic gneisses and schists. In other words, the impression gained from a study of the Cranberry granite area is to the effect that we have here a repetition of the conditions that prevail in the magnetite district in the highlands of New Jersey, where a series of dark femic gneisses and schists—known as the Pochuck gneisses—were intruded parallel to their schistosity by alkalic granites—the Losee and Byram gneisses.

RELATIONS BETWEEN ROAN GNEISS, CRANBERRY GRANITE AND OTHER ROCKS

The oldest rocks in the mountains are interbedded mica schists, mica gneisses and fine-grained granites which are grouped together under the name Carolina gneiss. They are regarded as the oldest because very widely distributed in such a way as to suggest a mass into which all the more distinctly igneous rocks appear to be intruded. "The

Roan gneiss appears to cut the Carolina gneiss, but the contacts are so much metamorphosed that the fact cannot be proved. The narrow dikelike beds of the former in the latter support this view, as well as the fact that the diorites are less altered than the Carolina gneiss and so appear to be younger. Moreover, narrow beds of diorite and hornblende-gneiss entirely similar to these cut the Carolina gneiss in adjoining areas toward the south."[31]

The Roan gneiss is believed to be older than the Cranberry granite because, although the prevalent metamorphism of the region and the heavy forest cover make it difficult to obtain precise evidence of eruptive contact with the adjoining formation, such contacts as can be seen show that the granite clearly cuts into the Roan gneiss and the Carolina gneiss. If the cutting granite is the same as that constituting the greater part of the Cranberry granite formation, this formation on the whole must be younger than the Roan gneiss.

All the other formations, except the soapstone, intrude the Cranberry granite or intrude rocks that in turn cut the granite, and are thus regarded as younger than the granite.

The soapstone formation occurs in numerous rather small areas scattered through the areas occupied by the other rocks and is of little importance in connection with the non-titaniferous magnetite ores. The formation comprises peridotites, dunites and their alteration products, serpentine and soapstone. Keith declares that the members of the "formation break through and across the Roan gneiss and in some places are found as inclusions in the Cranberry granite. Consequently the formation is concluded to be of intermediate age between the gneiss and the granite, although it is not markedly schistose. It is possible, however, that the peridotites and dunites may be much younger than the Roan gneiss and that the supposed inclusions in the Cranberry granite may be intrusions into the granite rather than inclusions. If this is so the soapstone may be even much younger than the granite.

ORE VEINS

VEIN-FILLING

The ores of all the deposits in the Mountain district 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 where it occurs, is an alteration product of plagioclase. These rather low grade ores occur in veins from a few inches to many feet wide traversing gneisses or gneissoid granites parallel to their schistosity. Most of the veins dip at high angles. In many places they swell into lenses several hundred feet wide and in others pinch to very narrow streaks.

[31] Keith, op. cit., p. 2.

Polished surface of portion of vein-filling, Cranberry mine, Cranberry, N. C., showing interlayering of ore and gangue. The darkest bands are hornblende, the mottled black and gray ones layers of hornblende and magnetite intermingled (ore), the dark gray ones mixtures of hornblende and epidote, the light gray epidotized feldspar, and the white ones quartz veins. (Natural size).

The richer portions of the veins, constituting the merchantable ore, occur as irregularly shaped masses cutting through the leaner vein matter and swelling into lenses, that are usually joined by streaks of rich ore. No general statements can be made as to the relation between ore and vein matter that will apply to all deposits, since in most places these relations can not be studied because of the very slight development of most of the deposits. Only in the deposit at Cranberry in Avery County, N. C., has extensive underground work been done, and, consequently, nearly all statements concerning the nature of the ore and of the vein-filling and the relations of these to one another, must be based on observations made at the Cranberry mine, and all conclusions as to the origin of the ore must be founded on the facts noted in this mine. There is no reason to suppose that the other magnetite deposits in the Mountain district are any different from that at Cranberry either in character, associations or origin, and, consequently, they are all grouped together as similar. Only the deposit at Cranberry has been studied in detail.

The veins in which the ore occurs comprise more or less banded mixtures of pegmatite, epidotic gneisses, hornblende schists and lenticular masses of a mixture of hornblende and magnetite, in places cut by small veins of magnetite. (See Plates III, IV and V.) The mixtures of hornblende and magnetite constitute the lean ores and when cut by veins of magnetite the rich ores. In a few places the magnetite veins are thick enough to furnish fragments that can be picked by hand from the run of mine and saved for high-grade ore.

The veins extend for variable distances. At Cranberry the vein has been traced continuously for 6,400 feet and that on the Ballou property in Ashe County, N. C., for at least half a mile. In most places the veins are located by but few exposures and a very few openings, so that their lengths are undetermined, but usually the exposures and openings are in lines following the schistosity of the rocks in which they occur, so that whether the individual veins are long or short they occupy zones which are narrowly limited in width and which in some cases are several miles long. The zone in which the Cranberry vein is situated is at least 25 miles long. So far as is now known all the veins follow the structure of the country, which is the same in direction as that of the schistosity of the rocks. They appear to be much more common in the gneissoid granites than in the schists of the region, but this seeming preference for the granite may be due to the fact that most of the veins that have been studied are in Mitchell, Avery and Ashe counties where the Cranberry granite or a closely allied gneiss is the pre-Cambrian rock that is most widely exposed.

Polished surface of portion of vein-filling, Cranberry mine, Cranberry, N. C., showing association of ore with hornblende. The light bands are epidotized pegmatites, the black mineral is hornblende, and the gray one, in the lower part of the figure, is magnetite. The mixture of magnetite and hornblende is the ore. At the bottom of the figure is a small bit of epidote-hornblende gneiss. (Natural size.)

THE ORE

The ore is a mixture mainly of magnetite and hornblende with minor quantities of quartz, epidote, feldspar, garnet, calcite and a few other substances. A small quantity of the contents of the veins may be hand-picked and shipped as good ore, but most of the material that can be mined economically is comparatively low-grade, containing about 40 to 42 per cent of iron. The larger portions of the veins are too low-grade to enter the furnace and must be concentrated before it can be used.

Since the Cranberry mine is the only mine operating on the siliceous magnetites its ore must serve as a sample of the ore of the district. In 1892 the crude ore taken from the mine analyzed as in column 1, and after hand-cobbing as in column 2. A representative analysis of cobbed ore, selected by the chemist of the Cranberry Furnace Company, is shown in column 3.

Analyses of crude and cobbed ore, Cranberry mine, Avery County, N. C.

	1	2	3
Silica (SiO_2)	20.97	20.74	23.50
Alumina (Al_2O_3)	.....	1.55	.....
Iron (Fe)	45.93	48.57	46.55
Manganese (Mn)	.31	.....	.46
Copper (Cu)	.....	.....	.004
Lime (CaO)	10.10	8.01	8.94
Magnesia (MgO)	1.43	1.74	1.68
Sulphur (S)	.02	.....	.041
Phosphorus (P)	Tr.	.0093	.0068
Titanium dioxide (TiO_2)	.....	.....	.039

Formerly the ore was concentrated by electro-magnets, but the process employed was not satisfactory and it was abandoned. In 1920-21 the ore was shipped direct to the furnace. This, however, resulted in such a large loss of material that measures are being taken to develop a cheap and efficient method of concentration that will save much of the magnetite in the crude ore that is now being wasted.

A selected sample of the Cranberry ore was analyzed by Mr. J. G. Fairchild of the U. S. Geological Survey with the result shown on page 102. There was in it no V_2O_3, Cr_2O_3, BaO, SrO, or F. An analysis of a selected sample of the Peg Leg ore (page 127) gave similar results. Both analyses showed small quantities of MnO and of TiO_2. They differ from analyses of the magnetite from the gneisses in New Jersey in showing less TiO_2, no V_2O_3 and no F.

The ore from different portions of the veins presents different aspects. The greater part consists mainly of hornblende and magnetite, but in a few places pyroxenic ores are found and in other places ores containing large quantities of garnet.

One type of ore is represented by that of the Kirby mine in Ashe County, N. C., and of the Peg Leg mine in Carter County, Tenn. These

Polished surfaces of two specimens of pegmatite and ore, from vein at Cranberry mine, Cranberry, N. C. The white is feldspar partially epidotized (light-gray), the black is hornblende, and the dark gray magnetite. The magnetite is always intimately associated with the hornblende. The mass in the lower left-hand corner of both specimens is 'rich ore.' In the lower specimen extensions of the hornblende-magnetite mixture appear to have penetrated the pegmatite. (Natural size).

ores consist mainly of green pyroxene and magnetite—the former in large anhedrons that often possess smooth curved boundaries. (See Plate II, *B*.) They are slightly pleochroic in green and yellowish-green tints and are crossed by many cleavage cracks, by the diallage parting and by many irregular fractures that are filled by quartz and calcite. The magnetite is in irregular masses between the pyroxene grains. Where magnetite is not present its place is taken by quartz or by quartz and calcite together with a few fibers or wisps of uralite, and an occasional grain of epidote, all of which appear to be secondary. In the Kirby mine ore the pyroxene encloses a series of very fine needles and plates, like the rutile needles and plates often observed in the augitic component of basic igneous rocks. In this ore the magnetite and pyroxene are cracked, as in the ore of the Peg Leg mine, but the cracks are filled with veins of a mixture of granular epidote, magnetite and a little uralite.

In the second type of ore hornblende and magnetite are the most prominent components. Usually the two are uniformly intermixed, but in some cases the magnetite is scattered as tiny grains through the hornblende (see Plate V), and again it occurs as little streaks (see Plate IV) and lenses in the midst of a granular hornblende aggregate (see Plate VI, *A*.) As the ore becomes richer in grade the magnetite is seen to become more and more abundant and the hornblende naturally less abundant until in the richest ore of this type the mass is a fine-grained aggregate of magnetite grains 1 mm. and less in diameter, with here and there a grain of hornblende, a rare grain of epidote, an occasional grain of quartz and little nests of calcite. A few white sugary quartz veins run through the mass and there is in it a very obscure schistosity. In many cases where the schistosity is a little more marked than elsewhere the more highly emphasized structure appears to be due to magnetite which is much more abundant in certain layers than others—either as many little lenses embedded in sparse hornblende or as numerous grains that are scattered through the hornblende in some layers, while entirely absent from other layers.

Where the ores are layered all the components are elongated in the same direction as the layering. This emphasizes the schistosity produced by the concentration of the magnetite in definite layers. The magnetite is in long, thin, ragged pieces, many of which are fractured, and in small grains which in most cases look as though they had been broken from the larger ones. The mass in which the magnetite is embedded is a very schistose matrix of uralitic hornblende, wisps of brownish-green biotite, and a little calcite and quartz. (Plate VI, *B*.) The quartz and some of the calcite are in veins that extend in the direction of the schistosity, and in the few sections studied the calcite veins are in the layers in which the magnetite is most thickly concentrated. Calcite is also scattered through the entire section, but it is more abundant and

(*A*)

(*B*)

(*A*) Photomicrograph of lean ore, Cranberry mine, Cranberry, N. C. Black is magnetite. All else is light-green amphibole. Ordinary light. X50.

(*B*) Photomicrograph of schistose ore from Teegarden mine, near Shell Creek, Carter County, Tenn. Black is magnetite and gray is green amphibole. Large white areas are calcite and small ones quartz. The needles are amphibole. Ordinary light. X25.

in larger grains in the layers in which magnetite is also most abundant. In these layers uralite is not common. The mineral, however, constitutes the principal component of the layers between the richly magnetitic layers. Its fibers are all elongate in the same direction. Associated with them are a few wisps of biotite and between these are little nests of calcite. Scattered through this aggregate are the small grains of magnetite already mentioned, and these are nearly always arranged roughly in lines.

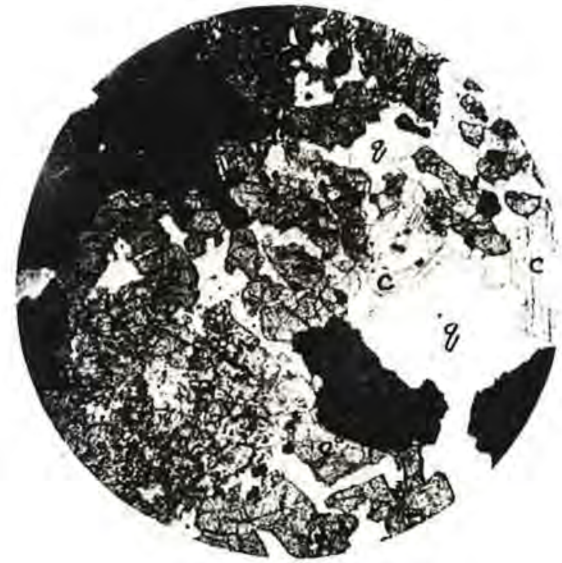
The biotite is the only component that does not orient itself with the schistosity. While most of its fibers in the hornblende lie parallel with the hornblende fibers, many others cross these perpendicularly and often extend into calcite grains. Evidently the biotite was produced after the ore had attained its schistosity.

The layers rich in magnetite are not sharply separated from those in which magnetite is present in small quantity only, nor are the magnetite lenses embedded in hornblende sharply separated from the surrounding material. The portions rich in magnetite grade into those containing little of this mineral, and in many cases it is impossible to designate in hand specimens any 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.

A third variety is a massive or slightly schistose garnetiferous ore that is found at different places in the veins, but more frequently near their borders or near pegmatite masses. (Plate VII) A slightly schistose phase from Smoky No. 2 opening at Cranberry is fine-grained and granular and in the hand specimen appears to be composed of little grains of magnetite and red garnet and between them a little chlorite or hornblende and tiny nests of calcite. The thin section shows the ore to be a mixture of green pyroxene, epidote, magnetite crystals and groups of crystals, large grains of calcite, irregular masses of pink garnet, spicules of uralite and little nests of calcite embedded in a fine-grained mosaic of quartz and calcite. The ore has evidently been crushed and recrystallized with the production of garnet, epidote and uralite as new minerals.

The uralite, epidote and calcite occupy areas in the slide that were originally occupied by pyroxene and the garnet frequently forms a wide border around them. With increase in the epidote there appears more and more calcite. The pyroxene broke into a lot of disconnected small areas and was changed to an aggregate of pyroxene, uralite, epidote and calcite.

The garnet is in small irregular and sharp-edged grains in the quartz mosaic and in borders around the pyroxene and magnetite. The mag-



(A)

(B)

(A) Photomicrograph of garnetiferous magnetite ore from Smoky No. 1, Cranberry, N. C. c = calcite. g = garnet. h = hornblende. q = quartz. Black is magnetite. Ordinary light. X50.

(B) Same as A. Between crossed nicols. X50.

netite is in large ragged masses that are often cellular and in numerous small crystals and irregular grains scattered indiscriminately among the other constituents. The large masses have a general elongation in one direction, imparting to the ore the slight schistosity noted in the hand specimen. Many of the small grains appear to have been broken from the larger masses.

The three varieties of ore described all show distinct evidences of crushing and consequent metamorphism. The first variety is least affected. It is a pyroxene-magnetite aggregate that has been minutely fractured and in which the pyroxene has been partially uralitized. (Plate II, *B*.) The second variety exhibits a greater degree of metamorphism in that the pyroxene has completely disappeared and has been replaced by amphibole and at the same time the whole mass has be come schistose and possibly more magnetite has been added. (Plate VI, *B*.) The third varieties differ from the other two in the possession of garnet. (Plate VII.) As the garnetiferous varieties are localized in the vein it is probable that for the production of the garnets the addition of some constituent was necessary that had not been present in the original pyroxene-magnetite mass.

In a fourth variety of ore 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 vary 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 thicker veins. In some places these 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 ore. The material of these veins is usually a mediumly 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 than this. They are black and have a brilliant luster, in which respect they are distinctly different from titaniferous magnetite, which has the color and luster of steel. It is this variety of ore that was analyzed by Mr. Fairchild. (See page 102.)

THE GANGUE

The only place in the district where the ore vein can be studied in detail is at the Cranberry mine. Here there are immense dumps in which the many different kinds of rock occurring in the vein are represented by excellent specimens. Moreover, on the walls of the large open pits the relations of the rocks to one another are well displayed. At no other place are more than a few square yards of the vein exposed to view, though at many places, especially in Carter County, Tenn., there are large dumps around the openings of explorations. As nothing was seen at any of these dumps that was essentially different from the

(*A*)

(*B*)

(*A*) Pegmatite (light), and ore (dark) in wall of open cut, Cranberry mine, Cranberry, N. C.

(*B*) Younger pegmatite cutting irregularly across ore vein in Teegarden mine, near Shell Creek, Carter County, Tenn.

things seen in specimens on the Cranberry dump, it was assumed that the veins are everywhere the same, and attention was directed mainly to the Cranberry occurrence.

The vein at Cranberry comprises a plexus of rocks in the midst of which occurs the commercial ore as a series of lenses, which so far as development has gone, appear to have no pitch. The plexus is cut by pegmatite and by veins of almost pure magnetite. The pegmatite cuts irregularly through the vein plexus twisting and turning in a complicated way and gradually fingering out. In some places it encloses lenses of ore and in others lenses of coarse, green hornblende. In places it cuts comparatively cleanly through the other rocks (Plate VIII, *A*), often with only one sharp wall, rarely with both walls sharp. Usually the walls are indefinite—the pegmatitic material grading into gneiss, so that frequently there is a little seam of gneiss between the pegmatite and the rest of the vein matter.

The main portion of the vein, aside from the horses that occur in it and the veins of pegmatite and magnetite in it, consists of masses of hornblende, or of hornblende and magnetite, of hornblende and epidote, of epidote and magnetite, or of epidote and quartz, with occasional small quantities of molybdenite.[52] All are slightly schistose parallel to the strike of the vein, and some of them are well-defined gneisses. Especially is this true of the aggregates containing epidote.

The epidote which is so abundant everywhere is apparently an 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. 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. In rare cases veins of epidote and quartz pass into veins of magnetite along their strikes, apparently indicating that the materials of 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 is closely associated with the pegmatite. The miners declare that the richest ore is always near pegmatite. (See Plate V.) The pegmatite and magnetite veins both cut the lean ore, which is the mixture of hornblende and magnetite referred to above, in the same way, and magnetite impregnations extend from the walls of the magnetite veins into the bordering rocks, causing an enrichment of these, and giving rise to magnetite gneisses. Moreover in many places magnetite forms a constituent of coarse pegmatite, exactly as does feldspar, quartz and hornblende. It has the same shapes as the

[52]Unpublished report by S. H. Hamilton to Tenn. Geol. Survey.

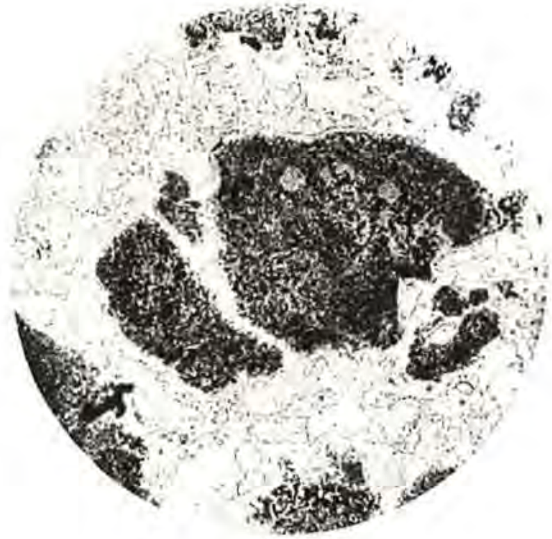
Polished surface of pegmatite streaks in vein-filling, Cranberry mine, Cranberry, N. C. The light material is feldspar and epidote, the black is hornblende, and the very dark gray, in the otherwise black areas, is magnetite. Small lenses of hornblende and magnetite are in the lower part of the figure, and just above them is epidote-hornblende gneiss. The streak through the center is a vein of quartz. (Natural size).

other components and the individual grains, when not aggregated, are of the same sizes as the grains of quartz, hornblende and feldspar. More frequently, 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 often they occur in great masses forming the lean ore deposits. It is probable that the magnetite separated in two stages, of which one was contemporaneous, or nearly so, 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 apt to occur on their borders with the magnetite in their centers, and where arms extend into the surrounding quartz-feldspar mass the main portions of the lenses may be composed of magnetite or a mixture of magnetite and hornblende, while the extensions consist entirely of hornblende.

PEGMATITE

The pegmatite in the vein mass contains very little quartz. In some cases it is nearly all feldspar and in others nearly all hornblende or hornblende and magnetite. (Plate IX.) The fresh feldspar is very light pink. Near its borders, however, and wherever it is in contact with hornblende it has become epidotized, so that in places it is composed mainly of light green epidote and dark green hornblende, or a distinct gneiss composed of the same two minerals. (See Plate IV.) Where the pegmatite has been sheared without epidotization its feldspar is crushed to a sugary mass that is saturated with quartz. The crushed material forms layers from one-quarter to one inch in thickness, separated by very thin layers of hornblende along which the rock breaks easily. Evidently some of the gneiss in the vein is crushed pegmatite.

In thin section under the microscope all of the pegmatites are more or less completely metamorphosed augite syenite varieties, that have been subjected to deformation processes. Their plagioclases, which are oligoclase and andesine, are shattered and cracked, and their twinning lamellae are gently curved or are bent into sharp angles at cracks which cross them. Throughout the feldspar epidote particles are common. (Plate X, *A*.) They appear in individual crystals or in groups of grains, but the mineral is most abundant near the contacts of the feldspar with hornblende or magnetite. At such contacts the feldspar is entirely replaced by epidote, and this is also the case in feldspar which 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 often grains of epidote. The consitutents of the mosaic frequently possess a parallel elongation. Here and there are areas in which a few large quartz grains are observable. These perhaps are the remnants of original quartz components of the pegmatite, since they are



(*A*)

(*B*)

(*A*) Photomicrograph of epidotized pegmatite in vein-filling, Cranberry mine, Cranberry, N. C. The darker gray masses are epidotized plagioclase fragments and the light gray ones granular quartz. The background represents voids. Ordinary light. X30.

(*B*) Photomicrograph of pyroxene-magnetite pegmatite, Cranberry mine Cranberry, N. C. E = epidote. EF = epidotized feldspar. H = uralitic amphibole. P = pale green amphibole with pyroxene nuclei. Ordinary light. X30.

always divided into differently oriented sectors which show wavy extinctions, while 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, are small masses of calcite. Since 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 that are partial pseudomorphs of pyroxene and in plates, fibers and acicular crystals, either forming groups or occurring as individuals scattered through portions of the quartz-mosaic. Within the large compact masses there are often remnants of a partially uralitized pyroxene which is slightly pleochroic in yellowish green tints. (Plate X, *B*.) This is surrounded by a zone of compact strongly pleochroic uralite, and around this is a border of spicules of the same uralite. 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 which is not demonstrably derived from pyroxene is in large crystals that have the sieve structure characteristic of minerals of metamorphic origin. In them are numerous quartz and epidote grains and occasionally little nests of calcite. Scattered through the hornblende in several sections are the small 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 quartz grains, a few tiny grains of epidote, and little nests of calcite.

GNEISSES

The gneisses that constitute such a large proportion of the vein-matter are for the most part medium-grained schistose aggregates of epidotized feldspar, hornblende and a little quartz (Plate IV), 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 does the hornblende, or as does any femic mineral in any other gneiss. Most of the gneisses in the Cranberry vein-mass (exclusive of that forming "horses") are believed to be igneous rocks closely related to the pegmatite, and their structure is thought to be the result of crushing and recrystallization under movement in the plane of the vein.

