PRELIMINARY REPORT ON THE DEPOSITS OF MANGANESE ORE IN THE BATESVILLE DISTRICT, ARKANSAS.

By Hugh D. Miser.

LOCATION.

The Batesville manganese district is in the southern part of the Ozark region, a short distance west of the Mississippi embayment of

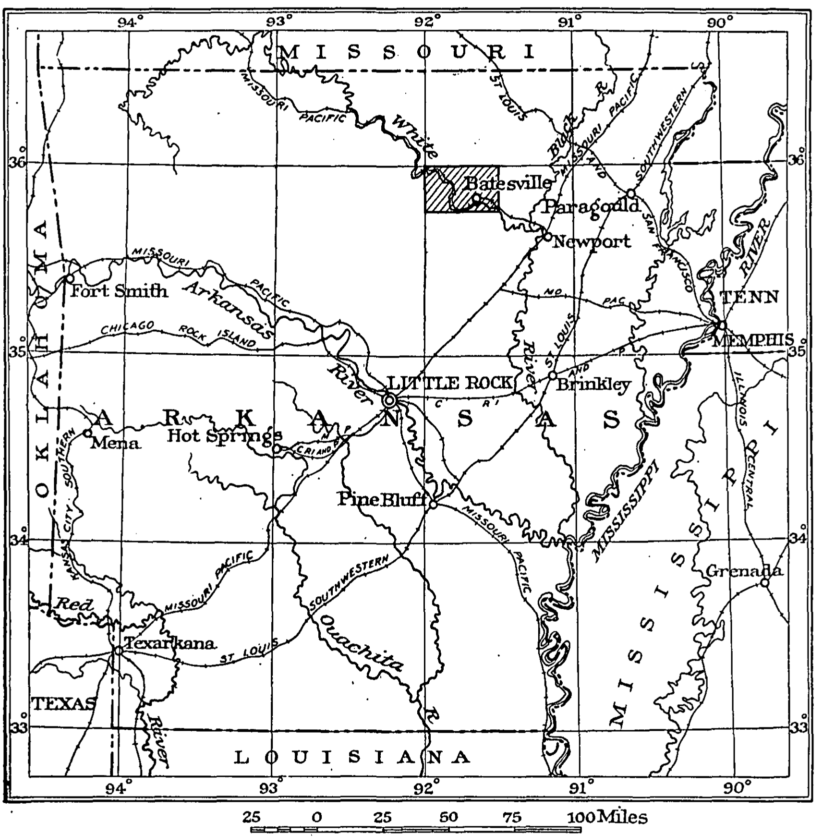

FIGURE 12.—Index map of Arkansas showing the location of the Batesville manganese-ore district.

the Gulf Coastal Plain, mostly in Independence County but partly in Sharp, Izard, and Stone counties, in north-central Arkansas. (See fig. 12.) It is an east-west belt, 4 to 8 miles wide, and extends from the Ball mine, 2 miles east of Hickory Valley, westward to Guion, a distance of 24 miles. (See Pl. VI.) The town of Batesville, from which it receives its name, is 2 miles south of the southern border of the manganese-bearing area.

PRESENT INVESTIGATION AND ACKNOWLEDGMENTS.

The field work on which this report is based was done by the writer during March, April, May, and June, 1918, in connection with the plan of the United States Geological Survey to obtain information regarding the location, character, and extent of the manganese-ore deposits in the United States, and to encourage the production of domestic manganese ores, so that as much shipping as possible could be freed from use in the importation of foreign ores in order to carry troops and supplies to Europe during the war.

A brief preliminary report entitled "Manganese in the Batesville region, Arkansas," was published in September, 1918, as a press bulletin of the United States Geological Survey. An abstract of a paper on the manganese deposits of the Batesville district that was presented April 23, 1919, before the Geological Society of Washington was published July 19, 1919.[1] A paper on hausmannite in the Batesville district, by J. G. Fairchild and the writer, was published January 4, 1920.[2] The present preliminary report is abstracted from the final detailed report, which the author has completed but which may not be printed for at least a year.

The writer desires to acknowledge his indebtedness to the following members of the United States Geological Survey: D. F. Hewett, for advice in planning the field work and for many suggestions during the office work; E. F. Burchard, for advice during both the field and office work; E. O. Ulrich, for the examination of fossil collections and for much information regarding the age and relations of the rock formations of the Ordovician, Silurian, and Devonian systems; G. H. Girty, for the study of fossil collections from the rock formations of Carboniferous age; W. T. Schaller and E. S. Larsen, for mineralogic determinations; and R. C. Wells, J. G. Fairchild, and Chase Palmer, for chemical analyses of rock and mineral specimens. Acknowledgment is also due to the residents in the Batesville district for their uniformly courteous treatment and to the mine operators and other interested persons for information.

The following reports on the district under discussion have been consulted:

Owen, D. D., First report of a geological reconnaissance of the northern counties of Arkansas, pp. 37–41, 136, 138, 1858.

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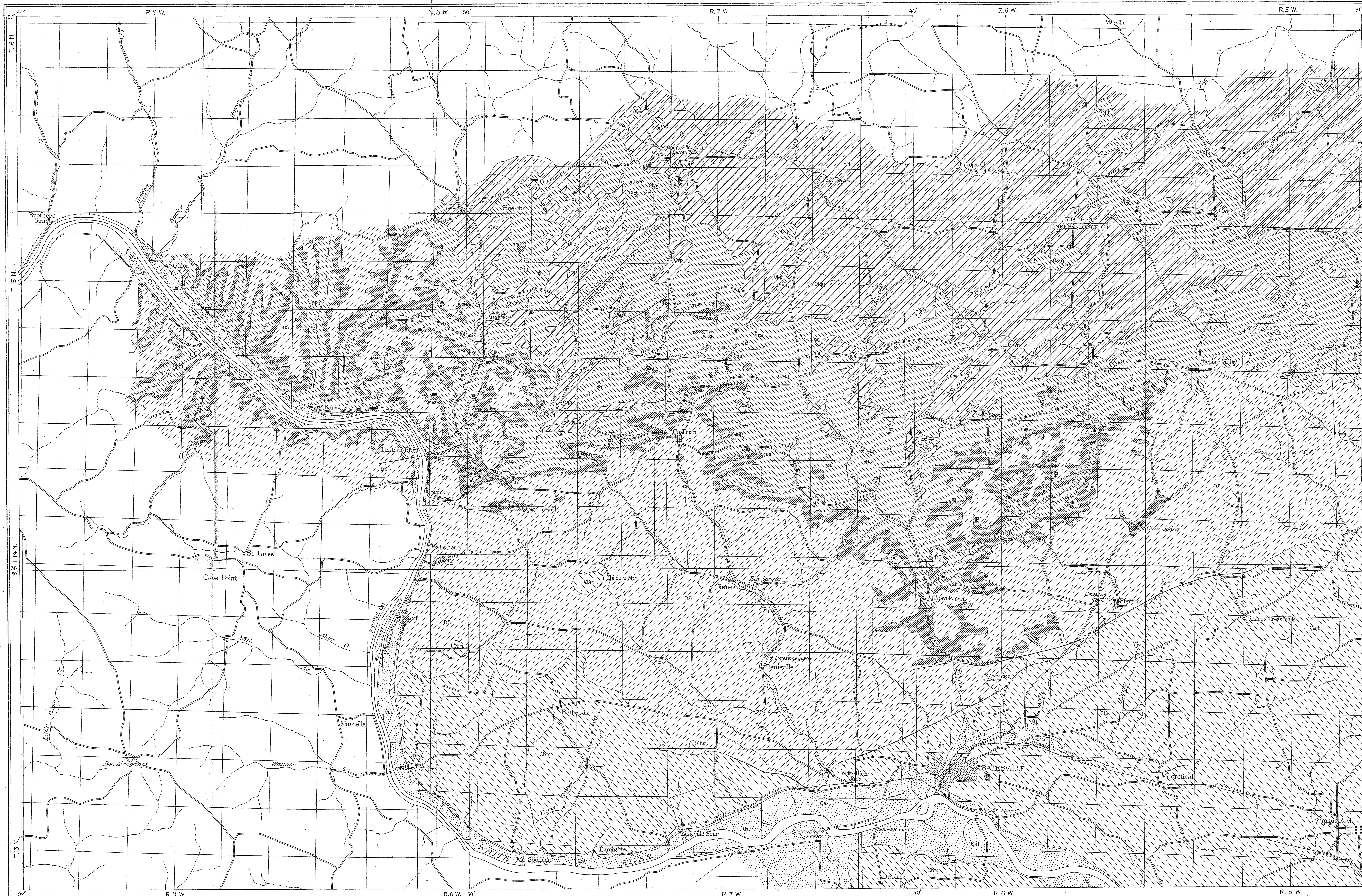
[1] Washington Acad. Sci. Jour., vol. 9, No. 13, 1919.
[2] Idem, vol. 10, No. 1, 1920.



Base from U. S. Geological Survey topographic map of Batesville quadrangle

GEOLOGIC MAP OF THE BATESVILLE DISTRICT, ARKANSAS

Scale 62,500

1 0 1 2 3 4 Miles

Geology by H. D. Miser. The geologic mapping in Stone County and the mapping of the Batesville sandstone and Moorefield shale are partly taken from maps in vols. 1 and 4 of the Arkansas Geological Survey annual report for 1890

EXPLANATION

SEDIMENTARY ROCKS

Symbol	Formation	Age
Qal	Alluvium	QUATERNARY
Cbm	Batesville sandstone Moorefield shale	CARBONIFEROUS (Mississippian)
DS	Boone chert UNCONFORMITY Chattanooga shale UNCONFORMITY Penters chert UNCONFORMITY Lafferty limestone St. Clair limestone	CARBONIFEROUS (Mississippian) (Boone chert); DEVONIAN (Chattanooga shale, Penters chert); SILURIAN (Lafferty limestone, St. Clair limestone)
Ocf	Cason shale UNCONFORMITY Fernvale limestone UNCONFORMITY	ORDOVICIAN
Okpj	Kimmswick limestone Plattin limestone UNCONFORMITY Joachim limestone	ORDOVICIAN
Osp	St. Peter sandstone and older rocks	ORDOVICIAN

Fault

⚒ Manganese mine

× Manganese prospect

LIST OF MINES AND PROSPECTS.

SHARP COUNTY.

1. McLeod prospect.
2. Cochran prospect.
3. M. A. Aldridge prospect.
4. K. D. Aldridge prospect.
5. Matlock mine.
6. Story mine.

INDEPENDENCE COUNTY.

7. Jackson prospect.
8. Woodyard prospect.
9. Ball mine.
10. Milligan prospect.
11. Eliza Patterson prospect.
12. Milligan-Perrin prospect.
13. Schlieper mine.
14. Ozark mine.
15. Searcy mine.
16. Matheny mine.
17. Dunegan prospect.
18. Bales mine.
19. Moyer mine.
20. Silberstein prospect.
21. J. A. Reves mine.
22. Henley mine.
23. G. A. Wilson mine.
24. M. W. Reves prospect.
25. G. D. Reves tract.
26. Oliver Iron Mining Co.'s prospect.
27. Martha Thompson mine.
28. Climer prospect.
29. Walter Chinn prospects.
30. O'Flinn prospect.
31. Walbert mine.
32. Adler mine.
33. W. A. Chinn cut.
34. A. R. Chinn prospect.
35. Baxter prospects.
36. Collins prospect.
37. Burge mine.
38. Rutherford mine.
39. Cason mine.
40. Champlain prospect.
41. J. W. Greenfield prospect.
42. Weaver-Dowdy prospect.
43. W. L. Greenfield mine.
44. Simmons prospect.
45 Allen mine.
46. Roberts mine.
47. Deener prospect.
48. Button mine.
49. W. W. Allen mine.
50. Criswell prospect.
51 Shaw mine.
52. Waco prospect.
53. Denison mine.
54. Marshall mine.
55. R. T. Patterson mine.
56. John Patterson prospect.
57. G. W. W. Patterson prospect.
58. Bell Hill prospect.
59. Perrin mine.
60. Kelley prospect.
61. Haigwood prospect.
62. J. B. Thompson prospect.
63. Wildcat mine.
64. Hunt Hollow mine.
65. Smith prospect.
66. McGee mine.
67. A. G. Gray mine.
68. W. T. Gray mine.
69. United States-Canadian Manganese Co.'s prospect.
70. E. W. Roach prospect.
71. Hawkins mine.
72. Jeff Weaver prospect.
73. Chapel Hill mine.
74. Pool prospect.
75. Alder-Southard mine.
76. Roach mine.
77. Montgomery mine.
78. Montgomery Hill mine.
79. Sis Clark mine.
80. Sis Clark Corner prospect.
81. Galloway mine.
82. Dead Tree Hill prospect.
83. Barnett mine.
84. Montgomery prospect.
85. Reed mine.
86. C. C. Johnson prospect.
87. Pritchett prospect.
88. Fortune prospect.
89. Brooks Hill mine.
90. Shell mine.
91. Kimmer mine.
92. Roseborough mine.
93. C. W. Maxfield prospect.
94. Rowe Field mine.
95. Blue Ridge mine.
96. Southern mine.
97. Grubb Cut mine.
98. Rogers mine.
99. Polk Southard mine.
100. Wren mine.

INDEPENDENCE COUNTY—Continued.

101. Turner mine.
102. Lassiter mine.
103. Cripple Hill prospect.
104. Maxfield prospect.
105. Section 34 prospect.
106. Friday prospect.
107. Simpson prospect.
108. Helms prospect.
109. Mount Etna mine.
110. J R. Dobson prospect.
111. J. P. Barnes prospect.
112. Wolford mine.
113. Neill prospect.
114. Calaway prospect.
115. Sterrett mine.
116. Sanders prospect.
117. Miller prospect.
118. W. L. Johnson prospect.
119. Bob Wilson prospect.
120. Page mine.
121. Club House mine.
122. Felts prospect.
123. Section 8 prospect.
124. Meeker mine.
125. R. W. Reeves prospect.
126. Jake Cole prospect.
127. Sand Field prospect.
128. Tosh Hill prospect.
129. Frazier prospect.
130. Hightower prospect.
131. F M. Barnes prospect.
132. W. C. Collie mine.
133. George mine.
134. S. W. Weaver mine.
135. Martin No. 1 mine.
136. Martin No. 2 mine.
137. Button prospect.
138. Kimbrough mine.
139. McBride mine.
140. Harvey mine.
141. South Hill prospect.
142. U. N. Dobson prospect.
143. T. M. Tate mine.
144. Hankins Hollow mine.
145. Salt Peter Hill mine.
146. Edwards mine.
147. Ellen Clark prospect.
148. Cutter mine.

IZARD COUNTY.