The sections of all the gneisses of this kind that have been examined show the same features. In one place, where the gneiss grades into pegmatite, the gneiss contains distinct layers of lean ore, consisting of hornblende and magnetite, that apparently bevel the foliation of the gneiss at a low angle. In the hand specimen the lean ore-layers and the gneiss

(*A*)

(*B*)

(*A*) Photomicrograph of epidote-hornblende gneiss. Vein-filling, Cranberry mine, Cranberry, N. C. G =garnet. H =hornblende. C =calcite. P =plagioclase. E =epidote. Q =quartz. Ordinary light. X50.

(*B*) Same as A. Between crossed nicols. X50.

appear to be tightly frozen, but they easily break apart revealing slickensided fracture surfaces coated with chlorite or uralite.

Under the microscope the gneiss is seen to consist principally of parallel flat lenses of granular epidote and feldspar and others of uralite and quartz and feldspar. In addition there are a few comparatively large lenses of feldspar with many tiny crystals of epidote scattered through them. These are cut by quartz veinlets parallel to the general schistosity.

Another section of epidote-hornblende gneiss grading into feldspar-hornblende gneiss is a mass of fragments of plagioclase, enclosing epidote grains, and nests of calcite in a matrix of smaller fragments of feldspar, quartz grains, hornblende flakes, grains of epidote and nests of calcite. Much of the epidote is in very small colorless granules scattered through feldspar, quartz and calcite indifferently; but there are also large masses of a yellow-green variety associated with hornblende. A few grains of magnetite are also present, and one of these is surrounded by leucoxene. Most of the plagioclase is characterized by bent twinning lamellae. (See Plate XI.)

Other gneisses are clearly injection gneisses. (See Plate IX) Thin layers of pegmatite are interlaminated with thin layers of hornblende and magnetite. The pegmatite appears to have intruded a schistose hornblende in little veins and stringers, all running in the same general direction, but in a few places crossing little streaks of the hornblendite and surrounding little islands of the rock. Some of the layers of pegmatite are very narrow (from .1 to .01 inch,) but they have a fashion of swelling into lenses half an inch wide, forming the well-known augen of augen gneisses. Many of the narrower streaks and the smaller lenses are now composed entirely of epidote.

All the gneisses studied are directly or indirectly the result of deformation, except, perhaps, the "augen gneiss" which may have been the result of intrusions into a schist. But even in this the intruding mass has suffered crushing, since the tiny streaks of feldspar and epidote that now represent the pegmatite are composed of little epidote crystals mingled with the debris of shattered plagioclase. (See Plate XI, *B*.)

RELATIONS OF THE ROCKS IN THE VEIN-MASS

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

In the case of the epidote-hornblende-magnetite gneisses the hornblende and magnetite appear to be contemporaneous, but distinct, and definite layers of magnetite and hornblende cut across the schistosity of the gneiss in such a way as to leave no doubt that the material of the gneiss is the older. Moreover veinlets of magnetite cut the gneiss as do also little veins of quartz. In other places almost pure magnetite sends tongues into epidotized pegmatite. In most places there is a little layer of hornblende between the epidote and the magnetite in the tongues and not infrequently the magnetite plays out and is replaced by hornblende.

Much of the gneiss is unquestionably a mashed and sheared pegmatite in which the feldspar has been altered to epidote and the augite to hornblende. Some of this originally contained magnetite. The hornblende and magnetite that cuts this gneiss is plainly a later intrusion.

Thus some of the pegmatite is later than some of the hornblende-magnetite aggregates that constitute much of the lean ore and some of the hornblende and magnetite is later than some of the sheared pegmatite, now forming gneisses.

The relative ages of the less gneissoid pegmatite and the less gneissoid magnetite and hornblende is not known. Probably they were contemporaneous in the sense that they were the result of a continuous intrusive process.

AGE

The most striking feature of thin sections made from ore and gangue is the granulation of the quartz and the feldspar. In many, too, 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, if one may judge from the appearance of the thin sections. This is directly in opposition to Keith's [53] view that the deposit was made after the deformation of the region, and long after the enclosing granite had been made schistose, because the minerals composing the ore and gangue "are only slightly crushed and rearranged, although they are the same varieties which in adjacent formations show the greatest metamorphism."

Keith did not have the advantage of a study of thin sections of the ore and gangue. Because he found no evidence of crushing in the vein-filling, he concluded that the vein could not have been earlier than the beginning of Mesozoic time.

The microscopic study of the ore and gangue shows that the vein-filling suffered a great amount of metamorphism. It was sheared, crushed and nearly all of its original components were altered. Consequently it must have been involved in the deformations that took place

[53] Keith, Arthur, U. S. Geol. Surv. Geol. Atlas, U. S., Cranberry folio (No. 90), p. 8, 1903.

before the beginning of Mesozoic time. Moreover, as there are no veins of a similar character in the Cambrian beds of the district, nor any pegmatites in these beds, so far as is now known, the vein is probably pre-Cambrian in age.

ORIGIN

Since the Cranberry vein was believed by Keith[54] to have originated in Mesozoic time, he was compelled to find a source for its material that was effective in Mesozoic time. This he believed to be at hand in the Bakersville gabbro to which he had assigned a Mesozoic age, because it seemed to exhibit no schistosity or other deformational effects. It seemed to him probable that the vein replaced an igneous, diabase-like mass that intruded granite, and that the ore was "due to alterations begun by the gabbro intrusions." However, since there are no "later intrusions" of gabbro or diabase in Ashe County where magnetites similar the the Cranberry magnetites occurs, it is unlikely that the ore in this region can have been produced by the process outlined. Mr. 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.

Since the study of thin sections of the country rock, the Bakersville gabbro and the vein-filling shows crushing in all cases, there appears to be no compelling reason for correlating the vein with the gabbro, nor is there any reason to assume that the vein was produced by the alteration of some pre-existing dike. It appears much more probable that the vein originated in the same way as did the numerous pegmatite veins of the district, *i. e.*, that it was forced into the country rocks by the same agencies that caused the intrusion of pegmatites elsewhere.

The relations of pegmatite, gneiss, hornblendite and magnetite in the vein suggest that they are all parts of a contemporaneous intrusion that took place before the general deformation of the mountain region was concluded. The intrusion was apparently a magnetitic pyroxene pegmatite, followed later by an intrusion of pyroxene-magnetite and finally by one of magnetite. According to this view the magnetites of North Carolina originated in pretty much the same way as those of New Jersey. In the northern State the iron ore was brought up by pegmatites that were differentiates of some igneous mass beneath. In both States intrusions of less siliceous ferriferous magmas, producing pyroxene pegmatite and magnetite, followed more siliceous magmas producing quartzose pegmatites and were themselves followed in the last stages of the intrusion by magmas or solutions that deposited pyroxene and magnetite and finally mainly magnetite. 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, etc., in the Roan gneiss series, which may not have antedated the Cranberry granite by any great length of time, or they may have come from the magmas that later rose as Algonkian volcanics and brought with them iron compounds to form the hematite-magnetite ores (page 244), of Buck Mountain, Carter County, Tenn. According to this view the magnetites in the Mountain district belong with the injected pneumotectic magmatic deposits, recently defined by Lindgren.[55]

[54] Idem., p. 8.

UTILIZATION

The availability of the magnetite deposits depends upon their ability to furnish to the furnace at a reasonable cost a large quantity of ore with an iron content of 40 per cent. or more. There are many deposits that will supply small quantities of such ore, but, as will be noted by reference to the description of the ore veins (see page 48), the expense of selecting it in the mine would be considerable. So far as is now known there are no deposits in western North Carolina or East Tennessee that could be made to yield a continuous supply of such ore to even a small furnace. Most of the ore is of lower grade than this and must be concentrated to be of commercial value. The Cranberry mine is now sending to the furnace ore that is of comparatively low grade, but even this is hand cobbed to some extent. During the last three months before the mine was closed the direct shipments from the mine to the furnace averaged:

	Iron	Phosphorus
September........	40.14	.0117
October	40.70	.0103
November........	38.85	.0097

and the average of the shipments in May, June and July for the same year (1920) was: iron, 38.72 per cent and phosphorus, .0112 per cent.

These shipments were made from selected headings in the mine and represent what is believed to be the best ore that can be obtained in large tonnages. It is not probable that any other deposit in the district will afford as much crude shipping ore as that at Cranberry. Most of the ore in the district will have to be concentrated before it becomes available, and the method of concentration employed must be such as to increase the content of its iron while avoiding the concentration of phosphorus. The mining of the ore will justify itself financially only if the resulting concentrate will make a very low phosphorus pig-iron. The Cranberry iron is guaranteed not to exceed 0.035 per cent in phosphorus, consequently the ore from which it is made must not contain an average of more than about 0.02 per cent of this element.

Until October, 1919, the ore was cobbed and then concentrated magnetically with the result that much of the ore too lean to be shipped direct was made available for use. The mill was closed at the end of

[55] Lindgren, Waldemar, A suggestion for the terminology of certain mineral deposits: Econ. Geol., vol. 17, p. 292, 1922.

October, 1919. During the last four months of its operation 9,941 tons were shipped. This was classified as cobbed ore, concentrates and fine concentrates, the latter including five-eighths inch material and dust. The proportions of each and the composition of each class were as follows:

Proportions and quality of different classes of ore shipped from the Cranberry mine in the summer of 1919.

	Tons	Percent	Fe	P
Crusher ore	......	100.0	33.28	.0275
Cobbed ore	1712	17.2	48.00	.0095
Tails	......	......	28.29	......
Coarse concentrates				
Heads			44.90	.0104
Tails			25.07	......
Coarse conc. retreats				
Heads			42.60	.0113
Tails			14.57	......
Finer concentrates	7276	73.25	......	......
Heads			45.15	.0111
Tails			18.41	......
Finer conc. retreats				
Heads			40.76	.0134
Tails			15.89	......
Fine concentrates				
5-8 inch ore				
Heads			57.91	.0079
Tails	953	9.6	17.27	......
Dust				
Heads			60.56	.0073
Tails			19.30	......

In 1913 a test was made to determine the quantities of the various classes of ore produced by the mill, using 20 cars of crude ore taken from the mine and the storage bin. The aggregate weight of crude ore used was 120,352 lbs. and the weights and proportions of the ore produced were:

Proportions of different grades of concentrates produced from ore of Cranberry mine in 1913

	Pounds	Percent
Cobbed heads	18,450	15.3
Coarse concentrates	23,895	19.8
Finer concentrates	14,700	12.2
Fine concentrates	11,600	9.6
Total	68,645	56.9

These results show clearly that in the case of the Cranberry ore and presumably that of the other magnetite deposits in the Mountain district it is possible, by magnetic methods, to secure a product with a higher content of iron than that in the crude ore without at the same time increasing the phosphorus. Indeed, the results show a diminution

of the phosphorus as iron increases, due no doubt to the fact of the phosphorus is in the mineral apatite, which is more closely associated with the hornblende in the ore than with the magnetite and consequently accompanies it into the tails. The magnetic process is satisfactory in producing a merchantable ore, its success commercially depends upon costs. The Cranberry mill was shut down, not because it could not produce a satisfactory concentrate from the ore at hand, but because costs were too high.

The runs made in 1913 showed that it required two tons of crude ore, then mined, to make one ton of concentrate containing about 46½ per cent. of iron; but there is no record of the iron content of the ore fed to the mill. The commercial success of the magnetic concentration method as applied to the mountain magnetites will depend upon the availability of a quantity of crude ore that will have a sufficiently high content of iron to yield a large enough product of satisfactory grade to pay costs of mining and concentration. Naturally the lower the grade of ore that can be utilized for the production of such a concentrate the greater will be the quantity of ore available for this purpose, and the larger will be the reserves for future use.

With the idea of working out a cheap method for the concentration of the mountain ores and of determining the lowest grade ore that would be profitable to mine for concentration by the method that might be developed, samples were taken from the Cranberry mine slopes and submitted to the Bureau of Mines Experiment Station at Minneapolis for study.

One series of low grade ores included 5 samples taken from the walls of the Cranberry mine at the points indicated by the sample numbers (see Plate XVI.) These were analyzed for total and magnetic iron and phosphorus and then subjected to the tests indicated below. One set of tests consisted in crushing to quarter-inch size and subjecting to the influence of magnets of gradually increasing strengths. The results are shown under the heading "Dry cobbing tests." A second set of tests consisted in fine grinding to pass sieves of 14, 28, 48 and 100 meshes and concentrating under water with magnets sufficiently strong in all cases to prevent loss of any iron in the tailings.[54] The results of this are shown under the heading "Wet magnetic concentration." Only the results of the study of the sample 5-L are given; since the results of the treatment of all samples were similar, except of course, that the percentage yields of high-grade concentrates were less in the case of crude ore containing smaller quantities of iron. Sample 5-L represents about the lowest grade ore that might be concentrated with profit under very favorable conditions with respect to costs and the selling price of pig iron.

[54] For detailed discussion of the method employed in making these tests, see: Davis, E. W. Magnetic concentration of iron ore: Minnesota School of Mines Experiment Station Bull. 9, 1921.

Composition of samples of low grade ore from the Cranberry mine, N. C., on which magnetic concentration tests were made by the U. S. Bureau of Mines Experiment Station, at Minneapolis, Minn.

Sample No.	Total Soluble iron *Percent*	Magnetic iron *Percent*	Total phosphorus *Percent*
Lot 5 G	15.52	10.47	.0362
" 5 H	13.84	7.35	.0223
" 5 I	15.11	9.81	.0303
" 5 K	21.51	14.54	.0180
" 5 L	25.47	22.03	.0575

Results of concentration tests on Sample 5–L.

Dry cobbing tests

Number of test	Concentrates Yield *Percent*	Composition Fe *Percent*	P *Percent*	Tailings Yield *Percent*	Composition Fe *Percent*	P *Percent*
First	29.57	59.65	0.0076	70.43	11.11	0.0785
Second	36.85	56.82	0.0125	63.15	7.17	0.0838
Third	41.91	51.83	0.0198	58.09	6.44	0.0847
Fourth	58.95	39.87	0.0326	41.05	4.78	0.0932

Wet magnetic concentration

Size *Mesh*	Concentrates Yield *Percent*	Composition Fe *Percent*	P *Percent*	Tailings Yield *Percent*	Composition Fe *Percent*	P *Percent*
14	39.38	57.87	0.0107	60.62	4.27	......
28	34.07	64.91	0.0058	75.93	4.95	......
48	33.95	67.91	0.0038	66.05	3.52	......
100	31.89	70.46	0.0020	68.11	4.27	......

After considering the results of the tests made on all the samples Messrs. E. W. Davis and H. H. Wade of the Bureau comment as follows:

"The results of these tests show that by dry cobbing at 1-4 inch, in all cases a concentrate can be produced assaying between 50% and 60% in iron and between .0178% and .0048% in phosphorus. In order to secure these results it was necessary to discard a tailing assaying from 3% to 7% magnetic iron. As the assay of the feed was low, a 7% magnetic iron tailing produced, in some cases, an excessive iron loss. Under ordinary conditions, however, these would be considered satisfactory results.

"In the finer grinding tests followed by wet magnetic concentration, the tailing produced contained in all cases practically no magnetic iron. This is due to the nature of the machine used in making these tests.

"The assay of the concentrate made at—100 mesh was in all cases between 65% and 70% iron and about .002% phosphorus. This is, of course, a very high grade concentrate, but in order to produce it from Lot 5G, for example, it would be necessary to mine, coarse crush and possibly cobb 6 tons of ore, fine grind to—100 mesh and concentrate possibly 3 tons of ore, and sinter one ton of ore in order to produce one ton of finished product. From an economic point of view this is undoubtedly out of the question, but it is interesting to notice that from an ore assaying only 7% magnetic iron a very high grade, low phosphorus concentrate can be produced.

"In most of these samples the magnetic iron assay was considerably lower than the soluble iron assay. This is due to the fact that some of the soluble iron exists in the ore in a non-magnetic state and therefore cannot be recovered by magnetic concentration methods. It is not possible by means of chemical analysis to determine the magnetic characteristics of an ore, and since the relation between the soluble iron and magnetic iron varies so considerably in the mountain ores, it is advisable to investigate the deposits with reference to their content of magnetic iron as well as of total iron."

In view of the results obtained in the experiments on the series of samples representing an average of the Cranberry vein, a second series of samples was taken to represent the average of the ore that might readily be taken from the vein without including the leaner portions of the vein-filling. The samples were taken from the headings that were being worked at the time the mine was closed. One represented the ore that is sent direct to the furnace without concentration, one is good milling ore and two represent average milling ore. The direct ore came from 5-Q and 5-R, the good milling ore from 5-P and the average milling ore from 5-K, 5-L, 5-M and 5-O. (See mine plat, Plate XVI.)

These samples were also sent to the Experiment Station of the U. S. Bureau of Mines at Minneapolis, Minn., where they were crushed and passed through the experimental magnetic concentrator with the results outlined in the following few pages.

Analyses of the samples gave:

Composition of samples of crude ore from Cranberry mine, Cranberry, N. C., on which magnetic concentration tests were made by the U. S. Bureau of Mines Experiment Station at Minneapolis, Minn.

Sample No.	Percent soluble iron	Percent total iron	Percent iron in magnetite	Percent total phosphorus
1	33.25	41.20	31.02	0.009
2	28.45	37.12	26.09	0.012
3	24.41	30.92	21.42	0.013
4	27.67	34.50	22.96	0.016

The ore was first crushed to quarter-inch size, and a portion was put over a dry cobber at various magnetic field strengths, the field strength being decreased with each succeeding test. Other portions of each sample were crushed to —14, —28, —48, and —100 mesh and wet concentration tests were made at each size in a magnetic tube concentrator. In these wet tests the magnet used was sufficiently strong to prevent the loss of any large amount of magnetic iron in the tailing. The results of the tests are tabulated below.

Results of concentration tests on samples of ore from Cranberry mine.

Dry cobbing tests.

Sample No. 1 Composition	Number of test	Concentrates Yield	Concentrates Composition Fe	Concentrates Composition P	Tailings Yield	Tailings Iron in magnetite
Percent		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Total Fe . . 41.20	First	89.74	43.88	0.008	10.26	1.69
" P . . . 0.009	Second	77.77	47.60	0.008	22.23	1.74
	Third	61.97	53.24	0.007	38.03	5.36
	Fourth	50.00	57.17	0.007	50.00	9.85
Sample No. 2 Composition *Percent*						
Total Fe . . 37.12	First	82.83	41.12	0.009	17.17	2.60
" P . . . 0.012	Second	69.10	45.44	0.008	30.90	2.83
	Third	54.94	50.87	0.007	45.06	4.92
	Fourth	42.93	54.76	0.007	57.07	9.07
Sample No. 3 Composition *Percent*						
Total Fe . . 30.92	First	71.70	37.47	0.011	28.30	3.05
" P . . . 0.013	Second	52.45	44.72	0.011	47.55	3.44
	Third	36.60	54.20	0.010	63.40	5.17
	Fourth	28.30	58.44	0.009	71.70	8.18
Sample No. 4 Composition *Percent*						
Total Fe . . 34.50	First	75.37	39.73	0.012	24.63	1.76
" P . . . 0.016	Second	59.83	44.71	0.011	40.17	3.31
	Third	43.11	51.92	0.008	56.89	5.69
	Fourth	31.97	56.31	0.007	68.03	9.48

Wet magnetic concentration tests.

Sample No. 1 Composition	Size	Concentrates Yield	Concentrates Composition Fe	Concentrates Composition P	Tailings Yield	Tailings Iron in magnetite
Percent	*Mesh*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Total Fe . . 41.20	—100	43.26	71.49	0.005	56.74	4.19
	—48	45.39	69.10	0.005	54.61	4.03
" P . . . 0.009	—28	52.05	62.86	0.006	47.95	3.58
	—14	62.55	55.63	0.006	37.45	3.50
Sample No. 2 Composition *Percent*	Size *Mesh*					
Total Fe . . 37.12	—100	36.88	71.44	0.004	63.12	3.59
	—48	39.79	68.03	0.004	60.21	2.89
" P . . . 0.012	—28	45.04	62.10	0.005	54.96	3.50
	—14	61.53	50.38	0.006	38.47	3.35
Sample No. 3 Composition *Percent*	Size *Mesh*					
Total Fe . . 30.92	—100	29.83	71.14	0.004	70.07	4.49
	—48	32.29	67.42	0.005	67.71	4.26
" P . . . 0.013	—28	35.29	61.79	0.005	64.71	5.02
	—14	45.13	51.90	0.005	54.87	4.87
Sample No. 4 Composition *Percent*	Size *Mesh*					
Total Fe . . 34.50	—100	30.37	70.99	0.004	69.63	8.91
	—48	32.69	68.18	0.005	67.31	8.14
" P . . . 0.016	—28	37.29	61.95	0.006	62.71	8.37
	—14	57.01	47.03	0.010	42.99	8.45

In the tables the only iron reported as being present in the tailings is that in magnetite. There is present in addition, however, also the iron that is in the silicates which are not carried to the magnets. The iron in the magnetite is significant as indicating the efficiency of the process used and for this reason is recorded. In the concentrates the iron in the silicates that are caught by the magnets as well as that in magnetite is of value to the furnace man, so that the figures given in the column showing the percentage of iron in the concentrate are for total iron.

The results of the dry cobbing tests show that each of the four samples when crushed to quarter-inch size produces a concentrate assaying between 50 and 60 per cent of total iron, and 0.007 to 0.010 per cent of phosphorus. However, the amount of the concentrate varies with the different lots. From lot No. 3, in the fourth test 28.30 per cent of the crude ore is recovered as a concentrate assaying 58.44 per cent total iron, whereas from lot No. 1, 50.00 per cent of the crude ore is recovered as a concentrate assaying 57.17 per cent total iron. The reason for this variation in recovery, according to Messrs. E. W. Davis and H. H. Wade of the Experiment Station, is the difference in (1) the amounts of iron in the original samples, and (2) the difference in their structure. The ore and gangue are more intimately associated in lot No. 3 than in lot No. 1. Cobbing at coarser sizes than quarter-inch was impossible on account of the small size of the samples.

In the wet concentration tests, a concentrate assaying 70 to 71 per cent of total iron and between 0.004 and 0.005 per cent of phosphorus was obtained in all four lots at —100 mesh. The average ratio of concentration for the lots is about 3 tons into 1. Coarser grinding and concentrating lowers the total iron content by from 2 per cent to 4 per cent but increases the yield, slightly improving the ratio of concentration.

Messrs. Davis and Wade remark[1] that "as a result of these tests it would seem that a satisfactory method of concentration could be provided by cobbing out 30 or 40 per cent of the weight of the crude ore assaying under 5 per cent. magnetic iron and then grinding the cobber concentrate to —48 mesh preliminary to wet magnetic concentration. This would mean that it would be necessary to mine, crush, and cobb three tons of ore, thus producing 1.2 tons of tailing to be discarded and 1.8 tons of cobber concentrate to be crushed to —48 mesh and concentrated wet. About one ton of concentrate would then be produced assaying about 63 per cent iron and 0.006 per cent phosphorus.

By careful sizing and cobbing, a dry method of concentration could be provided which would produce a concentrate assaying about 56 per cent iron and 0.01 per cent phosphorus. No fine grinding or sintering

[1] In report on Ore No. 582 dated Dec. 12, 1921.

plant would be required and the cost of operating and constructing a plant for this method of operation would be about one-half of that employing wet concentration. It is doubtful if a concentrate much higher than 56 per cent. iron could be made without producing a high tailing loss."

Their conclusions are essentially as follows:

(1) By dry concentration methods a concentrate assaying about 56 per cent of iron and 0.01 per cent of phosphorus can be made with a ratio of concentrates of about 2.5 tons into 1.

(2) By wet concentration methods a concentrate can be made assaying as high in iron as desired. However, for higher assaying concentrates, the grinding must be finer and the more expensive will be the process.

(3) Any grade concentrate can be made, but in order to determine the grade that would be most profitable to produce, a careful economic study of mining and milling costs is necessary.