149. Adler Hollow mine.
150. Izard mine.
151. Pugh mine.
152. Verna mine.
153. Skelton Hill mine.
154. Pittman mines.
155. Cummins Hollow mine.
156. Johnson Hill mine.
157. Skelton-Handford prospect.
158. United Phosphate & Chemical Co.'s mine.
159. Breeden prospect.
160. Shaft Hill mine.
161. United Phosphate & Chemical Co.'s prospect.
162. Love prospect.
163. Williamson-Gulley prospect.
164. H. M. Tate prospect.
165. W. K. Tate prospect.
166. Helm prospect.
167. E. D. Winkle prospect.
168. C L. Sanders prospect.
169. Sand Field mine.
170. Manganese Field mine.
171. Ruminer Rough mine.
172. Barksdale mine.
173. Earl Collie mine.
174. Caraway prospect.
175. L. J. Weaver mine.
176. Lewis prospect.
177. Cave Hill mine.
178. T. C. Winkle prospect.
179. H. J. Ray prospect
180. M. E. Wilson prospect.
181. Bevans prospect.
182. McConnell mine.
183. Klondike mine.
184. Haddock prospect.
185. Moser prospect.
186. L. B Ray prospect.
187. Hall prospect.
188. O'Gilsby prospect.
189. Anderson prospect.
190. Rudolph prospect.
191. Bone prospect.
192. Henry King prospect.
193. Hollawell prospect.
194. E. Winkle prospect.
195. W. A. King mine.

STONE COUNTY.

196 G. F Fults prospect.
197. A. T. Foster prospect.
198. Alex. Fults prospect.

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Woodbridge, D. E., The Arkansas manganese field: Eng. and Min. Jour., vol. 106, No. 15, pp. 669–670, Oct. 12, 1918.

Shiras, Tom, Manganese mining in Arkansas: Eng. and Min. Jour., vol. 104, No. 25, pp. 1079–1080, Dec. 22, 1917.

Special mention should be made of the monographic report by Penrose on the uses, ores, and deposits of manganese. Both the text of this report and the accompanying geologic map were constantly used by the writer in his field and office work. It is referred to at many places in the present report, and parts of it are quoted.

HISTORY AND PRODUCTION.

The manganese deposits of the Batesville district have been worked at times since 1849 and have yielded both manganese and ferruginous manganese ores. Most of the work on the deposits of manganese ore has been done during two periods of activity, one beginning in 1885 and ending in 1898, and the other beginning in 1915 and ending in November, 1918, when the demand for domestic manganese ores practically ceased, except for the filling of war-time contracts. Most of the work on the deposits of ferruginous manganese ore has been done since 1904. By far the greater part of the manganese ore produced during the first period of activity was mined at the Southern mine, and most of the ferruginous manganese ore was produced by the Cason mine.

The production of these two classes of ore in the Batesville district from 1849 to 1918, inclusive, is given in the accompanying table, which is compiled mainly from Mineral Resources, published by the United States Geological Survey, but partly from other sources.

Manganese and ferruginous manganese ores produced in the Batesville district, Ark., 1849–1918, in long tons.

Year.	Manganese ore (35 per cent or more of manganese).[a]	Ferruginous manganese ore (10 to 35 per cent of manganese).	Year.	Manganese ore (35 per cent or more of manganese).[a]	Ferruginous manganese ore (10 to 35 per cent of manganese)
1849–1867	600		1900	145	
1868	10		1901	91	
1881	100		1902	82	
1882	175		1904		600
1883	400		1905		3,321
1884	800		1906	62	8,900
1885	1,483		1907		4,133
1886	3,316		1908		4,066
1887	5,651		1909		3,325
1888	4,312		1910	500	5,030
1889	2,528		1911		2,177
1890	5,339		1912		1,332
1891	1,650		1913		9,650
1892	6,708		1914		1,970
1893	2,020	160	1915	1,288	2,655
1894	1,934		1916	6,250	3,645
1895	2,901		1917	10,140	9,100
1896	3,421		1918	7,731	9,173
1897	3,240				
1898	2,662			75,985	69,237
1899	356				

[a] The figures for production of manganese ore for 1910 and previous years perhaps include a small amount of ore carrying less than 35 per cent of manganese.

GEOGRAPHY.

The Batesville district is on the southern edge of the Ozark Plateau, south of which lie the Boston Mountains. Both the Boston Mountains and the Ozark Plateau are subdivisions of the Ozark region.

The district here described is rough, but the relief is not great. Many narrow valleys trench all parts of its plateau surface, so that very little level land remains in the interstream areas, which consist of hills and ridges. The lowest elevation, which is less than 250 feet above sea level, is on White River near Batesville, and the highest, 950 feet, is on Pine Mountain, 2 miles north of Anderson. The streams flow in channels that are generally 100 to 400 feet below the crests of the hills and ridges. The hill slopes are steep, and there are many bluffs adjacent to the streams, especially on the outer sides of the stream bends. Of the bluffs along White River the largest and most picturesque is Penters Bluff, which is about 1 mile long and about 400 feet high. The comparatively small number of level tracts and the more gentle slopes are mantled with residual soil or with wash from higher ground. Rock outcrops are common in most parts of the district but are especially abundant on the steeper slopes.

The drainage of the Batesville district empties into White River, the largest stream. Cura and Dota creeks enter Black River, which in turn enters White River outside the district. The streams north and northeast of Cave City enter Strawberry River, which joins Black River. White River is navigable above Guion, though a series of three dams and locks have been built by the United States Government to aid navigation. One of these is just below Batesville, the second is at Earnharts, and the third is at Walls Ferry station. The largest streams of the area besides White River are West Lafferty, East Lafferty, Spring, and Sullivan creeks, and Polk Bayou. Many of the creeks are perennial and are supplied with water from numerous springs in all parts of the area.

The Batesville district is not densely populated, though all parts of it are inhabited. The largest town is Batesville, the county seat of Independence County.

A branch of the Missouri Pacific Railroad passes through Sulphur Rock, Moorefield, and Batesville and thence runs near the left bank of White River beyond the limits of the area here described. Short branches of this railroad extend to Pfeiffer and Cushman. A spur formerly ran from the mouth of Lafferty Creek to the village of Phosphate, but both the spur and the village have long been abandoned.

Public and secondary roads reach all parts of the district, but only a few of them are maintained in good condition, although limestone, broken chert, and gravel suitable for road building are at hand in many places.

GEOLOGY.

ROCK FORMATIONS.

GENERAL FEATURES.

The rocks of the Batesville district are all of sedimentary origin and consist mainly of sandstone, shale, limestone, and chert, with beds of gravel and sand. They are of Ordovician, Silurian, Devonian, Carboniferous, Cretaceous (?), and Quaternary age. The Fernvale limestone and Cason shale, of Ordovician age, and their residual clays contain the manganese ores and are the only formations that need be described in detail in this report.

The succession and thickness of the Ordovician, Silurian, Devonian, and Carboniferous rock formations are shown on Plate VII, and their distribution is shown on Plate VI. The principal lithologic features of these formations are set forth below.

Batesville sandstone: Brown or buff fine-grained sandstone with lenticular beds of shale. Exposed south of manganese-bearing area.

Moorefield shale: Black and greenish shale, limestone concretions, and a limestone phase at base, which has been called "Spring Creek limestone." Exposed south of manganese-bearing area.

Boone chert: Composed mainly of chert but partly of limestone, sandstone, and shale. Lower part caps most of hills in manganese-bearing area.

Chattanooga shale: Platy black shale. Exposed only near village of Pfeiffer. Was described by Penrose[3] as a part of the Boone chert. A few fossils which have been procured from the shale are stated by E. O. Ulrich to show that it is of the same age as the Genesee shale of the northern Appalachian region.

Penters chert: Gray and bluish chert; upper part is dark colored at places. Exposed near Pfeiffer and Penters Bluff station, and receives its name from the latter place. No fossils have been discovered in the chert, but its lithology and stratigraphic relations indicate that it is of the same age as the Camden chert of west-central Tennessee and the lower part of the Arkansas novaculite of west-central Arkansas and southeastern Oklahoma. The Camden chert has yielded fossils and has been regarded by most geologists as being equivalent in age to a part of the Oriskany group of the northern Appalachian region. The Penters chert was described by Penrose[4] as a part of the Boone chert.

Lafferty limestone: Thin-bedded compact earthy limestone. Upper part gray, lower part mostly red but partly gray. Only known exposure at the Tate Spring, 1¼ miles north of Penters Bluff station. Name of limestone taken from West Lafferty Creek, which is half a mile east of exposure. The stratigraphic relations and lithology suggest that it is of the same age as the Dixon limestone of west-central Tennessee, and the evidence of a few fragmentary fossils from the Lafferty limestone is stated by Ulrich not to militate against this correlation.

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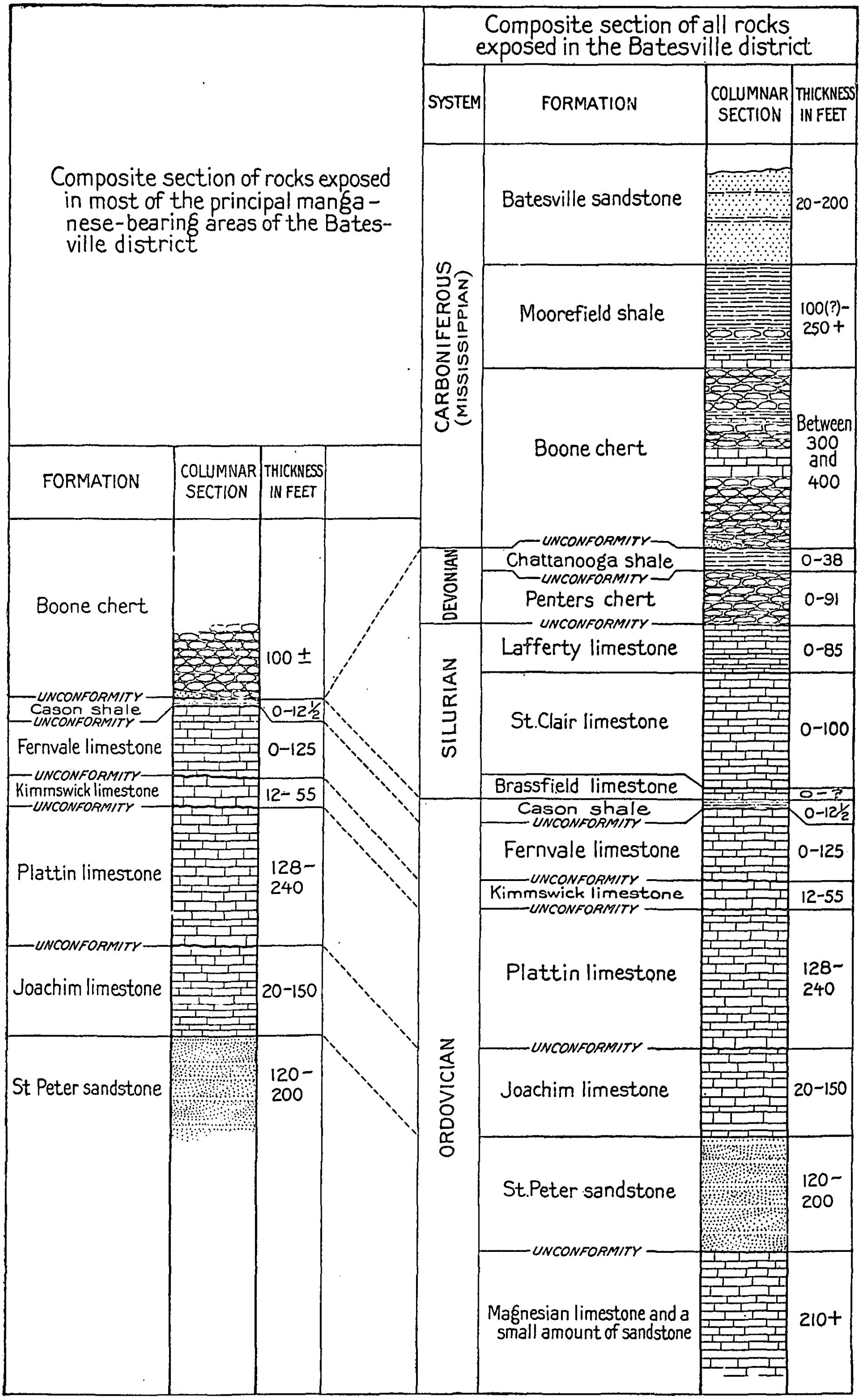
[3] Penrose, R. A. F., jr., op. cit., pp. 132–133.
[4] Idem, pp. 131–133.



GENERALIZED SECTIONS OF THE PALEOZOIC ROCKS OF THE BATESVILLE DISTRICT, ARK.

St. Clair limestone: Massive coarse-grained pinkish light-gray fossiliferous limestone. Exposed in several small areas but absent over most of manganese-bearing area. The typical St. Clair limestone is stated, by Ulrich, who has recently studied its fossils, to be of approximately the same age as the Rochester shale of New York or the Laurel limestone of Tennessee, Kentucky, and Indiana.

Brassfield limestone: No exposures are known in the Batesville district, but fossils derived from it through weathering occur in residual clay at the Montgomery mine. The limestone is exposed farther west in Arkansas. There its lithology, fossils, and stratigraphic relations show that it is equivalent to the Brassfield limestone of southwest-central Tennessee. In previous reports on northern Arkansas this limestone has been included in the St. Clair limestone, but it is not present at the St. Clair type locality and is regarded by Mr. Ulrich as of Albion (upper Medina) age.

Cason shale: Greenish-gray calcareous shale and smaller amounts of sandstone and phosphate rock; contains manganese and iron minerals. For a detailed description of the Cason shale see pages 101–104.

Fernvale limestone: Coarse-grained massive cross-bedded dark-gray and pinkish-gray limestone; contains manganese minerals. For a detailed description of the Fernvale limestone see below.

Kimmswick limestone: Even-bedded massive light-gray fine-grained limestone. Exposed in much of manganese-bearing area. This limestone, according to Ulrich, is the same as the Kimmswick limestone of southeastern Missouri. It comprised the lower part of the "Polk Bayou" limestone of some of the earlier reports on the Batesville district, whereas the Fernvale limestone, which overlies the Kimmswick, comprised the upper part of the "Polk Bayou" limestone.

Plattin limestone: Even-bedded dove-colored or grayish-blue compact limestone; breaks with conchoidal fracture. Exposed over a large part of manganese-bearing area. This limestone, according to Ulrich, is the same as the Plattin limestone of southeastern Missouri. In earlier geologic reports on this part of Arkansas the Plattin has been described as the "Izard limestone," but the "Izard" as it was defined included not only the Plattin but also the Joachim limestone.

Joachim limestone: Drab fine-grained magnesian limestone; thin beds of sandstone in lower part. Exposed over much of manganese-bearing area.