It will be learned from the results of the tests on samples of magnetic ores ranging from 13.84 to 41.20 per cent of total iron and 7.35 to 31.02 per cent of iron in magnetite that there is no difficulty in producing concentrates sufficiently high in iron to be merchantable. It is probable, however, that no ore would be profitable to work unless it contains at least 22 per cent of iron in magnetite and can be produced at a low cost for mining. At most of the deposits in the Mountain district ores of this grade can be produced, but at only a few of them can they be produced on a scale large enough to keep mining costs low. In estimating the value of a deposit it is necessary, therefore, not only to determine the percentage of magnetite present, but also to determine the quantity of ore present and the cost of mining it.

RESERVES

Because of the superficial character of nearly all the explorations of the magnetite deposits in the Mountain district there are no data on which an estimate of the reserves of magnetic ore in the district can be based. Most of the explorations have been confined merely to the uncovering of the ore. In Ashe County, N. C., a few tunnels and shafts have been excavated, but none of them reach more than a few score feet underground. In Carter County, Tenn., a number of openings have been made in the western extension of the Cranberry vein and at some places considerable ore has been taken out. But here, also, the depths of the openings are slight. Only at the Cranberry mine has any extensive opening been made. Nearly all the excavation has been confined to the ground above the floor of the tunnel which enters the base of the hill at the level of the railroad track. There has been little exploration ahead of mining and there is therefore almost nothing known of the ore conditions beyond the walls of the present mine opening.

It is known, of course, that there are numerous lenses of ore in the schists and gneisses of the district and that they occur in belts, but little is known about the sizes of the lenses, or about their distribution in the belts. In some places the lenses are so crowded that the series becomes practically a continuous uniformly thick vein of ore. In others they are some distance apart and are separated by stretches of vein containing little ore, or by pinches of the wall rocks leaving only a narrow width of vein between.

Another difficulty in attempting to estimate the reserves arises from the fact that it is impossible to determine the ratio between the magnetite and gangue in the deposits without chemical or physical analyses, and these are valueless unless the samples analyzed are so selected as to show the distribution of ore and gangue. In no case have such samples been available. Moreover, it is not yet known what constitutes an available ore. If an available ore is only that material which contains at least 39 per cent. of iron, the quantity that might be obtained from the mountain deposits is so small as to be negligible, as only few deposits would yield enough of such ore as to be worthy of consideration by furnace operators. On the other hand, if lower grade ores can be concentrated to yield a comparatively high grade product the available reserves are increased as the grade of crude ore that can be concentrated to a merchantable product becomes lower and lower. The limit will be reached when the grade of crude ore becomes so low that it will not yield a merchantable product in sufficient quantity to pay the cost of mining and concentration. What this limit is we do not yet know.

Since it is impossible to estimate the reserves on the strength of the data now at our disposal, it is necessary to base any estimate on assumptions. This kind of an estimate is justifiable if it is clearly understood that it is based on assumptions and not upon known facts and that it is offered merely as a quantity that should be modified to accord with conditions as new facts are developed by explorations and milling tests.

In 1892, at the Cranberry mine, according to Nitze[17], an ore body had been opened and explored through 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. "Assuming that the gangue and ore are equally divided, half-and-half, and taking the specific gravity of magnetite at 5.1 and of the gangue at 3, this volume would contain 4,800,000 tons (gross) of ore material, of which over 3,000,000 tons are pure ore." Since 1884 about 1,360,000 tons of ore have been shipped, though nearly the entire slice referred to by Nitze has been mined except those por-

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

tions which were too lean to warrant the expense of removal and concentration, and an additional quantity has been taken from the northwest portion of the mine which had not been developed at the time of Nitze's visit. It is evident that Nitze's estimate of 50 per cent ore in the slice was too large. It is now clear that the slice, the dimensions of which are given by Nitze, was not all occupied by a single lens of uniform thickness throughout, and that a fair estimate of the ore in the mine was impossible because of insufficient exploratory work. The same difficulties lie in the way of making a fair estimate today.

An inspection of the mine plat, (Plate XVI), will show that the ore has come from lenses separated from one another partly by pinches in the vein and partly by the narrowing of the richer portions of the vein-filling. There is no probability that the lenses terminate suddenly with depth. If the source of the ore was, as is supposed, a subterranean magma is is probable that the deposits extend downward for some distance. There should be ore below the present works, and the quantity should be approximately the same per unit of mass beneath the present workings as has been taken from the mine in those portions that have been worked out. If 1,500,000 tons of ore have been removed from the present workings which measure about 1,800 feet long, from a few feet to 200 feet wide, and about 550 feet high, and 200,000 tons still remain in the upper levels, in an equal vertical distance of 550 feet below the present bottom of the mine there is probably a similar tonnage (of 1,700,000 tons) in every 1,800 feet on the length of the vein. There is no evidence as to 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 beyond the present end of the mine with an average width beyond the present workings of only half of that in the workings, the quantity of ore that is still available above a depth of 550 feet below the present level is 3,000,000 tons, without considering that portion of the vein that extends southeast of Cranberry, in which there is considerable ore. In the past, however, much of the material taken from the mine has been rejected because too lean to pass as ore. Much of this might yield a good concentrate under proper conditions with an efficient concentrating plant. One has only to glance at the ballast on the Linville Valley Railroad, southeast of Cranberry, to realize that much good ore has heretofore been wasted. Had all the material removed from the mine been passed through a suitable concentrator the yield of merchantable ore would have been much greater than it has been and the calculated reserve would be correspondingly greater. The quantity of ore that can be produced will naturally depend largely upon the cost of mining and concentration. In the future mining costs should normally increase because the ore still to be won will require a longer tramming than that which has already been produced and most of it will have to be raised to the tunnel level, whereas heretofore much of it has been dropped to this level by gravity. However, it is probable that with an economical concentration plant, costs will still be below the value of the concentrate, for in the Hibernia mine[58] in New Jersey, where the ore is very like that at Cranberry, an ore containing about 30 per cent. of iron is being raised from a depth of 1,500 feet and concentrated, presumably at a profit. The concentrates at the Hibernia mine in 1908 had a content of 62.80 per cent. of iron and 0.231 per cent. of phosphorus. As a concentrate could be obtained at the Cranberry mine with a much smaller content of phosphorus than that in the Hibernia concentrate, it seems certain that a moderately rich Cranberry ore could stand the cost of mining from reasonable depths below the tunnel level.

Northwest of the Cranberry mine on the same vein, or at any rate, in the same belt of veins, there are known to be several other deposits of good ore that are connected by lines of magnetic attraction. (See Plate I.) The sizes, however, of these deposits are not known. At the Horse Shoe, Teegarden, and Wilder mines the deposits are probably large enough to be worked under present conditions, but in each case the ore is comparatively lean. With an efficient concentrating plant to which the crude ore could be sent it is probable that some of the other deposits might be exploited. Such a plant, if built, should be situated at Roan Mountain or Shell Creek, Tenn., where all of the ore that might be raised 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 raised 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 contributory to such a plant, but if the average width of those portions of the deposits that would be worth concentrating is 15 feet and 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 in depth. Since the width of the nearly pure magnetite exposed in the openings that have been made varies in width from 4 feet 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 are indicated for every 100 feet of depth.

At the Wilder and the Teegarden mines, south of Shell Creek, are the two most promising undeveloped deposits known in the belt. At both places magnetic surveys (Plate XIX) were made by Mr. S. H. Hamilton for the Cranberry Furnace Company[59]. The results of

[58] Bayley, W. S., Iron mines and mining in New Jersey: Final Report Series of the State Geologist, vol. 7, Geol. Survey of New Jersey, p. 456, 1910.

[59] Unpublished manuscript report in the possession of the Tennessee Geol. Survey.

these surveys indicate, according to Mr. Hamilton, the presence of 150,000 tons of probable ore and 600,000 tons of possible ore, and at the Teegarden mine and vicinity about 250,000 tons of probable ore and 1,000,000 tons of possible ore. Hamilton does not state, however, whether the estimate is for ore of shipping grade or for crude ore that must be concentrated, nor does he make any statement as to the depth to which mining must proceed to yield the tonnage estimated.

At no other localities in Avery County, N. C., or Carter County, Tenn., are there known to be any deposits comparable in size to those in the strip of the Cranberry belt that have been mentioned, except perhaps at the Peg Leg mine, 3 miles south of Roan Mountain Station. Here there has been developed a body of good ore, the size of which, however, has not been determined even approximately.

Elsewhere in these counties the veins are narrow and the ore-bodies too small to afford favorable conditions for cheap mining. In the aggregate a large quantity of ore might be obtained from them, but it would be in small lots at such widely scattered points that it could not be depended upon to furnish a continuous supply. There is no inducement to build a railroad to them, and without a railroad the cost of transportation over the hilly roads to the existing railroad would be prohibitive.

In Ashe County, N. C., the three most promising explorations are near the Ballou place on North Fork of New River, near the mouth of Helton Creek (page 157), and on the Graybeal property (page 150) and on Piney Creek (page 146) near Lansing. On the North Fork are two adjacent explorations known as the "Home place" and the "Calloway property." Both are in the same belt of deposits, the former north of the latter. At the "Home place" rather extensive explorations have been made, but no records of the results attained are now available. The "Calloway property" has also been explored, but not sufficiently thoroughly to prove the continuation of the vein, or to determine the presence of any wide portions. Consequently it is plainly impossible to estimate except in a very general way the quantity of ore in the area.

On the supposition that a continuous vein 20 feet wide has been proven on the Calloway property, there are between the top of the hill and the river about 350,000 tons of magnetite above the river level. On the same assumption with respect to the "Home place" there are about 250,000 tons between the top of the hill and the river. In both cases the vein is supposed to yield 65 per cent. of merchantable ore.

So far as we can now judge, that portion of the vein on the west side of the North Fork is at present of no value, since it is too narrow to bear the cost of mining and concentration. If, however, a concentrating plant were near at hand perhaps some portion of it might be mined with profit.

None of the ore on any of the three properties could be shipped without beneficiation. It would have to be concentrated before being placed on the market, since 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 three properties and of any material that might be furnished by deposits father 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. On the Graybeal property there is indicated as 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. (See also page 153.) At the Piney Creek locality about 65,000 tons are indicated above a depth of 100 feet below the level of the creek on the assumption that the vein is 12 feet wide and that its length is about 350 feet, or the distance between the two most widely separated openings upon it.

In either case some magnetic concentration would be necessary to secure the full yield, though at Piney Creek a large portion of the estimated yield might be produced by hand cobbing alone. The sizes of the deposits would not warrant the erection of an efficient concentrating plant, even though the output of both properties should be treated together.

CHAPTER V.

EXPLORATION

PRELIMINARY STATEMENT

One of the most striking characteristics of the mineral magnetite is its effect on a magnet, tending to draw the mineral and magnet together. This property is not only made use of in concentrating magnetic ores, but is taken advantage of also in the search for ore bodies containing magnetite. It is well known that the compass needle after swinging freely comes to rest in a position that is parallel to the line of magnetic force passing through the earth at the point on its surface immediately under the compass. This direction, in western North Carolina, is a degree or two west of north where there is no magnetite. The departure from the true north is known as the declination, and the direction to which it points as the magnetic north. Its amount is indicated on most of the topographic sheets issued by the U. S. Geological Survey for the year of publication. It increases a few minutes annually. In addition to the pull of one end of the compass needle toward the north there is also a pull of the north end downward toward the earth. For this reason the south end of the needle in all compasses is weighted to make it swing horizontally. If not weighted the north end of a magnetized needle free to move vertically in the plane of the magnetic north will dip downward in latitudes north of the equator, provided there are no influences that interfere with the normal action of the earth's magnetic currents. This vertical departure is known as the inclination, or dip, and the instrument made for measuring it the "dip needle."

The declination and inclination of a magnetized needle vary little from point to point over a rather broad area, unless some disturbing influence is nearby. If such a disturbing influence is in the neighborhood of the needle it will cause a variation in both declination and inclination, depending upon the strength of its pull, and its distance and direction from the needle. A buried mass of magnetite will thus affect a compass and a dip needle, and from the strength and direction of its pull its position may be determined. The two instruments employed for rapidly locating magnetite are the "dial compass" and the "dip needle."

INSTRUMENTS EMPLOYED IN EXPLORATION

THE DIAL COMPASS

The dial compass (Figure 2), can be obtained from most dealers in engineering instruments. It is a small, portable sun-dial provided with a compass needle swinging inside a graduate circle, which, when the instrument is level, is horizontal. On a sunny day, if this instrument

is set up, levelled, and turned until the shadow of the gnomon (a thread) falls on that division of the hour-circle which corresponds to the apparent time, the zero of the graduated circle will be in the true meridian, and the declination of the magnetic needle may be read off directly. In

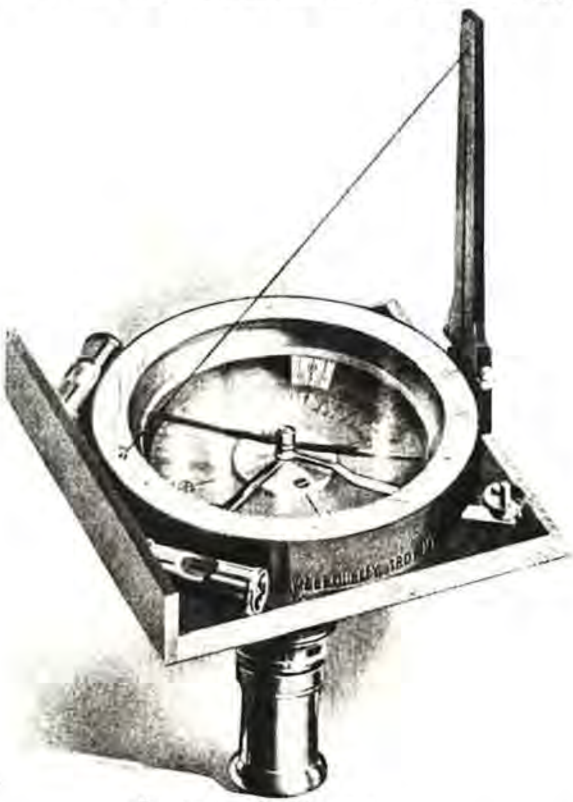


FIGURE 2. Dial Compass.

order that the instrument may be set in the meridian and the correct declination read, it must be properly constructed, that is to say, the hour circle must be accurately graduated, the gnomon must make with the plane of the hour-circle an angle equal to the latitude of the place, and the zero of graduation must be in the vertical plane of the gnomon; the plane of the hour-circle must be level; and the apparent time must be known. To obtain apparent time requires two corrections to standard time; first, a correction for the difference of longitude between the place of observation and the standard meridian, and, secondly, the addition or subtraction of the equation of time, taken from the Nautical Almanac for the proper day and year.[*]

[*] Much of the discussion of the use of the dial compass is taken from an article by H. L. Smyth: Magnetic observations in geological and economic work: Econ. Geol., vol. 2, p. 369, 1907.

In the correction for obtaining mean local time from standard time it is only necessary to multiply the difference in degrees between the longitude of the place of observation and that of the standard meridian (which is 75° for places using Eastern time and 90° for those using Central time) by 4. This will give the number of minutes that must be added to or subtracted from standard time to get mean local time. For convenience the watch may be set to give this time. In western North Carolina and the adjacent portion of Tennessee the product of the multiplication should be subtracted from the time of the 75° meridian and added to that of the 90° meridian. Thus the longitude of Asheville is about 82° 30′ as read from the Asheville topographic sheet. This is 7½° (90°—82° 30′=7° 30′) east of the 90° meridian. If reference is to Eastern time subtract 30 (7½′ ×4) minutes to obtain mean local time, or

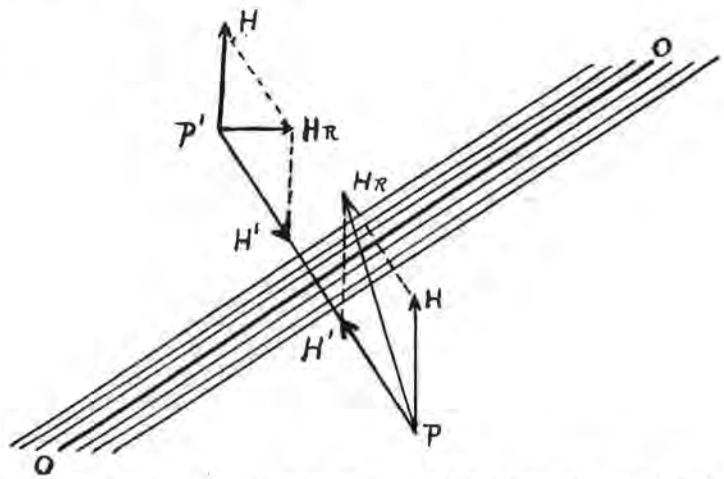


FIGURE 3. Diagram illustrating the influence of a magnetic strip in producing horizontal deflections of a compass needle. (After H. L. Smyth.) O-O is line of no deflection.

if reference is to Central time add 30 minutes. Thus at 10 o'clock Eastern time it is 9 o'clock Central time, and 9:30 o'clock mean local time at Asheville. To obtain apparent, or sun-dial time, the equation of time must be added to or subtracted from mean local time. The dial should then be set at the time indicated by the result. The zero point in the graduated circle will then face the true north.

As has been said, in the presence of magnetic matter the compass needle no longer remains in the magnetic merdian but is deflected from it. The final position assumed depends on the direction and amount of the horizontal component of the force exerted and is the line of the resultant of this horizontal component and the horizontal component of the earth's magnetism. The declination is then the angle which this resultant makes with the true meridian, and it is read in degrees.

In the area of magnetic ores the ore deposits occur as long, narrow, probably deep lenses that are exposed on the surface as strips running parallel to the structure of the country rocks. The intensity of their magnetic force varies (*a*) with the quantity of magnetite they contain, (*b*) with its arrangement in the mass, and (*c*) with the directions of strike and dip of the deposits. It is greatest for rocks dipping in the direction of the earth's force and least for those which dip at right angles thereto.

If the strip of magnetic material is uniformly wide and dips vertically the horizontal component of its force acts at right angles to the strike

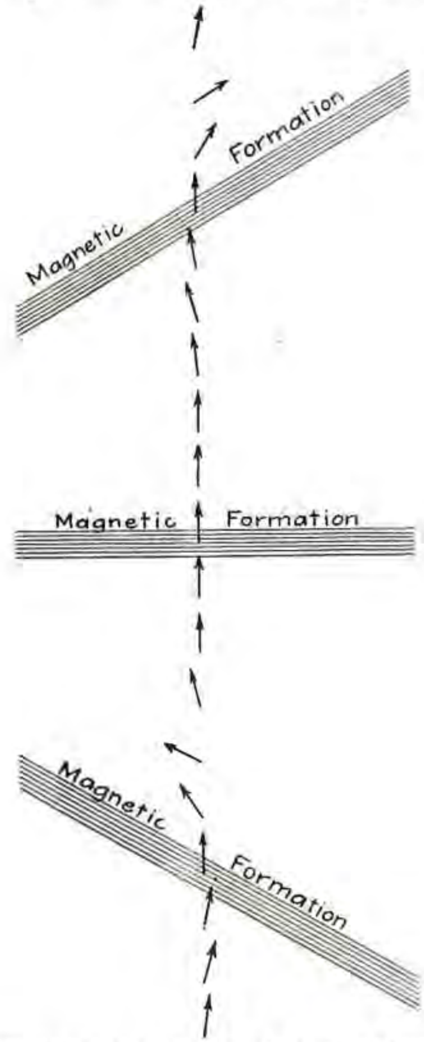


FIGURE 4. Diagram illustrating the effect of the strike of magnetic strips upon the needle of a dial compass. (After W. O. Hotchkiss.)

of the strip (Figure 3). Its direction at all stations on the same side of the strip is the same and opposite to that on the other side; consequently the deflection of the needle will be different on the two sides, and between the two points at which the deflections are at their maximum values there will be a position over the strip at which there will be no deflection. A strip which strikes E-W. will produce no deflection except on its north side, and then only at such stations, near the strip, where the magnetic force of the magnetic material is greater than the pull of the magnetic north. A strip that strikes N-S. will produce equal deflections on both sides at stations equally distant, and a strip that strikes NE. or NW. will produce greater deflections on its northern side than at corresponding stations on its southern side. (Figure 4.)

For instance, let P and P′ be two stations on opposite sides of a vertical strip of magnetic ore striking NE. (Figure 3.) Let H represent the strength of pull of the magnetic north, and H′ the pull of the ore strip. Completing the parallelogram of forces by drawing lines from H and H′ parallel to the direction of the forces, we have $P'H_R$ and PH_R as the resultants, or the directions assumed by the needle, and the angles HPH_R and $HP'H_R$ will be the declinations referred to the magnetic north. Since the magnetic north is, however, about 1½° west of the true north, in the longitude of western North Carolina, the observed declination must be corrected by this amount to give the true declination. In actual work it is more convenient to refer declination to the magnetic north, and consequently this is always done, and the custom will be followed here.

The points at which there are no declinations are always situated over the middle of the strip in the case of vertical layers, except where the strip strikes E-W., in which case it is indeterminate. The line joining these points of no declination indicates the strike of the strip. In the case of strips striking E-W. the strike is parallel to the line joining the points of maximum declinations, and the strip is south of this line.

The points at which the local attraction H′ is a maximum are determined by the fact that they are the points at which the declination of the needle is a maximum. They occur on each side of the strip and at equal distances from the magnetic line. This relation gives us a means of determining the cover over the strip if its width is known, or its width if the thickness of its cover is known, for:

$$d^2 = h^2 + a^2 \quad (1)$$

in which d is the distance of a point of maximum declination from the magnetic line of no declination measured at right angles to the strike of the strip; h is the depth of cover over the ore, and a is half the width, or thickness, of the strip. Since in most regions where magnetic ores occur the cover is not equally thick everywhere, and consequently the

ore is nearer to the compass at some stations than at others, and, moreover, the strip is not equally wide everywhere, nor uniform in its content of magnetite, the magnetic and maximum lines will rarely be straight. They will curve more or less irregularly, but will on the whole follow a generally uniform course, so that there is rarely any difficulty in locating the general position of any ore belt within comparatively narrow limits, though its exact position at any given point may be somewhat doubtful, if only the record of the dial compass is considered. (See Figure 8.)

All the relations discussed above relate to a strip of magnetic rock that dips vertically. Usually, however, the dip is not vertical but is more or less inclined to the vertical. Where the dip is high, as in the district under consideration, the correct location of the lines of maximum and of no declination determines the dip of the ore body and also its boundaries. Smyth[61] has shown that when the dip is involved the equation given above (1) becomes

$$d^2 = \frac{h^2 + a^2}{\text{Sin}^2 \text{ dip}}$$

In this case the line of no declination is not half way between the lines of maximum declinations, but is always nearer the maximum towards which the rock dips. This, therefore, gives us a means of determining the direction of dip.

The location of the lines of maximum declination gives also some idea of the position of the boundaries of the magnetized strip, for its width can never exceed the distance between the two maximums.

In the practical application of the method of declinations to prospect an ore body, it is simply necessary to set one's watch to dial time, as explained above, and then occupy successive stations on lines crossing the deposit perpendicularly and read the declinations of the needle, after setting the compass so that the shadow of the thread will fall on the corrected time indicated by the watch. It is best to place the compass on a jacob's staff or a tripod to hold it steady, and to read after the needle settles. Usually it is satisfactory to cross the strip at intervals of about 20 feet and make observations at intervals of 10 or 12 feet. There is no need to locate the stations beforehand. It is only necessary to stop every 10 feet as the strip is crossed and to set the compass at these stops. After all observations are correctly plotted it is easy enough to draw lines through the points of maximum and zero declinations and from the plot, to determine to position, dip and extent of the magnetic strip. If it is discovered during the course of the plotting that a mistake has been made in assuming the direction of strike, it is easy enough to

[61] Smyth, H. L., Trans. Amer. Inst. Min. Eng. vol. 26, p. 645, 1896.

change the traverses across the strip so that they will be at right angles to its strike.