St. Peter sandstone: Massive white or cream-colored sandstone. Exposed over large and small areas in northern part of Batesville district.

Rocks below St. Peter: These rocks crop out at places along West Lafferty, East Lafferty, and Sullivan creeks and Polk Bayou and are probably the equivalents of rock formations to which names have been assigned in other parts of the Ozark region.

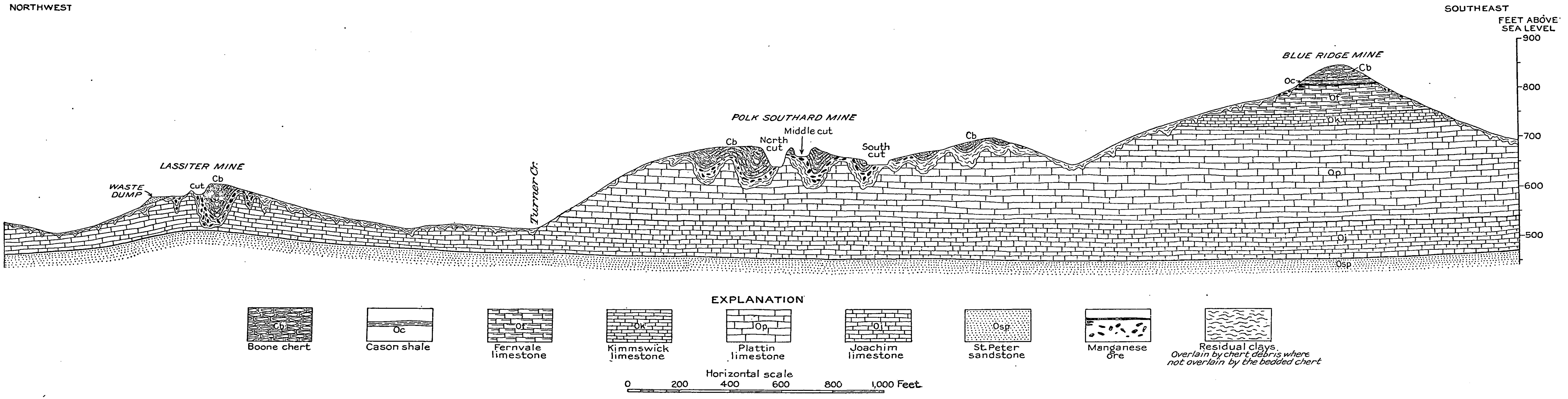
FERNVALE LIMESTONE.

The Fernvale limestone is the surface rock on the hill slopes in much of the manganese-bearing area. It ranges in thickness from a feather edge to 125 feet; the maximum thickness occurs at Penters Bluff. It is about 100 feet thick at most places, but it thins westward so that it is only 28 feet thick three-fourths of a mile northwest of Guion, and it thins out to the east less than 1 mile southwest of Hickory Valley.

The Fernvale consists almost wholly of limestone. The other constituents are manganese ore and a small quantity of chert. The limestone is coarse grained, massive, and cross-bedded. Its exposed ledges are friable and have rough surfaces, and on some steep slopes thin slabs break off parallel with the exposed surfaces that are at high angles to the bedding. The color is dark gray, but the unweathered parts of the limestone, as well as some of the weathered parts, have a pinkish cast. Parts of the limestone, especially the uppermost beds, are very dark gray or brown, owing to the occurrence of iron and manganese oxides that are more or less uniformly disseminated through the rock. A few fossils occur in all parts of the limestone, but they are most numerous in beds near the top and near the base.

At some places the limestone contains nodules and thin lenses of gray and brown chert and many irregular masses of brown chert as much as several feet in their longest dimensions. The irregular masses were formed in the limestone near the surface, but many of them have been freed from the limestone, so that they are now more numerous in the residual clays than in the limestone. Such masses are found in the manganese-bearing clays at many of the mines and prospects, one of the most noteworthy occurrences being at the Southern mine. There, as well as at other places, the chert contains much drusy quartz and numerous doubly terminated quartz crystals, half an inch or less in their longest dimension, which are now found on the waste dumps. Many of the crystals are transparent, but most of them are brown from the presence of minute inclusions of manganese oxide. Most of the chert is porous, and much of it contains casts of fossils. The presence of this chert in residual clays a few miles away from any known occurrence of the unaltered limestone indicates that the limestone once existed at such localities, though it has since been completely removed except for its insoluble constituents, which were chert and clay.

Although exposures of the Fernvale limestone are numerous, especially in bluffs and on steep slopes, it is concealed over much of the Batesville district by its own residual clay and by clays and chert fragments derived from younger rocks. The clay that is residual from the limestone is usually sticky, and the prevailing colors are red and chocolate-brown, but at some places parts of the clay are yellow. These clays and the other surficial materials overlie the irregular surface of the unweathered limestone, in which underground hollows and channels 50 feet or more deep have been formed by solution. (See figs. 14 and 15 and Pl. VIII.) Such channels and hollows, as well as the limestone pinnacles and horses that separate them, are well displayed in open cuts at the Cummins Hollow and Club House mines. Some of the channels are straight and rep-



SECTION THROUGH THE LASSITER, POLK SOUTHARD, AND BLUE RIDGE MINES, BATESVILLE DISTRICT, ARK., ILLUSTRATING THE OCCURRENCE OF THEIR MANGANESE-ORE DEPOSITS.

resent widened fissures along joints. A few caves and sink holes have also been formed in the limestone.

The Fernvale limestone rests unconformably upon the Kimmswick limestone and is unconformably overlain by the Cason shale or where the Cason is absent, by younger formations. The upper surface of the Fernvale is irregular, containing in places channels and fissures as much as 2 feet deep that are filled with the materials of the succeeding deposit, which is usually a conglomeratic or earthy material, but in a few of the fissures is a gray oolitic limestone.

The Fernvale is the oldest formation of Richmond age in the Batesville district. The Richmond deposits, according to the accepted usage of the United States Geological Survey, are placed in the Ordovician system, but they are placed by E. O. Ulrich in the Silurian system. The Fernvale was included in the St. Clair limestone of Penrose,[5] in the St. Clair marble of Hopkins,[6] Branner,[7] and Newsom,[7] and in the upper part of the Polk Bayou limestone of Williams[8] and other geologists.[9] This limestone was first identified by Ulrich[10] as being the same as the Fernvale limestone of middle Tennessee.

CASON SHALE.

The Cason shale receives its name from its occurrence at the Cason mine, 3 miles north-northeast of Batesville. It is generally present in the vicinity of Cushman, Penters Bluff station, and Williamson, and along East and West Lafferty creeks and their tributaries but is absent at most places along Polk Bayou and farther east. It appears to be absent also in the vicinity of Guion, although the rocks in that part of the district were not studied in as great detail as those farther east.

The shale is thin, at no place exceeding 12½ feet in thickness, but its residual clay at the Montgomery mine is 20 feet or more thick, suggesting that the shale at that locality was probably more than 12½ feet thick.

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[5] Penrose, R. A. F., jr., Manganese—its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, 1891.

[6] Hopkins, T. C., Marbles and other limestones: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 4, 1893.

[7] Branner, J. C., The phosphate deposits of Arkansas: Am. Inst. Min. Eng. Trans., vol. 26, pp. 580–598, 1896. Branner, J. C., and Newsom, J. F., The phosphate rocks of Arkansas: Arkansas Agr. Exper. Sta. Bull. 74, pp. 61–123, 1902.