THE DIP NEEDLE

The dial compass registers the strength of the horizontal component of the magnetic force by which it is influenced. The dip needle registers its vertical component. The dip needle is a more rapidly acting instrument than the dial compass and for preliminary work is quite as satisfactory. It consists of a magnetized needle so pivoted as to swing in a vertical plane when suspended loosely from a support, usually the hand. (Figure 5.) To avoid the effect of the horizontal component of the magnetism the instrument must be held in the magnetic meridian, *i. e.*, it must be held so that its vertical plane makes the same angle with the true north as does the compass needle. The amount of deflection from the horizontal is read on a vertical graduated circle and plotted at the point representing the position of the station occupied[62], indicating with a plus sign depressions of the north end of the needle and with a minus sign depressions of its south end. Lines are drawn between the points of equal deflections (see Figure 6), and inferences as to the extent of the magnetic body are deduced from the map thus produced.[63]

FIGURE 5. Dip needle.

In practical work the dip needle is first tested at some place where there is known to be no local attraction and its deflection is noted. This serves as the zero point against which other deflections are read. If the needle is accurately balanced for the district being studied the divergence from the zero gradation in the vertical circle will be nothing and the deflections due to local attractions are read directly. In the mountains the stations occupied may be the same as those occupied when reading the dial compass, but if only the dip needle is employed it should be read at intervals of about 40 feet crossing the belt and perhaps 60 feet along its strike. It is impossible to discuss in detail the method of interpreting dip maps. Messrs. Broderick and Hotchkiss have done this in an admirable manner in the two articles referred to above. In brief,

[62] For discussion of construction of dip needle and theory of its action see: Hotchkiss, W. O., Mineral land classification: Wis. Geol. and Nat. Hist. Survey, Bull. 44, pp. 75-125 1915.

[63] See Broderick, T. M., Some features of magnetic surveys of the magnetite deposits of the Duluth gabbro: Econ. Geol., vol. 13, p. 35, 1918.

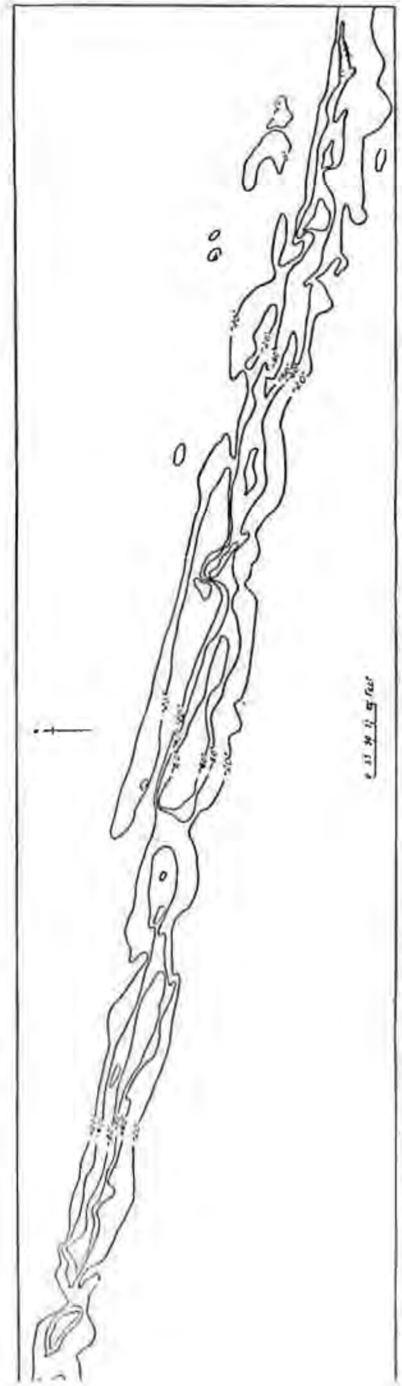


FIGURE 6. Contour map of dip needle deflections over a narrow band of magnetic ore in the Duluth gabbro. All deflections are negative. The contour interval is 20°. (After T. M. Broderick.)

however, it may be stated that the attraction at any point may be considered as being made up of two components: (1) the normal attraction of the earth as determined at some point far from railroad tracks, trolley

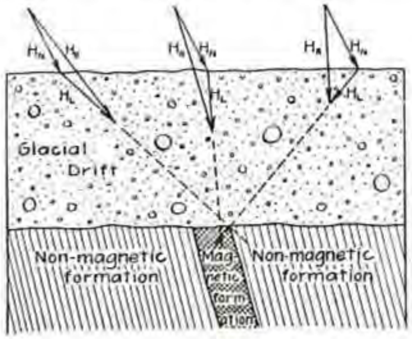


FIGURE 7. Diagram illustrating the effect of a buried magnetic strip upon a dip needle at different positions and the method of determining the depth to the magnet. (After W. O. Hotchkiss.)

wires or other disturbing influences, and (2) the local attraction due to buried magnetized bodies. In Figure 7 the effects of these two factors are shown at 3 points in a traverse across a steeply dipping magnetic

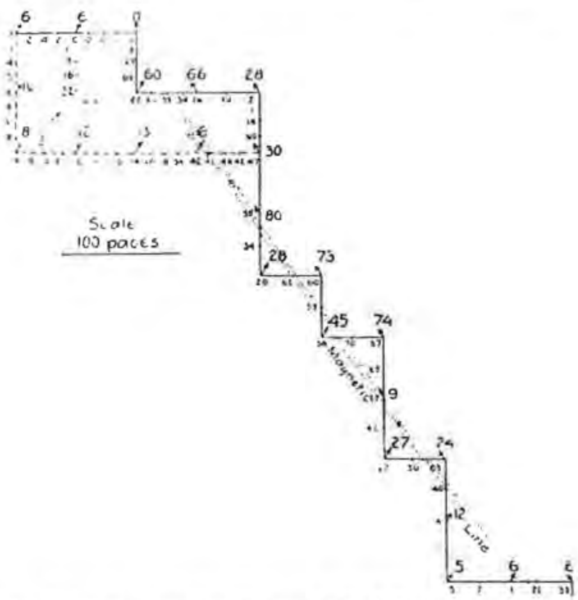


FIGURE 8. Diagram illustrating the use of the dial compass and dip needle to trace a magnetic line in Florence County, Wisconsin. The large figures are angular deflections of the compass needle, and the small figures are declinations of the dip needle.

The diagram shows the importance of combining dial and dip readings to detect the course of a magnetic strip. Had dial readings alone been considered the strip might have been thought to continue to the northwest. (After W. O. Hotchkiss.)

layer. The lines H_R represent the magnitudes and directions of the attractions observed at points where H_N represents the direction and magnitude of the earth's normal attraction and H_L the corresponding factors of the local attraction. H_R is the resultant of H_N and H_L. If the strength and direction of the earth's attraction[61] is known, since H_R is the observed dip of the needle, H_L can be plotted by completing the quadrangle of which H_R is the diagonal. This line will then give the direction of the local attraction from the point of observation. If three or four observations are made and the lines H_L are projected downward their points of intersection will indicate the approximate position of the attracting body. The matter of depth is not important in the case of the deposits in the mountain district because the ore bodies either outcrop or are so near the surface that they behave toward the dip needle as though outcropping. The principal use of the needle is to detect the deposit and serve as a means of estimating its approximate length and breadth. It is employed principally for confirming the indications of the dial compass. Moreover, since its use does not depend upon the sun it may be employed on cloudy days for detecting the approximate position of a magnetite deposit preliminary to more accurate work with the help of the dial compass. Figure 8 illustrates the method of tracing a curved magnetic line by combining the records of dial compass and dip needle.

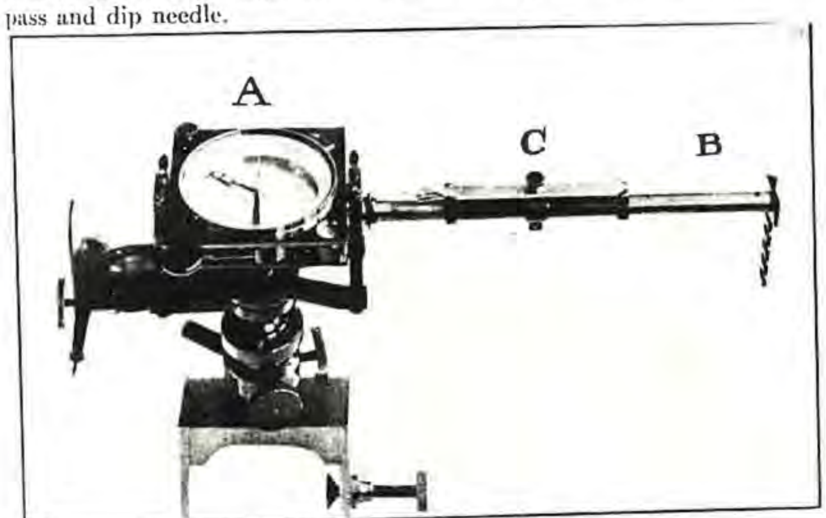


FIGURE 9. Magnetometer.

THE MAGNETOMETER

From the observations made with the dial compass or the dip needle the presence of a layer of magnetite of reasonable size, its dip and ap-

[61] For the method of determining the intensity and direction of the earth's magnetism and the intensity indicated by the vibrations of the dip needle, reference should be made to the article of W. O. Hotchkiss, op. cit. pp. 125-136.

proximate width may be determined. But the determination of these features does not afford an accurate means for deciding as to its size. This may be better accomplished by the use of the Thalen-Tiberg magnetometer (Figure 9), which is an instrument designed for making observations in the vertical as well as the horizontal plane, and for recording their intensities directly. It is a much more difficult instrument to use than either the dip needle or the dial compass, and its use requires that the area to be examined shall first be surveyed and stations established. Moreover it is slower working than either of the other instruments and consequently a survey made by it is much more expensive.[a] If it is desired to employ it to outline a little more accurately than can be done by the use of the dial compass or the dip needle, its manipulation should be entrusted to a professional engineer who is familiar with magnetic surveys. A skilled engineer may determine the size of the area underlain by magnetic material and may outline its borders, but even with the aid of the most precise instruments he cannot determine the value of the deposit without sampling it and analyzing the samples.

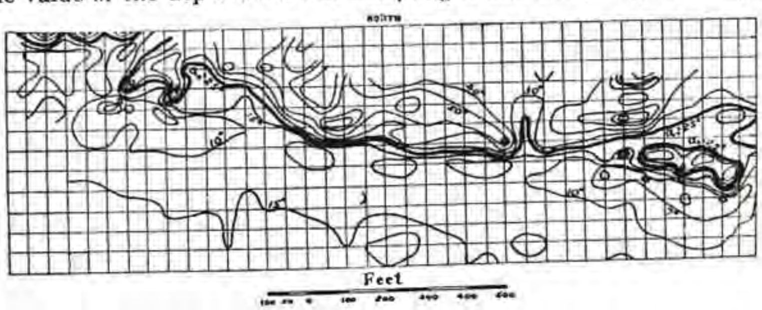


FIGURE 10. Map showing isodynamic lines over a belt of magnetic rock of practically uniform width outcropping freely in a rough country. The irregular courses of the lines are due mainly to the fact that the distance of the magnet from the instrument varied widely because of the irregular surface. (After H. L. Smyth.)

In outlining the size of a magnetite deposit the readings of the magnetometer are plotted as in the case of the dip needle and dial compass and a map is made by joining the points of equal and similar intensities by lines. Positive intensities are indicated by one color and negative intensities by another. Maps of this type are known as isoclinal or isodynamic charts, as they delineate the vertical or horizontal intensities. Their general features are shown by Figure 10 and by Plate XIX, which is a reproduction of a map made by Mr. S. H. Hamilton in the vicinity of the Wilder mine.

SAMPLING

The value of a deposit depends upon its size and its composition. Deposits of magnetic ores owe their value as economic sources of iron ore to the abundance of magnetite in them. Most of them have to be

[a]For a discussion of the magnetometer see Smyth, H. L., The magnetometer as a horizontal instrument: Econ. Geol., vol. 3, p. 200, 1908.

concentrated before use in the furnace and the cheapest methods of concentration are based on the magnetic property of their ore-mineral. Some of the minerals associated with the magnetite are iron-bearing, but since they are not sufficiently magnetic to be attracted by the magnets employed in concentrating plants they pass into the tailings and their iron content is lost. It is necessary, therefore, to determine the proportion of magnetite to gangue in a deposit before it can be decided whether it will yield sufficient magnetite to pay for mining and concentration. This may be done by making a magnetic separation of the magnetite from the gangue in crushed samples representing the average of the ore body. As chemical analysis is more convenient and cheaper than magnetic analysis, when small samples are involved, it is better first to determine the quantity of available iron present in an average sample to discover whether it is advisable to make a magnetic separation or not. If results are favorable it may be well later to subject large samples to magnetic analysis by running quarter ton lots through a concentrator after they have been crushed to the proper size. (Compare page 69.)

The satisfactory sampling of ore-bodies like those in the pre-Cambrian rocks of western North Carolina and East Tennessee is a difficult accomplishment because of the coarseness of the material and its rude banding. In order that samples may correctly represent the ore-body they must contain gangue and ore in the same proportions as these exist in the deposit. The tendency of the prospector is to discard samples containing little or no magnetite and to select those that appear to be rich in ore. If this is done the samples serve no important purpose because they will not represent the ratio of gangue to ore in the ore-body. It is well to cut trenches to the solid ledge across the full width of the deposit at intervals of 100 feet. To avoid unintentional selection a cord should be knotted at equal intervals of 3 or 4 feet and stretched the length of the trench, and, as nearly as possible, equally large samples of generous size should be broken from the ledge at the places indicated by the knots. These should be numbered and the corresponding numbers inserted on a map. The samples should then be analyzed for iron, phosphorus and sulphur, and the results also indicated on the map under the proper sample number. In this way the distribution of the pay ore at the surface might be learned and this might lead to a decision whether or not it would be worth while to sample more thoroughly. If the surface samples are promising further examination should be undertaken with the diamond drill, under the direction of a competent driller. The drills should be of such a size as to produce a core an inch in diameter and should be so placed as to cut across the deposit.

A great deal of care is necessary to secure a satisfactory core that will represent accurately the material drilled, and consequently it is much more desirable to have the whole operation of drilling directed by an

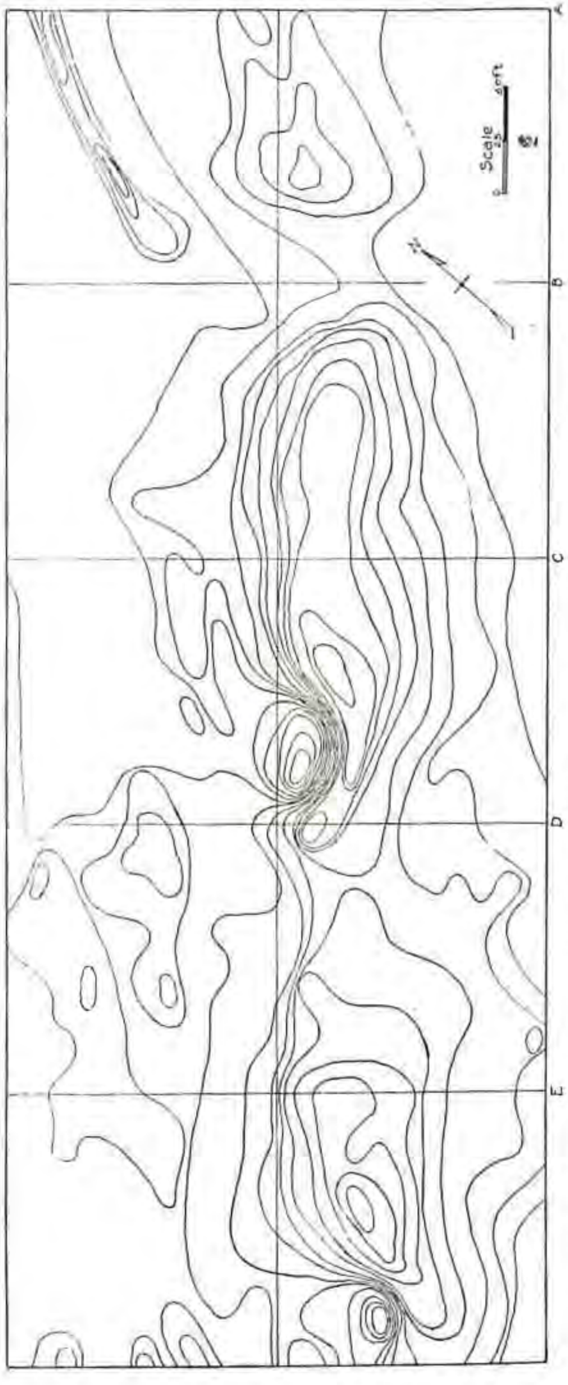


FIGURE 11. Map of isodynamic lines over a series of magnetic lenses near Ringwood, New Jersey, illustrating the use of a magnetic map for planning a drilling campaign. (After S. H. Hamilton.)
Three ore lenses dip nearly vertical, and pitch at a moderate angle to the northeast. The westernmost lens should be explored by diamond drilling between the stations E and D, the middle lens between B and C, and the easternmost at about A.

engineer than to attempt it without such supervision. In all cases the cores should be carefully and distinctly labelled with the number of the drill hole and the depth at which obtained. The positions of the holes should be carefully selected (compare Figure 11) and should be plotted on the surface map on cross-sections through the deposit and the character of the rocks cut through should be indicated in the proper places. Samples of the ore layers should be taken from the cores at fairly close intervals and analyzed for iron, phosphorus and sulphur, and the results of the analyses plotted on the cross-sections. Upon combining the cross-sections and the surface map and drawing lines through the various points outlining the areas within which analyses show the presence of ore of value, the size of the ore-body can be determined and its tonnage estimated. As the gangue of the magnetite ore is mainly hornblende it is easy to calculate the approximate tonnage of magnetite present in a deposit if the ratio of magnetite to gangue is known. About 7 cubic feet of pure magnetite weigh one ton, and 10 cubic feet of hornblende. If the crude ore consists of a mixture of 30 per cent. magnetite and 70 per cent. of gangue, it will require 9.1 cubic feet to constitute a ton, and of this weight 30 per cent. will be pure magnetite.

Before plotting drill holes their actual positions and courses should be determined accurately. Very rarely does a drill hole follow a straight course through rocks like those associated with magnetite ores. Mr. Hamilton[56] declares that all drill holes in such rocks will begin to meander

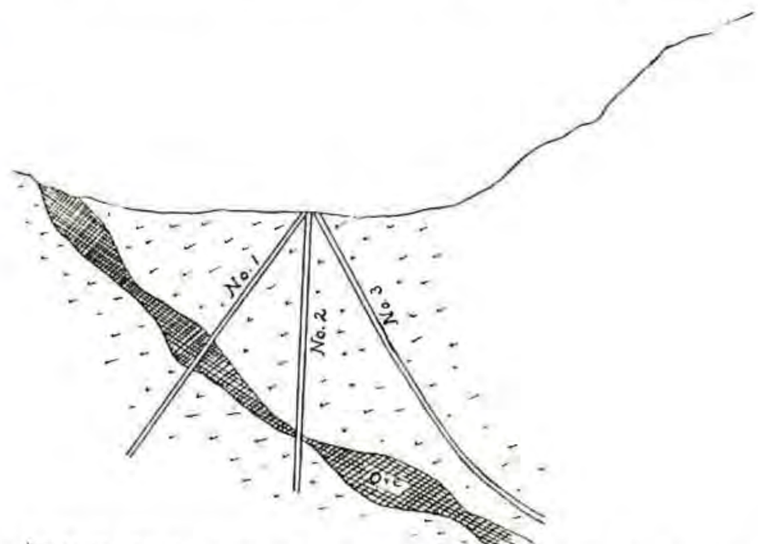


FIGURE 12. Imaginary sketch of section across an ore-body to show how the meandering of a drill hole may result in missing an ore-body. (After S. H. Hamilton.)

[56] Unpublished report of the Tennessee Geological Survey.

appreciably after reaching a depth of several hundred feet, and the greater the depth the greater will be their departure from a straight course. The meandering is least where the drilling is perpendicular to the dip of the formation. In some cases the deviation of a drill from a straight line is so great that it may not touch the ore-body to which it was directed and thus may give an entirely erroneous impression of the underground conditions. Figure 12 sketched by Mr. Hamilton, illustrates this point.

In view of the known deviation of drill holes from the direction in which they are started, it becomes necessary to survey them before plotting, in order that the actual position of any ore-bodies cut by them may be determined. Experience has shown that they must be tested at intervals of about 150 feet for both course and inclination. This is done by lowering into the hole a small tube into which some fluid etching agent is enclosed, and freeing the fluid at the depth at which the test is to be made, thus allowing it to etch the wall of the tube. By carefully controlling the lowering of the tube and noting its revolution during its descent, data are obtained from which the position and inclination of the tube can be calculated; and from the relative positions of the tube at successive intervals of depth the course of the hole can be determined and plotted. Since, however, this procedure is a complicated one, it is not practicable for any one not an experienced engineer to employ it successfully.

Thus, while the preliminary examination of an ore deposit might well be undertaken by any intelligent man, its thorough examination should be entrusted to an engineer in good standing, before any large amount of money is spent in developing it.

CHAPTER VI.

MINES AND PROSPECTS IN SILICEOUS MAGNETITES

GENERAL FEATURES

Only one mine, that at Cranberry, is now working in the siliceous magnetites. Formerly several others were operated for short periods on deposits like those at Cranberry, but after the best ore near the surface had been taken out the mines were abandoned, in most cases before they had been thoroughly explored. At a few places explorations have been fairly extensive. Some places have been abandoned because no large deposits were developed; others, because the crude ore required concentration before suitable for the furnace, and still others because too far from railroads. In most cases the records of the explorations have been lost, and there is now available no information as to what the work disclosed. Most of the openings in the district are small pits that furnished ore to the old forges that were scattered through the mountains, but very few of these went down into the solid rock. In some places the ore fragments were picked from the soil by hand; in others the soil was washed and boulders and finer fragments were shipped together. Other openings are pits and trenches that uncovered solid rock. These were used in prospecting, and when the width of the ore body had been exposed work ceased. Many of these openings have now been filled by wash, but some still show the rock.

Nearly all the information available as to the relations of the ore to the veins in which they occur has been obtained either from the openings of the Cranberry mine or from the material in the dumps of the abandoned mines. The prospect pits have been of value in showing that the veins on which they are situated are like the vein at Cranberry. The old pits serve to locate the positions of veins not now exposed. Descriptions of most of the older veins are to be found in the report by Mr. Nitze[a] on the iron ores of North Carolina. Some of these are reproduced in the following pages, and many references have been made to them. References are also made repeatedly to an unpublished report by Mr. S. H. Hamilton to the Tennessee Geological Survey for descriptions of deposits not seen by the writer.

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

THE CRANBERRY BELT

The only mine in the State producing siliceous magnetite is at Cranberry in Avery county, N. C., on the East Tennessee and Western

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

North Carolina R. R., about 32 miles from Johnson City, Tenn. Although other deposits have contributed to the output of magnetic ore from time to time the Cranberry mine has been operated almost continuously for many years and has contributed a tonnage many times greater than that of all the other mines combined. Its ore is famous because of its low content of phosphorus, and the metal made from it has been eagerly sought by manufacturers desiring unusually tough iron. The character of its ore, however, presents no specially 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 the two counties suggests that most of the non-titaniferous magnetite ores lie in a belt that follows the structure of the country from Cranberry west and southwest to the Toe River (Plate I.), beyond which no openings have been made and no outcrops of ore have been reported. The Big Ivy mine in Madison County is about 25 miles southwest of the point at which the line of openings in Mitchell County crosses the Toe River and this is thought by Nitze to be in the same belt. Since the deposits immediately north of the Toe River are widely scattered and no connection has been traced between any one of them and the Big Ivy mine, it is more reasonable to regard the Cranberry belt as ending at the river, than to suppose that it extends to the Big Ivy mine.

This belt of deposits is the most conspicuous in the State. Its best known deposit is at Cranberry where the Cranberry mine has been operating since 1876, and from which, before this time, 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, which is 4 miles southeast of Cranberry, beyond which Cambrian sediments cover the pre-Cambrian rocks in which the magnetites occur and consequently prevent farther tracing of the belt. To the west it extends across into Tennessee to beyond Doe River, a distance of 8 miles. Here it is lost as a distinct belt but a few deposits between the Horse Shoe mine on Doe River and Magnetic City may mark its course. Nitze[63] thinks that it bends to the southwest, passes close to Magnetic City and continues south and southwest toward Relief on Toe River. Near Toe River are a number of small deposits, but they are distributed over a strip of country 2½ miles wide, and are therefore not in a definite belt, like that at Cranberry.

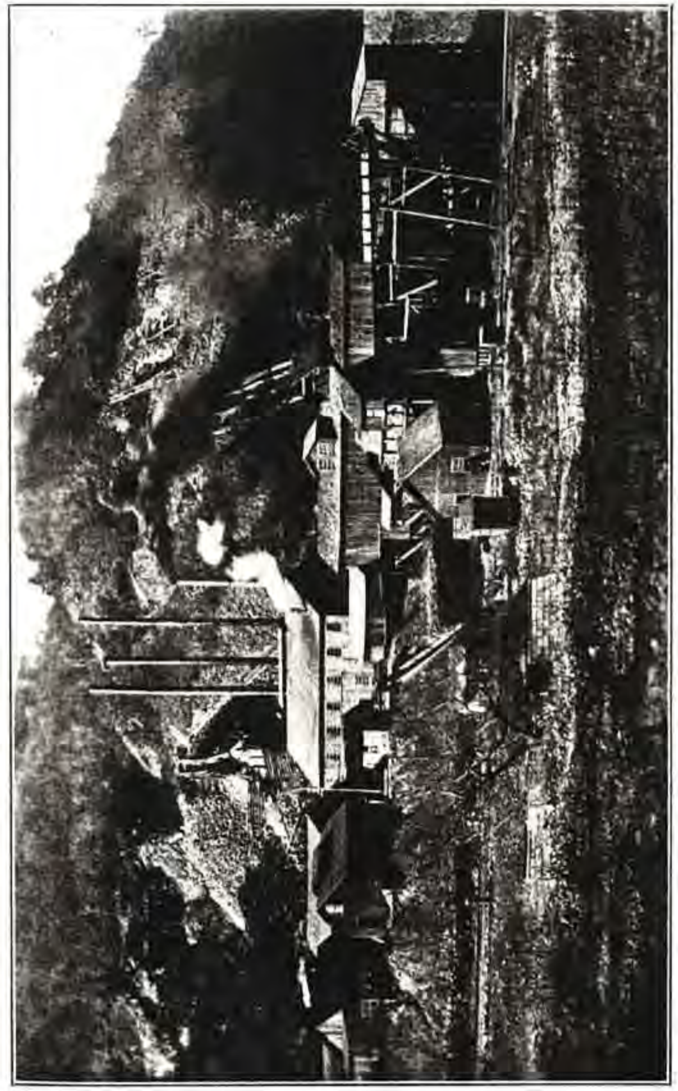
CRANBERRY MINE

General description of mine and ore

The most notable deposit in the belt running from Vale to the Doe River is, as has been said, at the Cranberry mine, on the east slope of

[63]Op. cit., pp. 168-182.

PLATE XII.



View of Cranberry mine, Cranberry, Avery County, North Carolina. Looking northwest along the vein.

Cranberry Ridge. (See Plates XII and XIII) In 1876 the mine came into the possession of its present owners and in 1882 it was connected with Johnson City by rail. In 1884 a small blast furnace was built and smelting of the ore was begun. Later, in 1900, this furnace was abandoned, a larger one having been built by the Cranberry Furnace Co. at Johnson City (Plate XIV), and since May, 1902, the ore has been smelted there. The capacity of the furnace is 100 tons of pig iron daily, and the Cranberry mine furnishes most of the ore from which the iron is produced. Since 1884 the mine has produced about 1,250,000 tons of merchantable ore, during the past 4 years (1917-18-19-20) at the rate of about 60,000 tons annually. The mine was closed temporarily in January, 1921, but was again working in 1923.

The ore as it comes from the mine is a non-titaniferous magnetite, which may be almost pure, or which may be intimately mixed with hornblende or with hornblende and other components of the gangue to be described later. Formerly the pure ore was separated from the leaner product by hand-picking, and the leaner ore was crushed to a 2-inch size, fed into a log-washer and from this to a screen for sizing, and after sizing the various portions were carried past magnets by which the richer material was separated from the lean portions, which were carried to the waste piles. The finest portions passing the screen were washed by a stream of water to a separate magnet by which the ore was concentrated. The concentrates were then screened by a 10 mesh screen into finer and coarser portions. During the last two years all the ore was shipped to the furnace as mined, without further concentration than hand-picking.

The chemical character of the ore and the effect upon it of magnetic concentration has already been discussed on pages 52 and 69. All the analyses given on these pages were for commercial purposes and are only partial. Two complete analyses were made by the chemists of the Tenth Census[69], one of a selected sample of nearly pure magnetite (*B*) and the other of a mixture of magnetite and epidote representing a lean ore (*A*). These are quoted below. A third analysis of a selected sample was made by Mr. J. G. Fairchild of the United States Geological Survey. This is recorded below under (*C*) The figures under (*D*) represent the composition[70] of the shipping ore from the south vein of the Richard mine, Morris county, N. J.

[69] Willis, Bailey, Notes on samples of iron ore collected in North Carolina: 10th Census U. S., vol. 15, p. 326, 1886.

[70] Bayley, W. C., Iron mines and mining in New Jersey: Geol. Survey of New Jersey vol. 7 of the Final Report Series of the State Geologist, p. 113, 1910.

PLATE XIII.

View toward 'Smoky Mountain' looking east from Cranberry, Avery County, North Carolina. The Cranberry vein runs across the mountain to the left of the high peak.

		A		B		C	D
Silica	(SiO_2)	29.99	29.99	5.27	5.27	14.28	8.48
Alumina	(Al_2O_3)	10.07	4.63	1.18	1.41	1.08	.86
Ferric oxide	(Fe_2O_3)	25.05		62.57		50.35	55.99
Ferrous oxide	(FeO)	18.93	3.78	26.68		28.30	26.98
Magnesia	(MgO)	1.78	.56	.55	.26	.62	1.89
Lime	(CaO)	11.33	4.62	1.46	.52	5.18	2.42
Soda	(Na_2O)		.07			.37	.33
Potash	(K_2O)		.10			Tr.	.19
Water at 110°	(H_2O-)	.37		.35		.04	} .15
Water above 110°	(H_2O+)	1.49		.49		.17	
Titanium dioxide	(TiO_2)			.95		.12	1.01
Carbon dioxide	(CO_2)	.07		.08		None	
Phosphorus pentoxide	(P_2O_5)	.024		.007		None	1.54
Pyrite	(FeS_2)	.18		.20			
Nickel sulphide	(NiS)	.09		.04			
Sulphur	(S)					None	.008
Sulphur trioxide	(SO_3)					Tr.	
Vanadium pentoxide	(V_2O_3)					None	.08
Manganous oxide	(MnO)	.76		.22		.18	.02
Chromic oxide	(Cr_2O_3)					None	None
Baryta	(BaO)					None	None
Strontia	(SrO)					None	None
Fluorine	(F)					None	.08
Total		100.134		100.047		100.69	99.948
Insoluble		43.60	43.75	7.20	7.46		
Iron	(Fe)	33.37		64.64		57.25	60.19
Sulphur	(S)	.128		.115			.008
Phosphorus	(P)	.010		.004			.672
Phosphorus ratio	($P:Fe$)	.031		.006			1.115

The ore is notable for its low content of phosphorus and sulphur. It differs from the titaniferous magnetites in its low content of TiO_2 and in the absence of Cr_2O_3 (see page 19.) It is very similar to the ore in the gneisses of New Jersey, but contains less phosphorus and less titanium. Moreover, vanadium is present in the New Jersey ore and in all other New Jersey magnetites in which it has been sought, whereas it is absent from the Cranberry ore and, so far as known, from all other North Carolina magnetic ores.

The Cranberry vein, which encloses the deposit at the mine, has been traced for 6,400 feet by pits, cuts and underground working, so that it is regarded as being continuous through this distance. (Plate XV.) It is not so, however, with the workable ore. There are stretches of the vein that contain such small quantities of available magnetite that they may be regarded as barren. At other places the magnetite is in sufficient quantity to warrant mining. In all cases the ore-bodies lie within the vein, but they are separated from one another by lengths of the vein that are occupied mainly by gangue. (Plate XVI.) But even in these portions there is always a little magnetite in strings or threads

PLATE XIV.

Cranberry Furnace, Johnson City, Tenn.

connecting the larger masses (the ore-bodies) with one another. In response to an enquiry made to President Howe of the Cranberry Furnace Co. the statement was made that in going north in the Cranberry mine, while at times the workings "passed through barren places where the ore almost entirely disappeared, it has in every case been the fact that it did not entirely disappear, and there was always a little thread of ore connecting together" the different deposits. Moreover, it is true that in each of the openings on Smoky Mountain, southeast of the mine proper, "both at the south and north ends, as far as we have gone, there has been at least a little thread of ore left indicating the possibility of their leading on to another lens."[71]

The country rock surrounding the vein consists of a crushed and sheared complex of acid feldspathic rocks, some of which are dark gray and others almost white, occurring in alternating layers with black gabbroitic gneiss, believed by Keith[72] to be portions of the Roan gneiss which have been intruded into the more acid rocks. The lighter colored layers constitute by far the greater part of the complex, which has been called by Keith the Cranberry granite.[73]

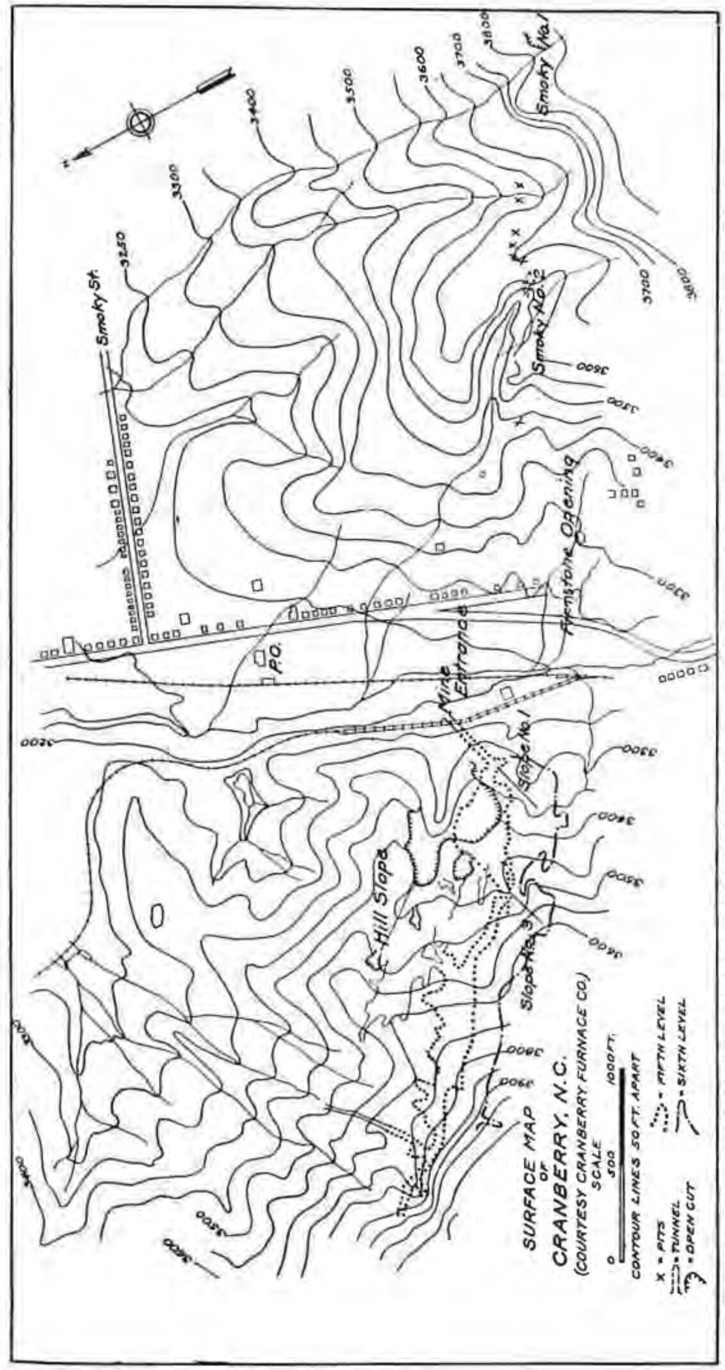
The vein follows the schistosity of the country rock. It varies in width from a few feet to 200 feet and is extremely complex. It comprises a plexus of rocks in the midst of which occurs the commercial ore as a series of lenses, which so far as development has gone, appear to have no pitch. The plexus is cut by pegmatite and by veins of almost pure magnetite. The pegmatite cuts irregularly through the vein plexus twisting and turning in a complicated way and gradually fingering out. In some places it encloses lenses of ore and in others lenses of coarse, green hornblende. In places it cuts comparatively cleanly through the other rocks, often with only one sharp wall, rarely with both walls sharp. Usually the walls are indefinite—the pegmatitic material grading into gneiss, so that frequently there is a little seam of gneiss between the pegmatite and the vein matter.

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 of hornblende and magnetite, of hornblende and epidote, of epidote and magnetite, or of epidote and quartz, with occasional small quantities of molydenite.[74]

Descriptions of the ore and of all the gangue rocks associated with it have already been given in a general way and their relations have been discussed on pages 48 to 67. It will not be necessary to repeat these statements but, since at some of the openings there are exhibited

[71]Letter of Mr. F. P. Howe, President, dated Johnson City, August 27, 1919, and reply thereto by Mr. S. H. Odom, Superintendent of mine, dated Cranberry, August 28, 1919.
[72]Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Cranberry folio (No. 90), p. 8, 1903.
[73]The Cranberry granite and Roan gneiss have been described on pages 39 to 46.
[74]Hamilton, S. H., Unpublished report to Tennessee Geol. Survey

PLATE XV.



Map of surface. Cranberry mine, Cranberry, N. C., with projection of underground workings. (Based on map by S. H. Hamilton, furnished by the Cranberry Furnace Co.)

special features that throw considerable light on the method of origin of the vein, brief descriptions of these will be given at the risk of repeating some of the statements that have already been made.

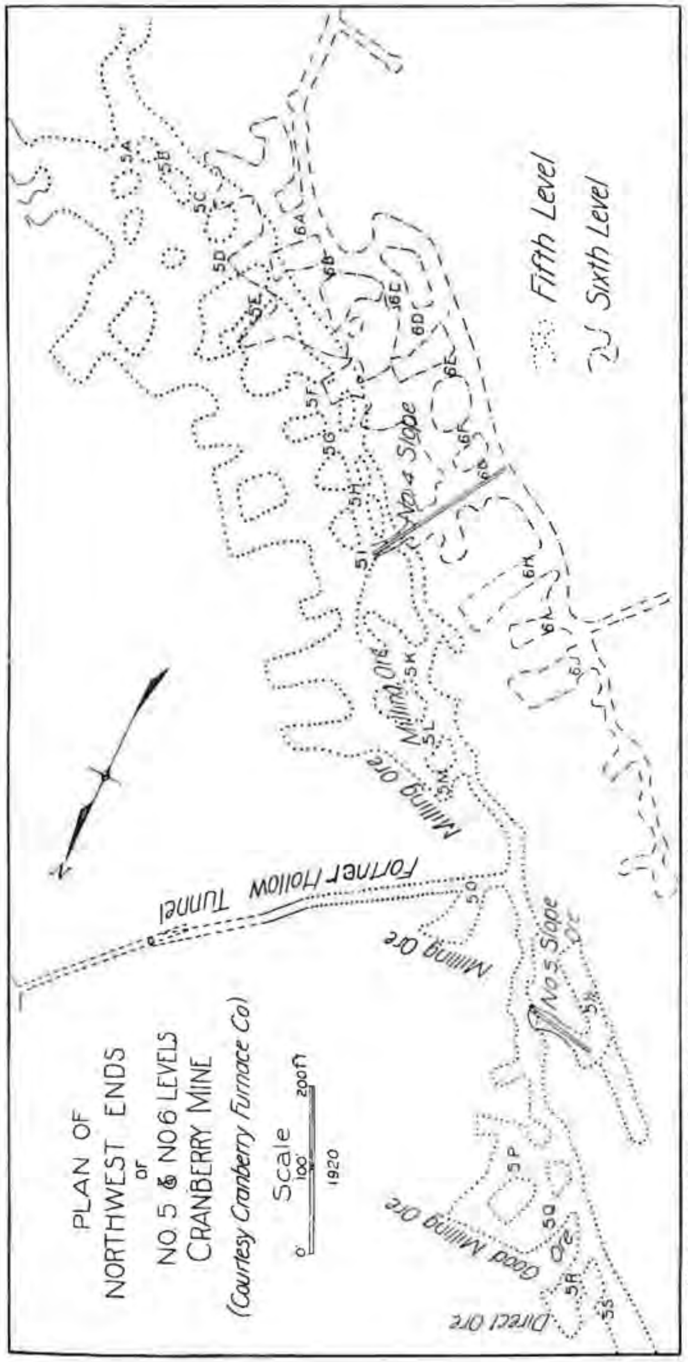
Smoky No. 1

The southeasternmost opening in the Cranberry mine tract is at the head of a ravine on the north slope of Smoky Mountain about three-quarters of a mile southeast of the main opening of the mine. The exposed portion of the vein widens and narrows by rolls in the hanging-wall, in some places being only 4 inches wide. Its general dip is southeast and both hanging and footwall are Cranberry granite. (See Plate XVII, *A*, and page 45.) The vein contains a great deal of epidote. In some places it consists exclusively of epidote and dark-green hornblende cut by quartz veins. Nearly everywhere it is bordered by a narrow seam of epidote rock which swells out at places into a coarse-grained aggregate of epidote, quartz, and idiomorphic hornblende. This coarse rock is plainly a pegmatite in which the feldspar has been changed to epidote. On the dump are fragments which show small masses of partially epidotized feldspar in the midst of nearly pure epidote-quartz aggregates. The hornblende is a greenish-black variety varying greatly in abundance in different portions of the pegmatite. It is entirely absent from some specimens, but it occurs in others forming crystal groups an inch in diameter, or, where in large quantity, forming lenticular masses that may be several inches or even several feet in length. Magnetite is always present where hornblende is abundant. It may occur in little streaks on the borders of the hornblende groups, or it may be scattered through them. Often the larger lenses are in reality granular mixtures of hornblende and magnetite, or granular aggregates of hornblende with little lenses of magnetite scattered through them. In some cases also short thin seams of magnetite and small lenses of the same mineral are to be found in the midst of the epidote, but this is not common. The magnetite and hornblende are so intimately associated that it is difficult to escape the suspicion that they are genetically connected.

Another feature that is prominent in all the pegmatite in this opening is the apparent schistosity of the rock. The lenses of hornblende, of magnetite and of the mixtures of the two and large isolated crystals of hornblende are all elongate in the plane of the vein. The quartz, however, rarely shows this parallelism to a marked degree and the epidote never.

The ore is mainly toward the center of the vein between the streaks of epidote rock near its borders. It is the usual mixture of hornblende and magnetite cut here and here by strings of nearly pure magnetite. (See pages 52 to 58.) In the midst of the vein is a banded gneiss that looks

PLATE XVI.



Plat of workings. Cranberry mine, Cranberry, N. C. (Compiled from maps by the engineer of the Cranberry Furnace Co. By courtesy of Pres. F. P. Howe.)

like a schistose diorite, and it is noticeable that the feldspar in it is pink and shows little trace of epidotization. The miners state that the rock is a horse in the vein, which plays out along its strike and often continues in the ore as partings. Moreover in this opening a small diabase dike cuts the ore lengthwise, but this is not significant, as similar dikes occur in the granite at some distance from the vein.

The material of the "horse" is a distinctly gneissic, somewhat fissile, gray and white mottled rock, with occasional white feldspar streaks and chlorite partings parallel to the schistosity. The mottlings are due to the presence of fragments of decomposed plagioclase (mainly oligoclase), scattered through a dark-gray matrix. The centers of the grains contain numerous small prisms of a light-colored epidote (probably zoisite), but they are surrounded by broad rims of newer plagioclase entirely free from decomposition products. The feldspar fragments are embedded in an aggregate of quartz, feldspar, plates and spicules of hornblende, and nests of yellow-green epidote. The quartz and epidote form a mosaic and the hornblende occurs as clumps in this mosaic as though representing grains of some mineral that has otherwise completely disappeared. Although the greater part of the hornblende is in the mosaic many spicules extend into the rims around the larger grains of feldspar and some penetrate into their altered nuclei. Many of the feldspar grains are granulated on their edges and nearly all show curved twinning lamellae.

Horses of this kind are not notably different from the more common varieties of Cranberry granite. They are apparently portions of the granite that have been enclosed in the vein and greatly metamorphosed. Their principal difference from the granite is in the greater proportion of hornblende and epidote in them.

Mention has been made of the fact that as a rule there is a narrow layer of epidote on the outside of the vein. This is usually between the ore and the walls; but at one place a little lens of ore, composed of the usual granular mixture of hornblende and magnetite, separates the epidote from the hanging wall. Between the ore and the wall is a gouge of chlorite mixed with particles of magnetite.

Smoky No. 2

The next important opening on the mountain is the pit and tunnel known as Smoky No. 2. It is about 1,100 feet northwest of the opening just described and 250 feet below it. At the end of the tunnel the vein can be seen to be 8 feet wide and to dip about 20° SW. The dip rises to 32° in some places, said to be due to rolls mainly, if not exclusively, in the hanging-wall. Between the Cranberry granite and the vein-mass on both walls are gouges of shaly or slaty chorite schist. This gouge is about 1½ inches thick on the hanging-wall and consists almost

PLATE XVII.

(*A*)

(*B*)

(*A*) Smoky No. 1 opening, Cranberry mine, showing platy structure of hanging-wall granite.

(*B*) Part of wall, open cut, Cranberry mine, showing irregular distribution of ore. All the rock in view is vein-filling.

solely of chlorite. The ore-matter is composed of a mixture of magnetite, hornblende, epidote and quartz, cut by veinlets of magnetite, and here and there by veinlets of epidote. The richer portions contain a greater number of magnetite veinlets or a few larger veins. Some of the latter are themselves cut by small calcite veins and by tiny streaks of pyrite. Ore of this kind is massive, or very slightly schistose. It is composed of large crystalloids of magnetite and in addition garnet in some places. A microscopic description of the ore is on page 56. A parting in the ore consists of very fine-grained epidote with parallel streaks of quartz. Its surfaces are covered with a thin coating of the same chloritic gouge that occurs on the walls of the vein, indicating movement in the ore-body after it became solid.