[8] Williams, H. S., The Paleozoic faunas of northern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 5, pp. 268–362, 1900.

[9] Ulrich, E. O., Determination and correlation of formations [of northern Arkansas]: U. S. Geol. Survey Prof. Paper 24, pp. 90–113, 1904. Purdue, A. H., Developed phosphate deposits of northern Arkansas: U. S. Geol. Survey Bull. 315, pp. 463–473, 1907. Harder, E. C., Manganese deposits of the United States, with sections on foreign deposits, chemistry, and uses: U. S. Geol. Survey Bull. 427, pp. 102–118, 1910.

[10] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, p. 421, pls. 27, 28, 1911.

The Cason is composed mainly of shale but partly of sandstone and phosphate rock in addition to manganese and iron minerals. Not only does the quantity of these constituents vary from place to place, but their character also varies considerably, so that sections of the formation even at places near together would generally differ.

The shale is greenish-gray, platy, and calcareous, and contains more or less quartz sand and phosphatic material. Several pieces of the shale were tested for phosphate, and it was found in all of them, indicating that at least a small quantity of it is probably present in all parts of the shale. At a few places the phosphatic material occurs as fine pebbles, some of which are almost 1 inch in their longest diameter. The shale in most of its exposures has been affected considerably by weathering and is yellow or brown, but at the Cason mine most of it as shown in the workings at the time of examination was red. Only a small part of the shale there retains its greenish-gray color.

A bed of greenish-gray, brown, or yellow sandstone attaining in places a thickness of several feet is generally present west of Polk Bayou. This sandstone contains quartz grains and more or less phosphatic material, which occurs in the form of fragments of shells or of well-rounded and angular grains and pebbles 1 inch or less in their longest dimension, and it is known as "phosphate rock" on account of its high content of phosphorus. It is exposed as ledges on the hill slopes, and blocks of it lie on the slopes below the ledges. These ledges are a great aid to prospectors for manganese ore, because the ore is always found below them.

Although phosphate is widely distributed in the Cason shale, it has been mined in commercial quantity at only a few places in the vicinity of the abandoned village of Phosphate. The mines have not been worked for several years. The developed deposits were described by Purdue, and deposits in all parts of the Batesville district were described by Branner and Newsom.

The Cason shale rests upon the Fernvale limestone everywhere in the Batesville district except at the Ball mine, where it apparently overlies the Kimmswick limestone, though both the Kimmswick and the Cason at that locality have completely disintegrated to clay. The contact between the Fernvale and the Cason is irregular. This fact, together with the thinning out of the Fernvale in the vicinity of Hickory Valley, indicates that an unconformity separates the Cason shale from the underlying rocks—in other words, that a period of emergence and erosion preceded the deposition of the materials that now constitute the Cason shale. The fossils, according to Ulrich, indicate that this shale was deposited in shallow marine waters. That it was deposited in shallow water is also indicated by the conglomeratic character of parts of the formation.

The Cason is overlain at some places by the St. Clair limestone, but the occurrence of fossils of the Brassfield limestone in residual clays above the altered Cason shale at the Montgomery mine shows that the Brassfield once overlay the Cason shale at that locality. The Brassfield, according to its fossils, is older than the typical St. Clair. This fact and the apparent absence of the Brassfield at other localities in the region seem to furnish sufficient proof that an unconformity separates the Cason from the St. Clair, but the contact between the Cason and St. Clair, wherever it is revealed, is even and does not suggest an unconformity, because there is no abrupt change in the character of the rocks at the contact. In much of the Batesville district all the

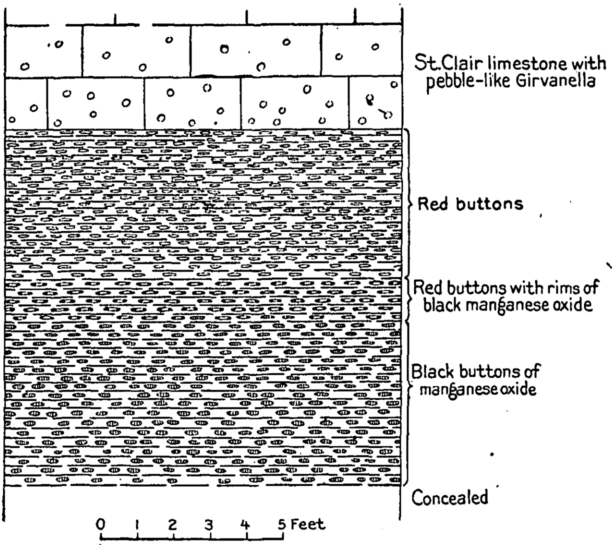

FIGURE 13.—Section near the central part of the Cason mine, Batesville district, Ark., showing the relations of the red and green shales in the Cason shale and the relations of the red, black, and partly blackened "buttons." The heavy ruling represents red shale, and the light ruling green shale.

Silurian and Devonian rocks, including the St. Clair limestone, are absent, and the Boone chert, of Carboniferous age, rests unconformably upon the Cason shale.

Except for the "buttons," which are numerous at a few localities, fossils are comparatively rare in the Cason shale. The "buttons" are flattened concretion-like masses half an inch to 1 inch in their longer diameter and from a quarter to half an inch thick and are stated by E. O. Ulrich [11] to be fossils belonging to the genus *Girvanella*, which is a form of algal growth. They were once spherical, or nearly so, and were composed mainly of calcium carbonate and partly of manganese carbonate, but they have been flattened by pressure. (See fig. 13.) As they are revealed in the rock outcrops and in the

[11] Personal communication.

residual clays most of them have been replaced by manganese and iron oxides. The unaltered "buttons" are greenish gray, the partly oxidized "buttons" red, the "buttons" of manganese oxides black, and those of iron oxide red. Many of them show concentric banding, and many contain centers of chert and earthy material. They lie parallel with the bedding of the shale and are more or less uniformly disseminated through the shale and its residual clay. Their most noteworthy occurrence is at the Cason mine, which has been the largest producer of low-grade ferruginous manganese ore in the district. There "buttons" composed of manganese oxides are so numerous that the residual clay itself has been mined and shipped without treatment, and much of the shale has been quarried as ore. Only a part of the shale at this mine, however, contains "buttons" of manganese oxides; the rest of it contains "buttons" whose principal constituents are manganese and calcium carbonates. This is in fact the only locality in the district where the carbonate "buttons" have been discovered.

These fossils, according to Ulrich, are similar to *Girvanella richmondensis*, a species which is found in beds of the Richmond group in Indiana. These and the other fossils, together with the relation of the Cason shale to the underlying and overlying rocks, indicate that the Cason is the next to the oldest formation of Richmond age, the Fernvale limestone being the oldest. The Richmond group, as previously stated, is placed in the Ordovician system by the United States Geological Survey and in the Silurian system by Ulrich.

The Cason shale was included in the St. Clair limestone by Penrose.[12] Williams,[13] the first geologist to define the Cason as a separate formation, placed it in the Silurian system.

STRUCTURE.

GENERAL FEATURES.

The strata in the Batesville district, which must have been deposited in a nearly horizontal position, have undergone little deformation. The general doming of the beds in the Ozark region has given those of this area a slight dip to the south, which is disguised at several places by minor folds and a few normal faults. Most of the minor anticlinal flexures form small domes, and the synclinal flexures form basins, but they are referred to simply as anticlines and synclines in this report.

[12] Penrose, R. A. F., jr., op. cit., p. 125.