On the dump at the tunnel are many large fragments of ore and vein-rocks that afford a better view of the relations of these to one another than can be seen on the walls of the tunnel, and also great fragments of a very feldspathic weakly schistose gneiss that is said to occur as a "horse." The feldspar of this gneiss is pink and fresh, and the rock shows no trace of epidotization. Under the microscope the rock is seen to be composed of large orthoclase and oligoclase or andesine grains, broken across, crushed on their edges, and often separated into sharp-edged fragments, surrounded by a quartz-feldspar mosaic containing numerous small plates of a yellowish-green biotite, that lie between the larger grains and wind around them. Other sections contain a great deal of granular epidote and a few wisps of green hornblende. The rock apparently is a crushed Cranberry granite.

The greater portion of the vein-filling is a foliated gneiss composed of alternating feldspathic and hornblendic layers. The feldspathic layers appear to have intruded a series of alternating layers of hornblende schist, sugary quartz and finely granular epidote making up a portion of the vein mass at this place. Certain of the feldspathic streaks appear to extend into the schists and to terminate in quarz-epidote veins; in other places they swell into pegmatite lenses.

Within this vein-mass are lenses of quartz and veins of granular epidote ranging from a tiny fraction of an inch to an inch or more in thickness. In many places, especially where they are in contact with hornblende, the epidote veins are bordered by narrow zones of magnetite. Lenses and veinlets of pure magnetite also occur in the hornblende layers. In some places the magnetite lenses seem to be isolated but in most places they are connected by small veins of magnetite. Those portions of the hornblende layers that are most closely crowded with the lenses and veins constitute the commercial ore. In some specimens the hornblende is extremely fine-grained and schistose, and where it breaks away from lenses of magnetite embedded in it the contact surfaces are seen to be coated with chlorite. Moreover, much of the hornblende in the schist

layers is also apparently chloritized. Evidently there has been movement within the vein since its solidification. This is also evidenced by the fact that the pegmatite lenses which are common in the foliated gneiss are in some places crushed into their component feldspar and quartz grains, so that their grains, especially the feldspar grains, are separated from the main mass of the pegmatite and surrounded by films of the hornblendic schist.

In the opening above the tunnel the vein exposed at the back and on the sides of the opening consists in the main of the same coarse-grained hornblende-epidote filling as elsewhere; but in addition there is present much garnet. Near the hanging-wall are several distinct veins of epidote cutting the vein-mass, and between these and the wall the usual vein matter is replaced by a compact aggregate of garnet, hornblende, feldspar and calcite, in which the hornblende appears to be the oldest component.

A slide made across the contact of a small epidote vein and the coarse hornblende mass shows the hornblende mass to consist of a fine-grained mixture of uralite, epidote, quartz, magnetite crystals, calcite nests, and veins and lenses of quartz mosaic. The hornblende, however, frequently polarizes uniformly over large areas, and produces the coarse texture noticed in the hand specimen.

The epidote vein is a granular aggregate of yellow-green epidote crossed by veinlets of quartz mosaic between the grains of which in places is a filling of calcite. There is no sharp contact between the epidote vein and the hornblende mass. In some places there is a thin seam of quartz between the two; but in most places the contact is simply a plane on one sid: of which there is an abundance of amphibole and on the other side none.

Toward the center of the vein, but distributed rather irregularly through it, are masses of lean ore consisting of a granular aggregate of magnetite, hornblende and epidote and masses of what was originally a coarse pegmatite but which now is a very coarse aggregate of hornblende and epidote, with hornblende individuals often half an inch long, containing numerous tiny grains of magnetite. Here and there a garnet is associated with the epidote and scattered through the mass are tiny veins of calcite. Calcite is especially noted on joint cracks, but it occurs also scattered among the epidote grains. Quartz lenses a few inches long are not uncommon in the midst of the hornblende. Near them are often little pyrite cubes. In certain portions of the vein the magnetite grains in the hornblende become larger. They group into little aggregates of lenses and the mass becomes a lean ore. Through this calcite veins run in all directions.

Sections from an irregular mass of epidote and hornblende taken from about the center of the vein when viewed under the microscope show large masses of pure epidote, cut by veinlets of quartz and epidote and surrounded by a mixture of epidote, hornblende, quartz, and feldspar containing little nests of calcite. A few little crystals of magnetite are scattered through the hornblende-epidote mixture and a thin border of garnet in a few places lies between the large epidote areas and those characterized by the presence of hornblende. Quartz veins and epidote veins cut through the rock in various directions. The areas in which epidote alone, or epidote and calcite occur and those in which hornblende is prominent, are so distributed as to suggest that the former represent feldspar and the latter pyroxene. Thus reconstructed, the rock appears to have been a coarse augite-syenite—probably a pegmatite.

Lean ore masses scattered through the vein are composed mainly of uralite, epidote, and magnetite. The uralite and epidote are in areas that suggest a granitic rock. The only differentiation observable in it is that in some areas the light colored granular epidote is free from hornblende and in others one-half or more of the mass consists of crystalloids of hornblende inclosing grains of epidote, feldspar, and calcite. The magnetite is in much smaller quantity than would be thought from a study of the hand specimen alone. It occurs in a few irregular grains surrounded by narrow zones of light colored epidote, even when present in areas characterized by abundant uralite.

Firmstone opening

Another opening, the Firmstone opening, at the base of the mountain, about 1,300 feet northwest of Smoky No. 2, is an old pit on the dump of which are many large fragments which show that the conditions in the vein at this point are the same as at Smoky No. 1 and Smoky No. 2. The vein does not change in its character through this length of half a mile.

Mine opening

Naturally, the best exposures on the Cranberry property are at the mine, where there is a large open cut on the east slope of Cranberry Hill (Plate XVI), an eastern spur of Hump Mountain, and a tunnel at its base. The mine is entered by the tunnel, which runs southwest to the vein, at an elevation of 3,211 above sea level. From the junction the vein is followed along its strike, which is N. 34° W., and the mixed ore and rock are taken out as the advance progresses. Above this level are others which were abandoned as the ore was removed. The ore is now being worked upward and downward from the tunnel level and this at the same time is being advanced along the vein by stoping at its end. From the southeast part of the mine a slice of mixed ore and rock has been removed which was about 200 feet thick, 800 feet long, and 300 feet high (measured on its dip). As the work advanced along the strike of the vein the ore body alternately widened and narrowed. It

PLATE XVIII.

(A)

(B)

(A) Part of wall of open cut, Cranberry mine, Cranberry, N. C., showing irregular distribution of pegmatite in the vein-filling.

(B) General view of wall of same cut, showing hanging-wall of foliated Cranberry granite.

also widened and narrowed on the dip. In other words, that portion of the vein that is minable occurs in lenses surrounded by portions that are not minable under present conditions. (Compare Plate XVII, *B*.) These non-minable portions contain magnetite, but not in sufficient quantity to pay for working. If an efficient concentrating process were available it is probable that much more rock might be removed from the vein and treated with profit, and it is possible that the entire contents of the vein might become available for concentration, in which case the lens-like character of the ore body might not be so distinct.

The portions of the vein that are now minable are certainly lenticular. (See plat, Plate XVI.) The lenses are about 800 feet long and 200 feet wide at their widest part. Their heights in the plane of the dip are not known but are in the neighborhood of 500 feet. So far as present observations are possible the lenses appear to have no pitch. They are separated from one another partly by pinches in the vein but more commonly by the narrowing of the richer portion of the vein-filling. However, they are connected by thin stringers of ore, which in every case thus far noted, lead from lens to lens. This is true not only for that portion of the vein in the neighborhood of Cranberry, but apparently it is true also for its northwestern extension as far as Shell Creek. Mr. Hamilton, who has investigated this portion of the vein by magnetic methods, states that a narrow line of attraction can be detected following the course of the vein and that at irregularly spaced intervals this line expands to broader areas. In the areas of most pronounced attraction are the Cooper, Wilder, Red Rock, Patrick, Teegarden, and Ellis explorations.

Explorations in the mine have not shown the downward termination of the lenses nor have they outlined their limits in all other directions. The mine plat (Plate XVI) shows that the general shapes of the horizontal sections of the ore-bodies are those of horizontal sections of lenses, but no complete vertical sections are available. The floor of the lower level of the mine is on ore, but drill holes that were sent downward to determine the extension of the ore-bodies down the dip are reported to have shown very little ore in this direction. It is reasonably certain that the ore occurs in lenses and that the lenses do not terminate abruptly with depth. If the source of the ore was, as supposed, a subterranean magma (see page 68), it is probable that the deposits extend downward for some distance. On this assumption there should be ore below the present floor of the mine. It is upon this supposition that the estimate of reserves given on page 78 is based.

The best exposures of the vein are in the large open cut on the slope of the hill. (See Plate VIII, *A*, Plate XVII, *B*, and Plate XVIII.) The vein here is about 80 feet wide. On the walls of the cut are excellent exhibitions of the relations of the various phases of the vein-filling to one another that have already been described (pages 48 to 67.)

Large "horses" of rock occur in the vein, and on the wall of the cut sections of some of them can be seen. Some of the specimens on the dumps are not very different in appearance from those taken from exposures of the Cranberry granite. They are so like the schistose portions of the Cranberry granite that they are believed to be splinters of the granite mass that were split off the main mass at the time the vein was formed. Other specimens of schistose granites are streaked porphyritic gneisses with here and there alternating layers of darkgreen hornblende like that associated with the ore. These were apparently a part of the vein-filling: They consist of zoisitized plagioclase fragments in a schistose matrix composed of small fragments of plagioclase, elongate grains of newly crystallized, striated and unstriated feldspars, a little quartz, some uralite, considerable granular colorless epidote and a few streaks of yellow-green epidote. (Plate XX, *B*.) Nests of calcite are scattered through the matrix irregularly. The hornblende flakes and epidote streaks wind sinuously between the large feldspar fragments and are separated from one another by a fine-grained mosaic of quartz or of quartz and feldspar. Much of the colorless epidote is in tiny grains and crystals scattered through the feldspar, but in some places the epidote particles are arranged in thin straight lines following definite twinning striae as though certain of the plagioclase lamellae had been more susceptible to change than others.

The general features of the rocks constituting the vein-filling have already been described (see page 48), but there are certain additional features exhibited by some of the specimens in the rock pile at the bottom of the incline that should be referred to briefly. One of the more abundant rocks in the pile is a coarse-grained hornblende pegmatite cutting a coarse hornblende rock. In most specimens this has the character already described (page 62), but in some specimens magnetite occurs abundantly as irregular masses in the hornblende. Where not scattered indiscriminately through the hornblende in the pegmatite it appears as a selvage between the pegmatite and the coarse hornblende rock through which the pegmatite cuts. The hornblende rock also often contains little blebs of magnetite and is traversed by veinlets of the same mineral.

A few fragments of pegmatite are essentially magnetite pegmatites. They differ from the more common hornblende pegmatites solely in the fact that magnetite has replaced most of the hornblende. The microscope shows that there still remains considerable hornblende in the black masses within the pegmatite but it is so completely saturated with magnetite, that the hand-specimen appears to consist exclusively of partly epidotized feldspar and magnetite. There is no magnetite present, however, except in aggregates with hornblende. It is not present in the feldspar unmixed with hornblende.

In many specimens the proportion of magnetite in the pegmatite is so great that the mass becomes ore. In these the feldspar is limited to a few ill defined crystals mixed with coarse hornblende crystalloids and a few little elongate grains of the same mineral forming lenses embedded in an irregular, more or less schistose aggregate of hornblende and magnetite, traversed by numerous veinlets of magnetite.

In a characteristic thin section are large plagioclase fragments crushed on their edges to small fragments which are mingled with grains of epidote and wisps of amphibole to form a matrix in which the large fragments are usually embedded. Often the large fragments are cracked and their parts slightly displaced, their twinning striations at the same time being bent and twisted in a complicated way. Between the fragments of the feldspar is a mixture of small quartz grains and epidote, the latter of which is not only present in small equidimensional grains but also in elongate grains and in large clusters of grains. The quartz grains are slightly lenticular. Their long axes are approximately parallel to the elongation of the epidote and to that of the hornblende, and as a result the rock is schistose. The epidote and much of the quartz are secondary as they both form little veins in the feldspar and some of the more compact hornblende. A little of the quartz is probably original. This is now represented by a few grains a little larger than the average that exhibit shadow extinction. Crystals and groups of crystals of epidote are also scattered through the feldspars, and veinlets of the same mineral occur in the cracks between their dissevered parts. Between neighboring large grains are often thin seams of amphibole inclosing in places large nests of bright-yellow epidote.

In the richly magnetitic pegmatites the magnetite is commonly associated with the hornblende. It is present either as comparatively large masses comparable in size with the feldspars and pyroxenes before they were broken, or as smaller sharp-edged pieces scattered through the aggregate of uralite, quartz, feldspar and epidote that lies between the large broken grains. In many places the sharp-edged pieces appear to be fragments of large grains that have been moved apart for considerable distances. In other places they are so close that they can be fitted together into a single grain. Where close together they are separated from one another by narrow cracks, in which may be a little brown biotite or a little uralite. The larger pieces have irregular boundaries as though they had been corroded, and it is noticeable that any feldspar in contact with them has been completely changed to epidote. In some sections are also a few crystals of apatite.

Allanite is the only other mineral that has been seen in any section of pegmatite. It is in crystals several millimeters in length, that seem to have suffered no deformation and but very slight alteration.

Where the feldspar of any variety of the pegmatite is in contact with masses of hornblende, the feldspar near the contact is commonly completely changed to epidote whereas that an inch or more from the contact is white and fresh and shows no trace of epidotization. The epidotizing solutions appear to have emananted from the hornblende, which may indicate that the hornblende was intruded after the pegmatite.

Most fragments of the pegmatite on the dump are of the kind described. There are, however, others of a very quartzose type, in which the quartz is blue. This variety contains no hornblende, but is composed of quartz and feldspar almost exclusively. As the rock shows very little schistosity and its components show no evidence of crushing, it must be a much younger rock than the more common syenitic pegmatite. (Compare Plate VIII, *B*.)

The garnet rock that occurs so abundantly in Smoky No. 2 (page 110), is fairly abundant on the dump of the mine. In part it is associated with hornblende and in part with magnetite. In the mine it is said to be always close to pegmatite, but the exact relations of the two are not more definitely known. Whether associated with hornblende or magnetite the garnet makes up by far the greater part of the mass. As a little feldspar and epidote are present in all specimens of the garnet rock it is probable that the rock is either a part of the pegmatite or a contact metamorphic product of some pre-existing rock.

The hanging-wall rock in the mine is a chloritic gneiss cut by a few quartz veins. (Plate XVIII, *B*.) It is apparently a very much sheared phase of one of the darker layers of the Cranberry granite. An analysis by Dr. J. I. D. Hinds of the Tennessee Geological Survey yielded:

Partial analysis of gouge in hanging-wall of vein at Cranberry mine, Cranberry, N. C.

Silica (SiO_2)	58.40	Magnesia (MgO)	3.10
Alumina (Al_2O_3)	19.52	Lime (CaO)	.96
Ferric oxide (Fe_2O_3)	11.28	Phosphorus pentoxide (P_2O_5)	.47
Ferrous oxide (FeO)		Water (H_2O+)	2.78

OTHER OPENINGS IN THE CRANBERRY BELT

Lee Johnson place

That portion of the Cranberry belt between Vale and the southeasternmost opening of the Cranberry mine near the crest of Smoky, or Little Fork, Mountain has been traced only in a very general way. There are two openings on the Lee Johnson place on the west side of the road, one mile north of Vale, and occasional small openings or outcrops on the northeast slope of the mountain, but most of the course of the vein is covered by such a thick forest growth that it cannot be followed. At the Johnson place are two openings, one a pit and the other a tunnel. At present both openings are overgrown and all that is visible at them are their dumps. The ore was like the rich ore at Cranberry. The Interstate Coal and Iron Co. is said to have shipped from them about 2 carloads. It is reported that the vein strikes NW. and that its dip is 25° to 36° SW.

Cooper place

The first openings on the vein northwest of the Cranberry mine are at the old Cooper place about three-quarters of a mile south of Elk Park. At present nothing can be seen of the mine but several large depressions which represent the old open cuts. Nitze[75] states that the openings were made about 1884 and that a small quantity of ore was shipped from them to Roanoke, Va. He declares that they exposed "a body of ore, and mixed ore and gangue varying in thickness, as visible at present near the outcrop, from 5 to 10 feet, with a dip of about 33° southwest. . ." Southwest of the Cooper openings is a series of shallow pits on the northeast slope of Hump Mountain, but they show nothing. Perhaps these openings are on the Crowder place which is described by Nitze as being 1 mile S. 30° W. from Elk Park. On the western slope of a ridge, near its summit, writes Nitze,

> "the outcrop was stripped for a short distance, exhibiting a backbone of ore from 1 to 2 feet in thickness; it was explored 15 feet below the surface by a short adit-level and found to widen to 3 or 4 feet. A shaft was sunk on the ore, at the mouth of this adit-level, to the depth of 40 feet, proving in increase of thickness. . . .
>
> "The ore resembles that of the Cranberry mine in every particular. The strike is northwest . . ., and the dip nearly vertical."

Ellers and Hardigraves Elk Park openings

It is possible that Nitze's last reference is to the openings about three-quarters of a mile southwest of Elk Park. These are known as the Ellers and the Hardigraves Elk Park openings. They are on opposite sides of one of the branches of that fork of Elk Creek which crosses the railroad just west of Elk Park station. It is reported that they have yielded about 3,000 tons of ore averaging about 42 per cent. iron and 0.012 per cent. phosphorus.

On the Ellers property there are three openings, of which one is a shaft. Although some work was being done at the shaft at the time of the writer's visit in 1919, no rocks were exposed. The miners stated that the vein is 4 to 4½ feet thick, possibly increasing to 9½ feet with depth. At the Hardigraves openings the vein rolls with a general southwest dip. As the walls have become covered with soil and weeds nothing of interest with reference to the ore could be seen here. However, a great vein of weathered pegmatite was recognized; but whether it cut the ore or not could not be determined.

[75]Op. cit., p. 180.

Small openings and surface exposures leave little doubt that an ore belt continues without serious interruption from Cranberry to Elk Park, and magnetic observations seem to indicate that if breaks do occur in the vein they are of such slight magnitude as to be of no significance. They may indicate merely that the ore is in lenses in the vein and not in a continuous sheet.

Wilder mine

The next openings to the northwest of the Elk Ridge mines are those of the Wilder mine, in Carter County, Tennessee, about one-third of a mile south of the railroad and half-way between Elk Ridge and Shell Creek stations. This mine is about 2 miles north of west of the Ellers mine. The Wilder mine was first opened before 1880, but was worked only on a small scale. It was taken over by Milt Miller and associates in 1896 and about 5,000 tons of lean ore was shipped to the Cranberry Furnace Co. at Johnson City. The last shipment (in July, 1918) was 10 cars of ore averaging 30.70 per cent of iron and 0.014 per cent of phosphorus. The average iron content of 4,915 tons shipped to the Cranberry furnace was reported by Mr. E. B. Kirby to be 37.5 per-cent and that of titanium oxide 0.15 per cent.[76] The mine is now owned by the Cranberry Furnace Co. The mine consists of several large open pits, several tunnels and underground drifts and a number of smaller openings that are distributed in a bewildering way (Plate XIX), until it is realized that the vein here is in folds. The country rock is Cranberry granite.

At the mouth of the large tunnel at the east end of the property the dips are about 20° toward the southwest and 100 feet farther southwest at the mouth of a smaller opening the dips range between 15° and 40° to the northeast. Again, at the northwest end of the large cut in the western part of the property the dip is 45° southwest and at the opening about 150 feet southwest of the east end of the cut is about 10° northeast. About 400 feet northwest of this point a flat dip is again observed. Observations are so few that they do not furnish sufficient data for working out the structure of the vein in detail. They indicate, however, that the two parallel deposits at this place are not in different veins but in the same one that lies in a synclinal fold, with its axis between the two lines of deposits.

The vein-matter is very much like that at Cranberry. The major part consists of layers of interbanded hornblende and epidote alternating with layers of coarse hornblende. The epidote grades into pegmatite which clearly is intrusive into the hornblende, giving an impregnation gneiss.

A section of a very evenly banded gneiss reveals wide layers of coarsely granular hornblende, very narrow layers composed of alter-

[76]Quoted by S. H. Hamilton in an unpublished report to the Tennessee Geol. Survey

nating layers of hornblende and epidote and slightly thicker ones of epidote, all evenly interbanded, as though the rock were an impregnation gneiss in which the feldspar had been changed to epidote. There are also a few narrow belts of fine-grained granular epidote alternating with bands of quartz mosaic containing a little uralite. Some of the quartz is in small lenses, and some in narrow seams or veins cutting through the epidote.

An analysis by Dr. J. I. D. Hinds, chemist of the Tennessee Geological Survey, of a specimen of a coarse-grained hornblende rock collected by Mr. Hamilton to represent the vein filling resulted as follows:

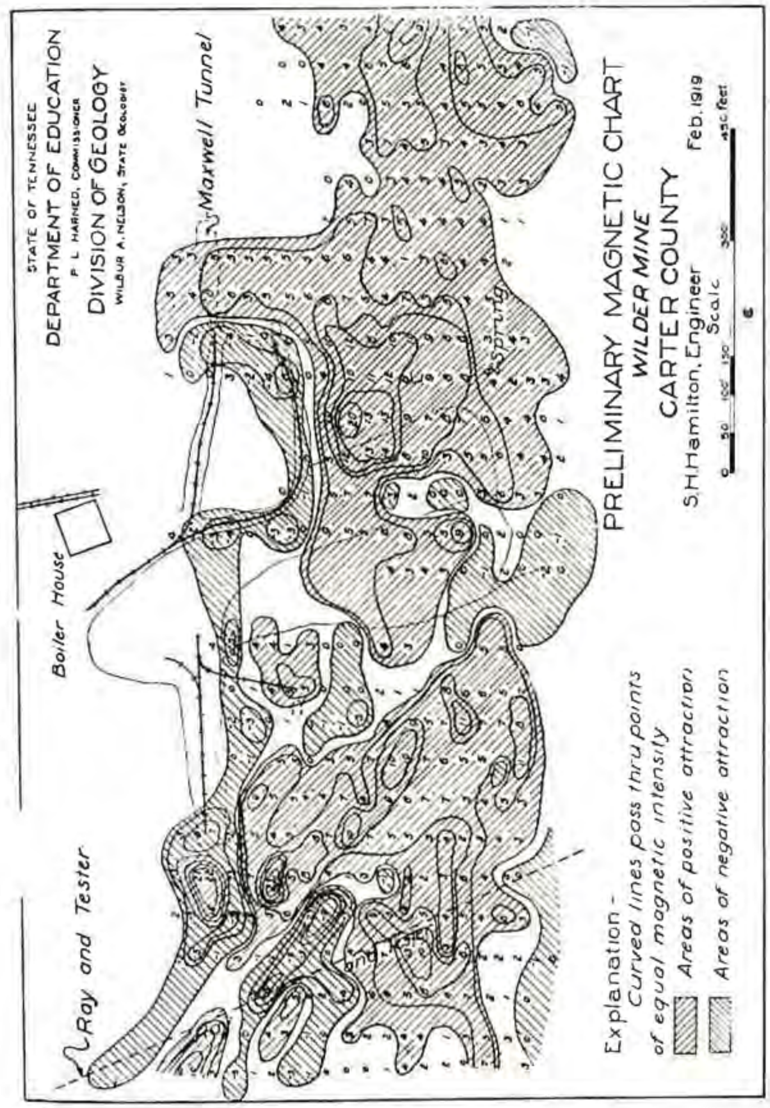
Partial analysis of vein-filling at Wilder mine, N. C.

Silica (SiO_2)	46.22	Magnesia (MgO)	2.92
Alumina (Al_2O_3)	5.44	Water (H_2O)	.40
Iron oxides (as Fe_2O_3)	27.52		
Lime (CaO)	16.00		98.50

A magnetometric survey made by Mr. Hamilton[77] indicated that on the east side of the little branch dividing the property into two parts a buried magnetic mass occupies about 210,000 square feet. (See Plate XIX.) It dips to the south and pitches to the east. If the ore-body is 5 feet thick, according to Hamilton it contains 100,000 tons of ore. To the west of the branch another ore-body is indicated, but it is broken at several places and contains only 50,000 tons of ore. If the ore-bodies are more than 5 feet thick, the quantity of ore in them is correspondingly larger. In the two bodies Hamilton estimates 150,000 tons of ore as probable and 600,000 tons as possible. Hamilton does not make any statement of the quality of this ore, but from the context in his report it is probable that the estimate is based on a content of iron averaging 25 per cent.

In order to determine the availability of the ore for concentrating he obtained 2 cubic feet of rock from the Maxwell tunnel (Plate XIX), on the east side of the creek, and crushed it to pass a five-eighths inch mesh. The material that passed a three-sixteenth inch mesh was screened out, and both coarse and fine screenings were passed over a Firmstone-type magnet actuated by a current of 13 amperes. A crude ore containing 25.08 per cent. iron, crushed to five-eighths, passed over a magnet carrying 13 amperes of current yielded a concentrate of 28.4 per cent. of iron, after retreating the tails four times. One-third of the total iron was lost. The smaller size screenings subject to the same treatment yielded a concentrate containing 28.3 per cent iron, but only one-fourth of the total iron was lost. When crushed to one-twelfth inch mesh and subjected to a magnet of the same strength in water a concentrate of 45.25 per cent iron was obtained, but no estimate was made of the quantity of total iron that was lost. Hamilton concludes that the ore of the

[77]Hamilton, S. H., Unpublished report to the Tennessee Geol. Survey.



Isodynamic chart of Wilder mine property, near Shell Creek, Carter County, Tenn. (By S. H. Hamilton. Courtesy of Cranberry Furnace Co.)

Wilder mine is valueless unless subjected to fine grinding and concentration.

Greenlee and Ray and Tester property

Higher on the hill and west of the Wilder mine are several open cuts and underground workings in which the ore is similar to that at the Wilder mine. Some ore was taken from them but it was shipped with the Wilder ore. Mr. Hamilton states that his survey showed no magnetic line going down the hill into the Morgan Branch hollow to the west.

Red Rock mine

About half a mile west of the Wilder mine is the Red Rock mine, which is well up on a steep slope on the west side of Morgan Branch hollow and about half a mile south of the East Tennessee and Western North Carolina Railroad. The property is owned by the Tennessee Coal, Iron and Railway Co. It was leased to Steven Pittman who mined a little ore and then abandoned it. The place is now so overgrown that it is impossible to learn much about the relation of the ore to the country rock. On the dump, however, are great fragments of a rock composed of garnet, magnetite, epidote, calcite, and quartz and also large pieces of a coarse pegmatite. Aside from the pegmatite the two most prominent rocks on the dump are a massive granular aggregate of garnet, hornblende and epidote and an equally massive aggregate of hornblende and epidote.

In the garnetiferous rock the garnet and hornblende form a rock without any trace of schistosity. In it are irregular lens-like masses of coarse hornblende and calcite and in this aggregate are nests of almost pure marble. Under the microscope the rock is seen to be an aggregate of anhedrons of garnet and a light green pyroxene which is uralitized in patches and saturated with calcite. Calcite occurs also as little nests in the uralite and in tiny veins crossing the partially uralitized pyroxene. The same mineral is also in large grains in corners between the other components and as enclosures in the garnets. Much of the calcite appears to be a result of the decomposition of the pyroxene, as it is more abundant in the more completely uralitized pyroxene grains than in those that have suffered little uralitization. Whether the large grains of calcite in the garnets and in the spaces between the garnets and the pyroxenes are original or secondary has not been learned.

On analysis the garnets carefully separated from the other rock components gave to Dr. J. I. D. Hinds, chemist of the Tennessee Geological Survey, the following result:

Analysis of garnet separated from the vein-filling at the Red Rock mine, Tenn.

Silica (SiO_2)	36.64	Ferrous oxide (FeO)	5.14
Alumina (Al_2O_3)	8.45	Lime (CaO)	29.20
Ferric oxide (Fe_2O_3)	20.52		99.95

The epidote-hornblende rock in thin section is seen to be very slightly schistose. Masses of granular epidote, a few irregular dark garnets, mixtures of uralite and epidote, little remnants of twinned plagioclase in the midst of the epidote, small irregular quartzes scattered through the other components, and forming mosaic veins cutting through them, and little nests of calcite in the mixtures of uralite and epidote make up the rock. The masses of granular epidote, with some quartz grains and remnants of feldspar scattered through them, may represent original feldspar; the mixtures of uralite, epidote, quartz, and calcite may represent augite. If this is so the original rock was an augite syenite. The garnet is in streaks between the epidote areas and those in which hornblende and epidote are both present and in coronas surrounding the epidote. It occupies the position of a contact product between the inferred original augite and feldspar.

The ore here is different from that of the other mines in the vicinity, in that it contains a great deal of calcite. In another place (page 195), are outlined the reasons for supposing that this difference may be due to the fact that in the mine the ore-bearing solutions encountered limestone rather than granite in their ascent.

Patrick mine

About three-quarters of a mile farther northwest are the old openings of the Patrick mine on the south side of the road running south along Shell Creek, and between this and the Red Rock mine are other old openings in which now practically nothing of interest can be seen. They are of importance at present only as indicating that the vein belt is continuous between the two mines.

At the Patrick mine are holes in the hill slope alongside the road and there is an outcrop in the road, but the relations of ore to vein-rock and of vein-rock to country rock are the same as at the Cranberry mine, so far as can be observed. A little ore is said to have been produced twenty or thirty years ago, but the place has been abandoned.

Teegarden and Ellis mines

Farther to the northwest are two comparatively new mines about half a mile apart on opposite sides of a little ridge, about three-quarters of a mile southeast of Shell Creek station on the road up Shell Creek. The strike of the vein at the eastern mine is N. 60° W. and its dip about 30° SW. The eastern mine, in Vance hollow, is known as the Teegarden or Shell Creek mine, and the western one, in Ellis hollow, the Ellis mine or Oakes Entry. The mines were worked by Messrs. Ellis and Kirkpatrick in 1917, producing about 500 tons of ore that was taken by the Cranberry furnace. In December, 1917, the Cranberry Furnace Co.

leased the property and operated the Teegarden mine until the end of May, 1919. The Ellis mine was worked mainly as a prospect. Both mines are now idle.

During the two years of operation there were shipped from the property 17,375 tons of ore, averaging 36.36 per cent iron and 0.0113 per cent phosphorus. It was fed to the furnace without beneficiation. As mining progressed the quality of the ore deteriorated to such an extent that it was no longer acceptable at the furnace and shipments were stopped. Between May and September, 1917, the average content of the ore shipped was 43.63 per cent iron and 0.0093 per cent phosphorus, and between January and May, 1919, the average iron content was 32.10 per cent and the average phosphorus 0.014 per cent.

At the Teegarden mine it is said that there was a streak of rich magnetite 5 feet or 6 feet wide in a lean ore vein 20 feet wide. Judging by the material on the dump the vein is a duplicate of that at Cranberry. Pegmatite cuts the vein and the ore-body, which pinches at intervals, in consequence of rolls in the hanging-wall. The pegmatite that crosses the ore extends beyond the vein walls into the surrounding Cranberry granite, cutting it at an inclination to its foliation. (Plate VIII, *B*.) However, it is, itself, more or less schistose in the same direction as the foliation of the gneiss surrounding it, suggesting that it may have been forced between the gneiss layers while schistosity was being imposed on the mass. The pegmatite is a quartzose variety containing much blue quartz. It is in every respect like the quartzose pegmatite at the Cranberry mine.

On the dump of the mine are all phases of the epidote-hornblende rocks noted in the description of the Cranberry mine. Moreover there are a few specimens of nearly pure hornblendite consisting of layers of a fine-grained slightly schistose hornblende rock in which there is a little feldspar and much magnetite, others of a coarse-grained hornblende rock exhibiting neither schistosity, nor the presence of feldspar or of any other component than hornblende, and others of a light-gray gneiss that is reported to occur as a "horse" in the vein.

The light-gray gneiss is a crushed mass of orthoclase and striated acid plagioclase, wisps of amphibole and a few grains of colorless epidote. Large fragments of the feldspars are embedded in a finer grained schistose feldspar-quartz matrix in which are many little nests of calcite, shreds of green amphibole, a few shreds of biotite and a comparatively few small grains of epidote. The fragments of this matrix are cemented by a still finer grained aggregate of the same composition. All of the larger pieces of the matrix have their longer dimensions in parallel orientation, and the shreds of amphibole are arranged in the same general direction, though they are much bent as they curve around the large fragments of feldspar. It is probable that the gneiss is a part of the Cranberry granite. It certainly is not a part of the vein material.

The fine-grained hornblende layers are lean ores and their schistosity is due primarily to the presence of the magnetite in parallel streaks. All their components are elongated in the same direction as the layering noticed in the hand specimen, thus accentuating the schistosity produced by the concentration of the magnetite in definite layers. The magnetite is in long, thin ragged pieces, many of which appear to be fractured and in small grains which in most cases look as though they had been broken from the larger ones. The mass in which the magnetite is embedded is a very schistose mixture of uralitic hornblende, wisps of brownish-green biotite, calcite, a little quartz and small particles of magnetite. The quartz and some of the calcite are in veins that extend in the direction of the rock's schistosity, and in the section studied the calcite veins are in the layers in which the magnetite is most thickly concentrated. Calcite is also scattered throughout the entire section, but it is much more abundant and in much larger pieces in the layers in which magnetite is also most abundant. Uralitic hornblende constitutes the principal component of the coarse-grained layers between the richly magnetic layers. Its fibers are all elongated in the same direction. Associated with them are a few wisps of biotite, and in the spaces between these are little nests of calcite. Scattered through this mass are small grains of magnetite, which are in nearly all cases arranged roughly in lines. The biotite is the only component that is not in all cases oriented with the schistosity. Although most of the wisps of biotite that are embedded in the hornblende lie parallel with the hornblende fibers, many others cross them nearly perpendicularly; and the wisps that penetrate the calcite are arranged radially, in some cases forming radial groups. The biotite is evidently the youngest mineral in the rock as its spicules cross indifferently the borders between hornblende grains and calcite grains. They were evidently not present when the schistosity was produced.

Where epidote veins cut the lean ore, the epidote is bordered concentrically by thin selvages of hornblende, layers of nearly pure magnetite, and layers of mixed magnetite and hornblende.

Pegmatite fragments on the dump are often garnetiferous, and one specimen shows a mixture of sugary marble and light red garnet with the pegmatite. The relations of the two rocks could not be determined.

A selected specimen of the lean ore, analyzed by Dr. J. I. D. Hinds, of the Tennessee Geological Survey, gave:

Analysis of lean ore from the Teegarden mine, near Shell Creek, Tenn.

Silica (SiO_2)	22.65	Lime (CaO)	10.24
Alumina (Al_2O_3)	0.48	Phosphorus pentoxide (P_2O_5)	0.16
Ferric oxide (Fe_2O_3)	19.30	Titanic dioxide (TiO_2)	0.00
Magnetite (Fe_3O_4)	37.46	Carbon dioxide (CO_2)	2.70
Magnesia (MgO)	0.00	Water	0.28
			99.90

At the Ellis mine the vein is said to be 10 feet wide. Its strike is about 10° to 15° north of west, but it varies slightly. The dip is southerly, as high as 45° in places. The vein rock is much shattered. Large coarse hornblende masses are cut by quartz veins and by a few streaks of pure magnetite.

A magnetometric reconnaissance of the country between the Teegarden and the Ellis mines showed a continuous magnetic line between them.[78] A short distance east of the Teegarden opening is a pinch in the vein extending for 100 feet. Beyond this to the eastward another lens is indicated, and beyond this another larger ore-body that is folded. Below the present level of the mine and farther west another ore-body 300 feet long is to be expected. However, none of the ore-bodies are large, and Hamilton's estimate of the probable ore that might be reached by the two mines is 250,000 tons.

Heupscup Ridge prospects

Heupscup Ridge is the spur of Big Yellow Mountain extending northward between Shell Creek and Hampton Creek. On the east slope of the ridge are a few outcrops and several prospect holes that mark the westward course of the vein through the Teegarden and Ellis mines. On the west slope of the ridge, near Hampton Creek, a cut was run into the hillside years ago by a Mr. Young. Although the cut is now so overgrown that no rock can be seen in its walls, from the size of the opening it is safe to infer that some ore was obtained.

The rock exposures on the road between the mines and Shell Creek are of a light-gray granite, presumably Cranberry, which is coarse and gneissic in some places and finer and banded in others. No schists were associated with either type of the granite, but it is streaked in places with pegmatite.

Peg Leg and Old Forge mines

On the divide between Hampton Creek and Doe River are the openings of the Peg Leg mine which has been worked intermittently since colonial days. As late as 1885 ore was taken from the surface to supply the Doe River forge on the banks of Doe River. In 1898 the place was reopened by the Crab Orchard Iron Co. and about 1,000 tons of ore was shipped. It was then again closed and remained idle until 1917 when it was prospected by the Magnetic Iron & Coal Co., without satisfactory results. A cut was driven 600 feet in an easterly direction through a vein 50 feet wide, of which about a third was lean ore. An analysis of a sample of the ore by Dr. J. I. D. Hinds resulted as below:

[78]Hamilton, S. H., Unpublished report to Tennessee Geol. Survey.

Analysis of sample of lean ore from northeast end of the Peg Leg prospect, Carter County, Tennessee.

Silica (SiO_2)	23.52	Magnesia (MgO)	Tr.
Alumina (Al_2O_3)	.60	Barium oxide (BaO)	.21
Ferric oxide (Fe_2O_3) / Ferrous oxide (FeO)	66.15	Soda (Na_2O)	1.12
		Potash (K_2O)	Tr.
Manganese oxide (MnO)	0.00	Phosphorus (P)	Tr.
Lime (CaO)	7.20		
			98.80

Mr. E. B. Kirby in a report [79] on the iron resources of the Doe River valley states that the east cut of the Peg Leg mine shows ore averaging 33.8 per cent of iron through a distance of 150 feet along the vein, and that it may be broken in faces 10 to 17 feet wide.

At the opening made in 1917, which is about one mile south of Roan Mountain station on the road up Doe River, is a large dump of fresh rock on which nearly all the varieties of rock seen at Cranberry may be recognized. The ore fragments show a very rich, coarse magnetite like that of the later ore at Cranberry. The ore, as seen under the microscope is very much like that at the Kirby place. (Plate II, *B* and page 52). It consists mainly of green pyroxene and magnetite, the former in large anhedrons that often possess smooth curved boundaries. They are slightly pleochroic in yellowish-green and pure-green tints and are crossed by numerous cleavage cracks, by the diallage parting, and by many irregular fractures that are filled by quartz and calcite. The magnetite is in irregular masses between the pyroxene grains, and often surrounding several. Where magnetite is absent as the filling of the interstitial spaces between the pyroxene grains, its place is taken by quartz, or by quartz and calcite, with a few fibers or wisps of uralite. In the narrowest spaces between the pyroxene a thin filling of uralite or of calcite may exist alone. Moreover, where a pyroxene is in contact with the quartz-calcite filling the pyroxene is bordered by uralite and in some cases uralite spicules extend entirely across the space occupied by the filling. Here and there are large grains of epidote, but they are rare. The same mineral occurs also as little veins in the magnetite. The filling appears to be secondary.

The Old Forge openings are about 500 feet from the west bank of Doe River, nearly opposite the Peg Leg mine. The place is now overgrown, but Hamilton states[80], that old pits and float ore are so distributed as to indicate a vein about 100 feet wide. Mr. Kirby in the report already referred to, says that on the west side of the river the ore appears in two streaks 6½ and 5 feet wide. In the first streak the total iron content of the ore determined was 39.98 per cent and the quantity of

[79]Quoted by S. H. Hamilton, through courtesy of Mr. M. F. Miller, Erwin, Tenn. Unpublished report to Tennessee Geol. Survey.

[80]Unpublished report to Tennessee Geol. Survey.

magnetite present 28.86 per cent. In the second streak the total iron was 21.30 per cent and the magnetite only 7.73 per cent. Sixteen hundred feet beyond are exposures of "36 per cent ore in a face 16 feet wide," and on the crest of the hill about 1,300 feet farther west is an old shallow pit that uncovered a vein 7½ feet wide. Mr. Kirby believes that lenticular ore bodies follow one another along both the strike and the dip of the vein, that there need be no fear of the stoppage of the ore, and that the magnitude of the available reserves depends solely upon the cost of mining and concentration.

Horse Shoe prospect

In the little hollows running back into the hill on the west side of Doe River at the horse shoe curve are a few exposures of ore and much float ore. About half a mile from the river and 600 feet above it the most promising exposures have been prospected by several pits and small cuts. The country rock which is mapped as Cranberry granite by Keith is markedly different from the Cranberry granite farther east. Most of it is strongly schistose and very dark. It seems to be very chloritic and its feldspathic constituent is crushed and drawn out into lenses. It is interlayered with light-colored granite. The impression made by the relations of the two rocks is to the effect that the granite had intruded a schist series, in some places the granite being in great excess and in others the schist being more abundant. Where the granite predominates the result is an area of granite, streaked in places by schist; where the dark schist is in excess there is an area of schists cut by granite.

At the two large openings examined the vein rock is very dark. It is cut by pegmatite, epidote and quartz veins as at Cranberry. Moreover the ore contains much green hornblende. The strike of the vein is apparently a little north of west. If this is correct, the vein is probably a different one from that on which the Peg Leg deposit is situated.

Hamilton quotes Kirby as believing that the vein at the Horse Shoe openings is a different one from that at the Old Forge prospect. Most of the ore was found to be of low grade, but one streak 400 feet long and about 8 feet wide assayed 31.9 per cent of iron.

Kirby's conclusion is that the available iron ore resources of the Doe River valley between the Peg Leg and the Horse Shoe mines aggregate from 180,000 to 270,000 tons but that the veins might yield ore indefinitely if it were not necessary to consider the cost of mining.

In order to learn whether the crude ore of the area would pay to concentrate, Kirby made up samples of the ore layers in the Peg Leg, Old Forge and Horse Shoe openings, crushed them to 20 inch mesh and subjected the pulverized ore to the influence of a magnet. The process resulted in a production of 32.5 per cent of a high-grade concentrate and 67.5 per cent of tailings carrying 17.1 per cent of iron. The composition of the crude ore and of the concentrate is given as below:

Analyses of crude ore and concentrate from Peg Leg and Old Forge openings, Carter County, Tennessee.

	Crude ore	Concentrate
Silica (SiO_2)	33.86	6.54
Iron (Fe)	33.80	64.52
Alumina (Al_2O_3)	5.68	1.18
Lime (CaO)	8.87	1.26
Magnesia (MgO)	4.31	1.62
Titanium dioxide (TiO_2)	.00	
Sulphur (S)	.03	
Phosphorus (P)	Tr.	Tr.

Mr. Kirby declares that a very rich product may be obtained from the ore of the Doe River valley, but that as it requires 2.8 tons of the crude ore to make 1 ton of concentrate, and the concentrate would have to be sintered before charging to the furnace it is doubtful if the operation would pay.

Julian prospect

About one mile south of the line between the Peg Leg and Horse Shoe mines, and therefore about the same distance south of the Cranberry vein is a prospect hole on the west side of Shorr Hollow Ridge between Heaton Creek and Sugar Hollow.[a] The old dump shows lean ore composed mainly of magnetite and epidote. An analysis of a specimen by Dr. J. I. D. Hinds, of the Tennessee Geological Survey, gave:

Partial analysis of specimen of iron ore from Julian land, Carter County, Tennessee.

Silica (SiO_2)	48.20	Lime (CaO)	14.80
Alumina (Al_2O_3)	5.03	Magnesia (MgO)	9.78
Iron (Fe)	15.68	Phosphorus pentoxide (P_2O_5)	Tr.

Campbell prospect

On the strike of the vein passing through the Peg Leg and Horse Shoe mines and about half a mile west of George Creek, prospecting was begun over an area in which pieces of exceptionally rich ore had been found. A magnetic survey showed attraction over a larger area than at the Cranberry mine, and active operations to mine the ore were started. However, some of the backers of the project were drowned in the Titanic disaster and work was abandoned. The composition of the ore, as quoted by Hamilton[b], was: 62.6 to 67.0 per cent of metallic iron (Fe), 3.25 per cent of silica (SiO_2), 0.05 to 0.19 per cent of phosphorus (P), and no titanium (Ti). Hamilton states, on the authority of Hon. J. C. Campbell, that several thousands of dollars worth of work had been done without finding ore in commercial quantity.

[a] Abstracted from Hamilton's unpublished report to Tennessee Geol. Survey.
[b] Abstracted from Hamilton's unpublished report to the Tennessee Geol. Survey.

Chestnut Ridge prospects

Chestnut Ridge forms the divide between Doe River and George Creek. On the west side of the ridge about half way down the slope of Little Rock Knob is a cut and small tunnel in a vein of epidotized pegmatite containing a one foot wide magnetic seam. The country rock is a schistose granite. It is mapped by Keith as Cranberry granite.

From an eastern spur of Chestnut Ridge, locally known as Strawberry Ridge, some ore was shipped in 1890.

About a mile west of Little Rock Knob are outcrops and magnetic attractions over an east-west belt about 4,000 feet long. The country rock is Cranberry granite and the vein matter like that at Cranberry. A few pits and small piles of ore can still be seen, but other visible evidence of the vein is lacking. The work at this place was done between 1885 and 1890 under the direction of J. R. Engelbert, according to Hamilton[83]. It apparently uncovered a fairly large ore body.

These openings are probably the ones mapped by Keith[84] in Carter County near the State line, and referred to in the text as prospects.

Magnetic City prospects

At about the location of the Engelbert openings the vein turns sharply to the south, crosses into North Carolina and continues southward until lost.

About 1 mile south of the State line is a group of prospects which are probably those described by Nitze[85] under the name "Jenkins ore bank," and mentioned in the Tenth Census report as being on the Wilder place. The main openings are situated 2½ miles above the mouth of Greasy Creek and 1 mile south of the Tennessee State line. One opening was a large open cut 100 feet long along the strike of the vein. It was 130 feet above the creek level, and was once worked to supply a forge at Magnetic City. The ore-body is reported to be 18 feet thick and to be like the ore-body at the Cranberry mine. The gangue is similar to that at Cranberry, but the relation of the ore to the gangue is not known. The strike of the country rock which is "pegmatite and hornblende gneiss," is N. 55° E., and its dip 45° SE. An analysis[86] of the dried ore taken from a small pile at the pit is given below.

A smaller opening 350 feet above the creek level[87] is in a very lustrous compact ore free from gangue, about 5½ feet wide, and near the summit of the ridge at about the same elevation is another opening which shows an ore body 1 foot thick at the top and widening to 5½

[83] From S. H. Hamilton's unpublished report to the Tennessee Geol. Survey.
[84] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Roan Mountain folio (No. 151) Economic Geology map, 1907.
[85] Op. cit., p. 180.
[86] 10th Census U. S., vol. 15, p. 560, 1886.
[87] Nitze, H. B. C., op.cit., p. 181.

feet at the bottom of the cut. This also is free from gangue but in its upper portion it contains numerous quartz grains. The ore in these smaller openings differs from that in the larger one in that no hornblende-epidote gangue is present. It also differs in that it is markedly titaniferous. The analysis below is of an average sample from the two openings:

Partial analyses of ore from near Magnetic City, Mitchell County, N. C.