[13] Williams, H. S., On the age of the manganese beds of the Batesville region of Arkansas: Am. Jour. Sci., 3d ser., vol. 48, pp. 325–331, 1894.

FOLDS.

Many small folds were observed during the present investigation, and many others can doubtless be discovered in future field work, especially with the aid of a better topographic map than the one at present available. Although a few folds are so small or so poorly defined as to make their description impracticable, a few are sufficiently pronounced to warrant special mention. Folds that are intimately associated with valuable manganese deposits are also described.

An anticline whose axis lies along the crest of the ridge north of the Cason mine extends in a northeasterly direction for at least 1¼ miles from the mine. A small area of outcrop of the Plattin limestone half a mile northeast of this mine is on the crest of the anticline.

The rocks at the Cason mine lie in a shallow syncline on the southeast side of the anticline just mentioned. The axis of the syncline trends northwest. In the West cut, which is on the west side of the syncline, the St. Clair limestone and Cason shale dip 15°–20° NNE., and in the North cut, which is on the east side of the syncline, they dip at about the same angle to the southwest.

A broad eastward-trending syncline lies about 1¼ miles north-northeast of Cushman, and in it are the Blue Ridge, Southern, Grubb Cut, Rogers, Wren, Polk Southard, and Turner mines. The Blue Ridge, an east-west ridge which is capped by the Boone chert, is on or near the axis of the syncline. (See Pl. VIII.) On the south side of the syncline the St. Peter sandstone and Joachim limestone are revealed in an anticline in the southern part of sec. 3, T. 14 N., R. 7 W., and on the north side of the syncline these two formations are revealed in two anticlines just north of Turner Creek, in secs. 33 and 34, T. 15 N., R. 7 W.

The axis of a shallow east-west syncline half a mile wide passes through Anderson. The oldest exposed formation in this syncline is the St. Peter sandstone, and the youngest that is present in the part of the syncline east of Anderson is the Fernvale limestone. The Earl Collie, Sand Field, Manganese Field, Ruminer Rough, and Barksdale mines and the Caraway prospect are in this syncline.

FAULTS.

Faults are rare in the Batesville district, only seven being known, and all are normal faults. They are shown on the accompanying map (Pl. VI). The longest fault is 7 or 8 miles long, and the amount of downthrow along the faults is 400 feet or less.

ORE DEPOSITS.

MINERALS OF THE ORES.

General features.—The manganese ores of the Batesville district consist of oxides, six of which, psilomelane, hausmannite, braunite, manganite, pyrolusite, and wad, have been identified. Although these minerals may be found separately, two or more are generally mixed in a single deposit, and at a few places they are associated with ferruginous manganese ores and with small quantities of brown and red oxides of iron. At some places the ferruginous manganese ores predominate. Psilomelane is the most abundant manganese mineral, but hausmannite, braunite, and wad constitute a considerable part of the ores.

Psilomelane.—Psilomelane is black or steel-blue, is amorphous, breaks with a conchoidal fracture, and at a few places shows botryoidal surfaces. It has a specific gravity of 3.7 to 4.7 and commonly has a hardness of 5 to 6.5, which means that a knife blade scratches it with difficulty if at all. Although the chemical composition may be represented by the formulas $MnO_2.(Mn,K,Ba)O.nH_2O$ and H_4MnO_5, the composition is not definite, as the percentage of manganese varies from 50 to 57 and as the amounts of minor accessory ingredients, such as iron, barium, potassium, and water, show a wide range.

Hausmannite.—Hausmannite is a brittle steel-gray mineral with a chestnut-brown or reddish-brown streak and submetallic luster. It is finely to coarsely granular but partly crystalline, is weakly magnetic, is translucent on thin edges, and has an uneven fracture, a perfect basal cleavage, and a hardness of about 5.5. The crystals, which resemble small octahedra, line cavities in the massive mineral. The chemical composition is expressed by the formulas Mn_3O_4 and $MnO.Mn_2O_3$. This mineral, next to psilomelane, is the most abundant in the Batesville district. It has heretofore been classed as braunite. It differs from braunite in having a lighter-colored streak, in containing very little or no silica, and in having a higher percentage of manganese protoxide (MnO) and a smaller percentage of oxygen. Chemically pure hausmannite contains 72 per cent of manganese. The following analyses, which were made in the chemical laboratory of the United States Geological Survey by J. G. Fairchild, show the composition of samples from the W. T. Gray and Club House mines. The samples were carefully separated as much as possible from the psilomelane, with which the hausmannite was rather intimately mixed.

Analyses of hausmannite from the Batesville district, Ark.

[J. G. Fairchild, analyst.]

	W. T. Gray mine.	Club House mine.		W. T. Gray mine.	Club House mine.
Manganese protoxide (MnO)	91.38	90.40	Magnesia (MgO)	Trace.	Trace.
Oxygen (O)	7.78	8.87	Baryta (BaO)	0.26	None.
Iron (Fe)	None.	(a)	Total water (H_2O)	.62	1.03
Silica (SiO_2)	None.	.10		100.04	100.88
Alumina (Al_2O_3)	None.	b.48	Manganese (Mn)	70.76	70.00
Lime (CaO)	Trace.	Trace.	Specific gravity at 15.5° C.	4.836	4.778

a Included with alumina. b Plus a trace of iron.

Braunite.—Braunite is a brittle steel-gray mineral that has a brownish-black streak and submetallic luster and a hardness of 5.5 to 6. It is weakly magnetic, and is either granular or crystalline but generally crystalline. Its crystals are small and numerous and are octahedral in form. The composition is usually expressed by the formula $3Mn_2O_3.MnSiO_3$. Some silica—7 to 10 per cent—that is, chemically combined, is always present, as is indicated by its occurrence in all the specimens that have been tested. It appears as a gelatinous residue when hydrochloric acid containing braunite in solution is evaporated. The percentage of manganese in chemically pure braunite ranges from about 63 to 66.

Manganite.—Manganite ($Mn_2O_3.H_2O$) is a brittle steel-gray granular or crystalline mineral with a dark-brown or nearly black streak. It has a hardness of 4 and therefore can be scratched with a knife but not with a brass pin. Manganite crystallizes in the orthorhombic system, and the crystals are generally bladed, wedge-shaped, or needle-like. It contains 62.4 per cent of manganese and 10.3 per cent of water. The specific gravity ranges from 4.2 to 4.4. Although it is present at a number of localities in the Batesville district it forms a very minor part of the manganese ores. Nodules from some of the deposits are made up of alternate layers of psilomelane and radiating crystals of manganite.

Pyrolusite.—Pyrolusite (MnO_2, generally with a little H_2O) is a grayish-black to black mineral with a crystalline or granular structure and a black or bluish-black streak. It has a hardness of 2 to 2.5 and can therefore be scratched with a brass pin. Much of it crumbles between the fingers, which it blackens. The specific gravity is about 4.8. It contains 63.2 per cent of manganese. It has been generally regarded as having been derived from manganite by the loss of water. Pyrolusite is present in small quantity at a few localities in the Batesville district.

Wad.—Wad is a dark-brown to black, very soft earthy mineral which is commonly considered an impure hydrous oxide of manganese. It is associated with more or less iron, silica, alumina, and water. It is present at many localities in the Batesville district, and at some of them is more abundant than the higher-grade manganese minerals. During the last few years, when there was a demand for low-grade ores, considerable wad was shipped from the district. Most of the wad that has been shipped contained from 20 to 30 per cent of manganese. Dendrites, branching mosslike growths of wad, are common along joints in the parts of the Boone chert that are associated with the manganese deposits and along cracks and on fossils in the St. Clair limestone.