	Lower cut	Average of upper cuts
Silica (SiO_2)		6.58
Iron (Fe)	63.41	54.48
Sulphur (S)		.023
Phosphorus (P)	.012	.033
Titanium dioxide (TiO_2)		4.96
Phosphorus ratio (P-Fe)	.019	.060

Evidently the three deposits are not on the same vein, though close together. The occurrence at the large open cut is similar to that at Cranberry, both in the character of the ore and the nature of the gangue. The other occurrences are unlike that at Cranberry in both these features and are like the occurrences of titaniferous ore in Ashe county. On the other hand they are not on the titaniferous belt described by Nitze as being south of the Cranberry belt and parallel to it. It is probable that the deposits are entirely independent of the deposits on Nitze's "Roan Mountain titaniferous belt," and it is probable that they are independent of each other. At any rate, no connection can be shown to exist between them.

Deposits between Magnetic City and Toe River

From the Jenkins place Nitze[88] reports that the Cranberry belt of ore has been traced in a course approximating S. 50° to 55° W. to Toe River, but he mentions the occurrence of the vein only at the following points: an outcropping on Bad Creek, 2½ miles above its mouth on the land of Chas. Garland; an opening on a body of "mixed ore and hornblende," 1 mile northeast from the Garland place on the waters of Bean Creek; an outcrop near Peterson's mill on Brummetts' Creek, 2 miles above its mouth, and another at the Elisha Street place on the northeast side of Toe River, half a mile below the mouth of Pigeon Roost Creek. Only the Peterson occurrence is described and the description of this is limited to the statement that "the outcrop is fully 30 feet across, in a massive bluff, but it is very lean; its strike is N. 55 E.; dip SE."

The Peterson place was visited by the writer. It is now owned by Julie Herrell. The vein has been opened recently, as the dump is fresh. The opening is a hole blasted in the face of a cliff. The sur-

[88] Op. cit., p. 181.

rounding rock is evidently Cranberry granite. This is crossed by narrow hornblende-epidote veins spotted by magnetite and cut by magnetite veinlets. The ore is a mixture of granular hornblende and small grains of magnetite. The occurrence is a small scale replica of the Cranberry vein, except that its walls are not so well defined.

On the road between Relief and Red Hill two other small deposits have been uncovered. If these deposits are on the extension of the Cranberry vein, it must have divided into a number of parts. There is evidently no continuous vein in this portion of the district, but the deposits are in short parallel independent veins. On the south side of the road about a quarter of a mile east of Brummet Post Office, J. W. Hughes opened a vein 2½ feet wide in a white gneiss, and a quarter of a mile east of the crossing of Rock Creek, A. G. Renfroe has some explorations, but in neither case was anything promising developed.

Between Renfroe's explorations and Rock Creek, blasting for road improvement has thrown out excellent, fresh rock that appears to be Cranberry granite. It is an evenly banded light-gray and dark-gray gneiss, in which the dark layers are much more micaceous than the light ones. Both contain many small red garnets. On Keith's map of the Roan Mountain quadrangle this area is colored for Roan gneiss, but since the Roan gneiss is indicated as alternating with belts of Cranberry granite, it is possible that the rock being blasted is in a narrow belt that Keith did not see.

MADISON COUNTY, N. C.

Big Ivy mine

After crossing Toe River no further outcrops of the Cranberry vein have been discovered, but the Big Ivy mine, which is in Madison County 25 miles S. 50° E. from the mouth of Pigeon Roost Creek, is on its strike. The Big Ivy mine was not seen by the writer. Nitze, however, examined it and from his description we learn that it is on the only considerable deposit discovered in Madison County.[89] The mine, known also as the Heck mine, is 6 miles north of Alexander, on the south side of Big Ivy Creek, 3 miles above its mouth. Two principal openings and a number of minor ones on the north slope of a hill expose ore. The lower main opening, a long trench 150 feet above the level of Big Ivy Creek, cuts a vein 98 feet wide between walls of hornblendic gneiss. About 46 feet of the vein is occupied by masses, or horses, of hornblende, epidote, and quartz (probably pegmatite). The other 52 feet consists of a hard compact magnetite, with the composition given below. The upper main opening is a long cut several hundred feet S. 40° W. from the trench and 30 feet above it. Here the ore-body was not entirely cut through. It was, however, uncovered for a width of 30 feet. This ore is more

[89]Op. cit., p. 188-189.

granular than that to the northeast and resembles the Cranberry "rattlesnake ore." Float has been found as far as 3 miles farther northeast, suggesting that the vein runs in this direction.

In the Tenth Census Report[90] the ore is described as being a mixture in various proportions of pyroxene and magnetite, the former decreasing toward the center of the vein, but being present to some extent throughout the entire deposit. It was estimated that the ore rich enough to bear transportation did not have a greater thickness than 10 feet. Analyses of this ore are quoted below:

Partial analyses of ore from Big Ivy mine, Madison County, N. C.

	Ore from trench	Rich ore
Silica (SiO_2)	15.54	
Iron (Fe)	48.54	57.84
Sulphur (S)	.012	
Phosphorus (P)	.019	.021
Phosphorus ratio (P:Fe)	.039	.036

[90]10th Census U. S., vol. 15, p. 377, 1886.

Pennington opening

The C. Pennington opening is a pit on top of a low hill overlooking Wallen's Creek. It is about 1½ miles southwest of the McCarter place and about half a mile northwest of Mr. Pennington's house. Near the pit is a small ledge of hornblende, but no other rocks are exposed in the immediate vicinity of the hole. On the road to the east are fairly massive schists striking N. 20° E. and dipping high to the southeast, that are not unlike those on Helton Creek south of the Kirby mine at Sturgill.

Nothing can now be seen but the dump on which are pieces of ore composed of hornblende and magnetite. Nitze[213] declares that the ore consists of an 8-foot wide vein of a fine-grained, compact, steel-gray, granular magnetite with a little gangue which is generally epidote. He gives no further details.

Analyses of three specimens, probably of selected samples, gave the following results:

Partial analyses of ore from Pennington opening, near Sturgill, Ashe County, N. C.

	1	2	3
Silica (SiO_2)	4.75	4.72	5.07
Iron (Fe)	52.23	52.44	52.45
Sulphur (S)	.112	.077	.....
Phosphorus (P)	.012	.004	.022
Titanium dioxide (TiO_2)	8.91	5.38	9.11
Chromic oxide (Cr_2O_3)	1.19	.....	.....
Phosphorus ratio (P:Fe)	.010	.007	.042

The ore picked from the dump shows no epidotic gangue. It is very much like that of the mine of the old McCarter place, west of Shippey Branch (see page 215). It consists of broken, fresh magnetite fragments, others that are now composed of interlayered yellow and red rutile and magnetite, or ilmenite, and a mass of light-green fibers and plates, which in some places constitutes oval areas that are almost isotropic, and in others a kind of interstitial weakly polarizing aggregate with great numbers of brightly polarizing green fibers scattered through it. (See Plate XXII, *B* and *C*.) Some of the fibrous aggregate has a radial structure as though representing the alteration of a primary mineral grain, while the rest is a confused aggregate which surrounds the more definite areas as though representing a matrix. Through all of the material, whether in definite areas or not, there are numerous little clumps and prisms of rutile and tiny grains of magnetite. The fibers of weakly polarizing aggregate, which may be some variety of chlorite, are often arranged perpendicular to the peripheries of the large magnetite grains and perpendicular to the walls of the cracks that are so numerous in them. Evidently the fibrous material is entirely secondary,

[213] Op. cit., p. 160.

but the characters of the minerals from which it was derived are not certainly known. It is probable, however, that the original rock was basic, probably very much like that at the Smith place.

ALLEGHANY COUNTY, N. C.

In Allegheny County, which adjoins Ashe County on the east, a zone of hornblende schist, often altered to steatite or soapstone, and carrying crystalline grains of titaniferous magnetite, which in some places is concentrated into workable ore beds, crosses the State line at a point about 3 miles west of the east line of the county and follows the Little River southwestward.[214]

Where concentrated into lenses the magnetic ore is a coarse or fine-grained, lustrous, granular mass with a steatite or an asbestus gangue. Analysis[215] of a sample from the Carrico farm at the north end of the belt gave: Silica (SiO_2), 6.20 per cent, iron (Fe), 54.72 per cent, sulphur (S), 0.038 per cent, phosphorus (P), 0.047 per cent, and titanium dioxide (TiO_2), 4.860 per cent. The belt is bordered on the northwest and on the southeast by quartz zones carrying a little menaccanite.

The steatite impregnated with magnetite continues for 6 or 7 miles farther southwest and at several places is said to be bordered on both sides by quartz and hornblende schist. Below the lower hornblende schist is another steatite layer that is magnetitic, but nowhere is the magnetic mineral known to be concentrated into workable deposits. About 9 miles farther southwest[216], and half a mile east of the mouth of Pine Swamp Creek, however, there is a heavy outcrop of the magnetitic soapstone on the farm of H. Crouse, where a fragment of compact ore was found to contain silica (SiO_2), 3.08 per cent, iron (Fe), 57.54 per cent, chromic oxide (Cr_2O_3), 11.05 per cent, sulphur (S), 0.016 per cent, and phosphorus (P), 0.007 per cent. No titanium was reported.

Southwest of this point the steatite rock is lost and magnetite deposits show neither high titanium nor chromium.

Nitze gives no description of the "quartz" or the "hornblende schist" associated with the ore nor of the relations of these rocks to the "steatite." It is significant, however, that the ore is associated so closely with a rock that is quite different from the rocks that accompany the non-titaniferous ores.

AVERY AND MITCHELL COUNTIES, N. C.

DISTRIBUTION

In Avery and Mitchell counties Nitze[217] describes a belt of titaniferous ores as lying from 3 to 5 miles south of the Cranberry non-titan-

[214] Nitze, H. B. C., Op. cit., p. 125.
[215] Idem., p. 126.
[216] Idem., p. 128.
[217] Op. cit., pp. 182-183.

iferous belt and generally parallel to it. He states that it begins at the mouth of Roaring Creek, 7 miles west of south of Cranberry, crosses near the head of Old Cabin Branch, then trends northwest over Grassy Bald Ridge, where it passes into Tennessee.

"The belt traverses the edge of Tennessee for a distance of about 4 miles, bending gradually towards the southwest and crossing into North Carolina near the headwaters of Big Rock Creek . . . ; thence it continues in a generally southwesterly direction across the Roan High Bluff and Fork Mountain, and along the waters of Big Rock Creek, to the Yancey county line at Toe River, a distance of about 9½ miles."

No reason is given by Nitze for supposing this line to be continuous, or even to be a definite series of discontinuous lenses. At its eastern end the course ascribed to it crosses the structure af the country, and its direction does not correspond with the strike of the veins supposed to comprise it.

Senia deposit

At the mouth of Roaring Creek on the land of the Toe River Land and Mining Co., Nitze[218] found some shallow openings in an altered olivine rock showing streaks or seams of magnetite not over two inches thick.

There is at this place a small strip of massive dunite that is sheared in places to a chlorite-talc schist. In this is a vein of magnetite mixed with a little pyrite. The vein as a whole is made up of a series of twisting veinlets each of which is not more than an inch or so wide, but which together constitute a stockwork about 8 inches wide. At the time of the writer's visit there was little to see at the pit which was full of water. The ore is a fine-grained, glistening variety like the titaniferous ores elsewhere.

The dunite is a fine-grained, yellowish-green rock which under the microscope is resolved into an aggregate of olivine and a very light green tremolite, a little antigorite and a few grains of a very pale chlorite or serpentine. Between these minerals are small areas of a structureless, green, faintly polarizing material that may be serpentine and here and there are clumps of skeleton-groups of magnetite or chromite surrounded by a corona of serpentine plates. The section is almost a duplicate of that of a dunite pictured by Pratt and Lewis[219] from Shooting Creek, Clay county.

The country rock surrounding the serpentine is Roan gneiss, which consists largely of layers of a dark, massive rock that looks like a fine-grained diabase. A very fine-grained phase of this rock resembles in appearance a baked shale. Under the microscope its section shows mainly a fine-grained aggregate of little equi-dimensional grains of green

[218] Idem., p. 182.
[219] Pratt, Jos. H., and Lewis, J. V., Corundum and the peridotites of western North Carolina: North Carolina Geol. Survey, vol. 1, pl. 35, fig. 1, 1905.

hornblende and unstriated feldspar. The small triangular spaces between the grains are occupied by quartz, and embedded in the aggregate are large garnet masses made up of numerous small grains of about the same size as those of the hornblende-feldspar aggregate. There is also present a very little magnetite, which appears only as an interstitial filling between amphibole grains.

Avery place

The other deposits on this belt have been worked so slightly that they offer little opportunity for study. At the Avery place, on the southwest slope of Big Yellow Mountain, near the head of Old Cabin Branch about 2½ miles north of Roaring Creek is an old hole and a dump on which are some fragments of a very rusty rock that may be a phase of the Roan gneiss. No ore is now to be seen.

Nitze[220] declares that "the country rock is a very coarse-grained pegmatite, hornblende schist, epidote and garnet rock dipping towards the northeast. The ore is a highly lustrous, titaniferous magnetite, compact, homogeneous and free from gangue. It occurs in thin irregular seams and lenses from 2 inches to 2 feet in thickness." He states that at the time of his visit all the ore had been removed and attempts to find other lenses had failed. Nevertheless, he gives two analyses of selected samples as follows:

Partial analyses of ore from Avery place, Avery County, N. C.

	1	2
Silica (SiO_2)	1.46	.54
Iron (Fe)	65.32	66.95
Sulphur (S)	.025	.00
Phosphorus (P)	.009	.015
Titanium dioxide (TiO_2)	4.80	6.80

As no rocks were seen during the writer's hurried visit to the place Nitze's observations can neither be contradicted nor confirmed. It is noteworthy, however, that no gangue was seen with the ore.

Grassy Bald of Roan Mountain

The next point on this supposed belt at which ore is known to occur is at the summit of Grassy Bald of Roan Mountain where there is a very different ore from any other observed in the two States. The country rocks on the southeast side of the knob are banded massive and schistose Roan gneisses cut by pegmatite. The massive gneiss resembles a very slightly schistose fine-grained gabbro and the schistose varieties differ from this only in their greater schistosity.

At the pits, which are on top of the mountain, are dumps on which are fragments of a coarse pegmatite made up mainly of biotite and feld-

[220] Op. cit., p. 182.

spar, with very little quartz, and containing here and there large irregular masses of grayish, brilliantly lustrous magnetite or nests of magnetite and biotite. The quartz and feldspar are thoroughly crushed and the magnetite and biotite appear to penetrate the crushed masses. No evidences of the presence of definite veins of magnetite were seen. All of the magnetite appeared to be in the form of irregular constituents of a pegmatite. Mr. Hamilton reports the pegmatite as extending across the mountain in a nearly east-west direction.

Evidently the ore here is quite different from that at Cranberry. It apparently is different also from that on the Avery place and at Senia. A test made for titanium by Geo. Steiger of the U. S. Geological Survey laboratory showed the presence of about 2 per cent of titanium dioxide (TiO_2). As might have been suspected from its association with pegmatite this ore does not belong with the more usual types of the titaniferous magnetite.

Jenkins prospect

The main Jenkins openings are on Road Ridge about 2½ miles above the mouth of Greasy Creek, a tributary of Rock Creek, and 1 mile south of the line between North Carolina and Tennessee. They are in a non-titaniferous magnetite (see page 130). Other openings higher on the ridge, however, are in titaniferous ore[221]. One of these, 350 feet above the creek, shows a very compact lustrous ore free from gangue. This ore is said to be in a vein 5½ feet thick. The second opening, near the summit of the ridge, is in a streak of ore that is 1 foot thick at the surface and 5½ feet thick at the bottom of the cut. In its "upper part the ore has small quartz grains porphyritically enclosed, but lower down it is free from this admixture, being very pure, homogeneous and highly magnetic." The wall rock is reported by Nitze to be hornblende gneiss and pegmatite.

An analysis of a mixture of samples from the two pits gave: Silica (SiO_2), 6.58 per cent, iron (Fe), 54.48 per cent, sulphur (S), 0.023 per cent, phosphorus (P), 0.033 per cent, and titanium dioxide (TiO_2), 4.96 per cent.

These two deposits are not in the belt of titaniferous ores outlined by Nitze, but are about 4 miles west of it. On Keith's Roan Mountain map they are located in an area of Cranberry granite. Unfortunately the openings have so badly caved that it is impossible to learn whether the rocks immediately associated with the ores are basic or not. The country rock is a series of schists and pegmatites that resemble in some places more nearly the Carolina gneiss than the Cranberry granite.

[221]Nitze, H. B. C., Op. cit., p. 181.

Other deposits

The remaining deposits placed by Nitze in this belt are at its southwest end, where a few pits have uncovered ore containing titanium, but in no cases are the geological relations of the ore-bodies known. On the north side of Little Rock Creek, half a mile from its junction with Big Rock Creek, a small pit is described[222] as exposing an ore lens about 3 feet across, on the land of Joel Gouge. At the depth of 4 feet it is entirely cut by a trap dike, which Nitze states accompanies the formation all the way south to Toe River. The ore is dark red and homogeneous, thus being unlike the other ores in the belt, but Nitze ascribes this peculiarity to the presence of the dike. The strike of the gneisses at the pit is N. 40° E. On Keith's map this area is mapped as being underlain by Cranberry granite.

Analysis of the ore showed:

Partial analyses of ore from land of Joel Gouge, Mitchell County, N. C.

Silica (SiO_2)	1.13	Phosphorus (P)	.078
Iron (Fe)	64.56	Titanium dioxide (TiO_2)	4.48
Sulphur (S)	.027		

Other deposits of similar ore are said to be at Jas. Herren's on Pepper's Creek, a quarter of a mile from Rock Creek, and 3 miles farther southwest on the property of Irwin Hughes, half a mile above the mouth of Rock Creek, but at neither of these places could anything definite be learned as to the character of the ore, or of its associated gangue.

The Herren deposit on Pepper Creek may be that on the land of Miles Herren, at Pepper P. O. Here there is an opening on the top of a hill just north of the road, on which are exposures of Roan gneiss that looks very much like a sheared basic porphyrite. Nothing can be seen in the holes. Nitze reports the vein to be 6 feet to 8 feet thick. The dump is also overgrown but the few specimens of ore taken from it resemble the lustrous crystallized ore seen elsewhere.

The farm of Irwin Hughes was not found; but in about the same location, on the land of M. C. Bailey, are some old holes which are now filled with soil. One piece of ore picked from the soil where the old dump is said to have been, is a black massive homogeneous magnetite that lacks the high luster of the titaniferous phases. If the location of the holes is correct the surrounding rock is Cranberry granite.

The only other deposit of titaniferous magnetite known to occur in Mitchell county is indicated by float near the head of Wadkins Branch, on the south slope of Pumpkin Patch Mountain about 2 miles north of west from Bakersville[223]. An analysis of specimens picked from the surface showed the presence of 4.56 per cent of titanium dioxide and 57.98 per cent of iron.

[222]Nitze, H. B. C., Op. cit., p. 183.
[223]Nitze, H. B. C., Op. cit., p. 184.

"Similar traces of float ore have been found along the southern slope of the mountain range in a westerly direction for 4 miles to Red Hill, and in an easterly direction for 1½ miles, but no developments have been made."[224]

CARTER COUNTY, TENN.

Lost Cove prospect

The deposit on which this prospect was opened is described by Hamilton[225] as being on the land of David Street, on the west side of the ridge between Burbank and Lost Cove. Its more exact location is not given but it is probably the prospect mapped by Keith[226] about 1 mile southwest of Burbank, in which case it is on the belt designated by Nitze as south of the Cranberry mine belt and parallel to it. On Keith's map the pit is shown in an area of Cranberry granite, but Hamilton states that it is in Roan gneiss. The hole is now filled and the only specimens of the ore obtainable were found as fragments in the soil.

Analyses of two samples were made by Dr. J. I. D. Hinds of the Tennessee Geological Survey.

Partial analyses of ore from Lost Cove, Carter County, Tennessee.

	1	2
Silica (SiO_2)	1.46	4.80
Alumina (Al_2O_3)	1.60	3.28
Iron (Fe)	56.00	51.74
Titanium dioxide (TiO_2)	10.50	17.20
Phosphorus pentoxide (P_2O_5)	1.97	Tr.

In sample No. 2 special tests were made for zinc, tantalum, tungsten, vanadium, calcium, copper and tin but none were found.

A complete analysis of a third sample of the same ore was made by Mr. Farrar of the same Survey, and determinations of ferrous and ferric iron and of titanium dioxide in a fourth sample. Mr. Farrar's results were:

Analyses of titaniferous magnetite from Lost Cove, Carter County, Tenn.

	1	2
Silica (SiO_2)	0.18	.....
Ferric oxide (Fe_2O_3)	47.92	41.69
Alumina (Al_2O_3)	1.26	.....
Ferrous oxide (FeO)	32.11	32.02
Manganous oxide (MnO)	1.48	.....
Magnesia (MgO)	Tr.	.....
Lime (CaO)	None	.....
Titanium dioxide (TiO_2)	16.34	19.48
Phosphorus pentoxide (P_2O_5)	.43	.....
Chromium trioxide (Cr_2O_3)	Tr.	.....
Vanadium pentoxide (V_2O_5)	None	.....
	99.72	.....

[224] Nitze, H. B. C., Idem., p. 185.
[225] Unpublished report to Tennessee Geol. Survey.
[226] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Roan Mountain folio (No. 151), Economic Geology map, 1907.

Assuming that all the ferrous iron which is not in magnetite is present in ilmenite, the percentages of magnetite, ilmenite, and rutile present in the specimens, as indicated by the analyses, are 69.60, 22.19, and 4.8 for the first specimen, and 60.55, 27.97, and 4.8 for the second.

Specimens of the ore collected by Hamilton are as a rule a compact, coarsely crystalline black mass with a purplish tinge, containing a few small white grains in ill-defined lines, parallel to the walls of the vein. In some places the ore has been mashed to a schistose aggregate in which spangles of a brassy-yellow mica coat the schistose planes. Under the microscope the white grains are seen to be crushed feldspars, a few of which exhibit twinning bars. A few flakes of mica occur in the feldspar and scattered sparsely through the ore mineral. Tiny, irregular particles of rutile are also scattered through the ore mineral and in some portions of it the particles are arranged in lines. The proportion of rutile to the opaque ore minerals is very much smaller than in the case of the Ashe County ores (pages 209 to 216), and there is no suggestion that it has arisen through decomposition of ilmenite.

Other deposits

On the road between Shell Creek and Lunsford Branch Hamitlton reports the presence of several small deposits of magnetite, but states that exposures are insufficient to show whether they are of importance or not. Specimens picked from the surface of the "lands of Montgomery, Cordell and others" on Cordell Branch of Laurel Fork contain a comparatively large quantity of titanium. One specimen yielded Dr. J. I. D. Hinds, of the Tennessee Geological Survey, the following result:

Partial analysis of titaniferous magnetite from lands of Montgomery, Cordell and others, near Shell Creek, Carter County, Tenn.

Silica (SiO_2)	15.20	Lime (CaO)	5.20
Alumina (Al_2O_3)	11.96	Phosphorus pentoxide (P_2O_5)	7.30
Iron (Fe)	37.40	Titanium dioxide (TiO_2)	8.00

YANCEY COUNTY, N. C.

So far as known titaniferous magnetites in Yancey county are sporadic. In the western part[227] of the county near the head of Possom Trot Creek and 9 miles west of Burnsville magnetic float ore on the land of Jerry Ferguson contains 2.56 per cent of titanium dioxide (TiO_2), and 39.00 per cent of iron (Fe).

Six miles north of Burnsville, on the south side of Mine Fork, two openings[228] on the land of D. M. Hampton expose the same bed of ore 6 to 10 feet across, with a nearly vertical dip. The magnetite is in "a

[227] Nitze, H. B. C., Op. cit., p. 186.
[228] Idem., p. 187.