Iron oxides.—Iron oxides that probably comprise several hydrous sesquioxides of iron are associated with the manganese ores at many localities. Of these limonite ($2Fe_2O_3.3H_2O$) and hematite (Fe_2O_3) are the most abundant.

Ferruginous manganese ore.—The ferruginous manganese ores are generally mixtures of poorly defined oxides of manganese with oxides of iron in various proportions. The iron oxides are usually limonite and hematite. The manganese is generally in the form of psilomelane, though at some places braunite, manganite, and wad are common. The iron and manganese oxides occur as a mixture of two minerals that are readily distinguishable in the hand specimen or so intimately mixed that it is impossible to determine the proportions of each. The amount of manganese in the ferruginous ores ranges from 10 to 35 per cent or more and the amount of iron from a few per cent to 31 per cent. The higher-grade ores are used in the manufacture of spiegeleisen and ferromanganese, and the lower-grade ores are used in the manufacture of high-manganese pig iron.

Other minerals.—Minerals that are found in small quantities associated with the ores besides phosphate rock are barite, quartz, calcite, arsenopyrite, chalcopyrite, pyrite, galena, pyromorphite, manganiferous calcite, and a mineral that is composed of manganese, iron, and calcium carbonates.

TYPES OF DEPOSITS.

The workable manganese and ferruginous manganese deposits may be grouped into five types, partly according to the different rock formations and clays in which they occur and partly according to their origin:

1. Replacement deposits in the Cason shale and its residual clay.
2. Replacement deposits in the Fernvale limestone.
3. Residual deposits derived from the Fernvale limestone.
4. Replacement deposits in clays.
5. Transported deposits in stream gravels.

The residual deposits derived from the Fernvale limestone are represented at more mines than those of any other type and have yielded more high-grade ore than any others. At most mines and prospects only one type is represented, but at some two types and at a few three types are present and have yielded ore in commercial quantities.

The principal features of these different types of deposits are described below in the order in which they have just been named.

REPLACEMENT DEPOSITS IN THE CASON SHALE AND ITS RESIDUAL CLAY.

Manganese and ferruginous manganese ores are widely distributed in the Cason shale. They have been worked at a number of places and have furnished most of the ferruginous manganese ores and a considerable part of the manganese ores that have been produced in the Batesville district. This formation is generally present in the vicinity of Cushman and farther west and occurs at a few places east of Cushman, where its ore deposits are larger and contain a higher manganese content and a lower iron content than the deposits farther west.

The ores consist of iron and manganese oxides, which are in places more or less intimately mixed. The manganese oxides are mainly psilomelane and braunite, and the iron oxides include both red and brown oxides. These minerals occur as irregular masses, as thin horizontal seams and beds, and as "buttons" or flattened concretion-like masses about an inch in longest diameter.

The most noteworthy occurrence of the manganese "buttons" is at the Cason mine, which has produced more low-grade manganese ore than any other mine in the district. (See fig. 13.) Here they are so numerous that the "button"-bearing residual clay of the Cason shale has itself been shipped without any treatment, and in recent years much of the "button"-bearing shale has been quarried and shipped as ore. The average manganese content of the ore thus shipped has been about 20 per cent and the iron content has ranged from 6 to 10 per cent. Only a part of the shale at the Cason mine contains "buttons" of manganese oxide; the rest contains red and gray "buttons" composed largely of manganese-bearing calcite. Various stages in the transition of the gray carbonate "buttons" to the red carbonate and the replacement of the red "buttons" by manganese oxide are well displayed in the cuts.

Other noteworthy occurrences of "buttons" of manganese oxide are at the Montgomery mine and Button prospect, and comparatively small numbers of them were observed at the Adler mine, O'Flinn prospect, Johnson Hill mine, and Ball mine. At the

O'Flinn prospect, Button prospect, and Johnson Hill mine some of the "buttons" are in shale; at the other places they occur in clays.

"Buttons" of red iron oxide were observed in the residual clay of the Cason shale at two of the Pittman mines, at the mine of the United Phosphate & Chemical Co., at the Breeden prospect, and at the W. T. Gray mine.

The irregular masses of ore are generally porous and usually have rough surfaces, but some of them have botryoidal surfaces. Such masses constitute most of the ore at the Ball mine and much of it at the Montgomery mine. The lenses and beds are shaly and porous at most places and are parallel with the bedding of the shale. Three of the localities at which they occur are the Meeker and Blue Ridge mines and the F. M. Barnes prospect. (See Pl. VIII.) Although they occur in different parts of the shale, they are most common in the base. At some places it is difficult or even impossible to distinguish the ore bed in the base of the Cason shale from a nearly horizontal deposit of ore that occurs in the top part of the Fernvale limestone, which the ore has replaced.

The masses, lenses, and beds just described occur partly in sandstone but mostly in shale and clay, and the manganese oxides have replaced parts of these rocks, as is shown by the occurrence of sand grains, of pebbles of phosphate rock, and of irregular areas of shale, clay, and sandstone in the ore. "Buttons" of manganese oxide were also observed in lenses and masses of ore at the Ball, Cason, and Montgomery mines, showing that manganese oxides have replaced some of the clay and shale through which the manganese "buttons" were originally scattered.

The occurrence at the Cason mine of manganese-bearing calcite disseminated through parts of the Cason shale that have been least affected by weathering suggests that all the manganese oxides in the deposits described above have been formed by the oxidation of the carbonate. This supposition is corroborated by the occurrence in the Fernvale limestone of manganiferous calcite that has yielded at least some of the manganese oxides in that limestone and its residual clays. If this supposition is correct, the oxidation of the manganese-bearing carbonates is perhaps superficial, and the oxides may not extend below the water level of the district.

REPLACEMENT DEPOSITS IN THE FERNVALE LIMESTONE.

The occurrence of manganese minerals in the Fernvale limestone is discussed as follows by Penrose:[14]

The manganese, as seen in the St. Clair [Fernvale] limestone, exists in the same or almost the same chemical and physical condition as in the clay that now incloses it in the various manganese localities—that is, it occurs as

[14] Penrose, R. A. F., jr., op. cit., pp. 167–168.

oxides in bodies of different sizes. It is very probable that the manganese originally existed in the limestone in the form of a carbonate and was subsequently oxidized into its present condition. Possibly this oxidation may be only superficial, and below the water level of the country the ore may still retain its carbonate form. Small quantities of the carbonate sometimes exist in a finely disseminated state in the limestone, even on the surface, but practically all the manganese in the limestone, as now seen in surface exposures, is in the oxide state, and the disseminated carbonate is insignificant in comparison with the larger masses of oxides. * * *

The shape of the ore bodies in the limestone varies considerably in different places, but always conforms in a general way to the bedding of the rock. The ore occurs as irregular lumps and masses, often connected by thin layers of the same material; as lenticular bodies, a few feet to several yards in length; as flat masses or small concretions lying in the planes of bedding of the rock; as small disseminated particles and nodules, the size of small shot; and, in some places, in so fine a state of division as to form a dark chocolate-brown coloring matter. This last form sometimes occurs in thin layers in the rock and sometimes as a finely disseminated material, giving the dark-brown color often seen in the limestone. When considerable quantities of it are present, the rock often loses part of its highly developed crystalline structure and presents a dark, earthy appearance. The larger masses of ore occur both in this dark-colored and in the light-colored rock. In the latter case they are usually associated with more or less red clay, either in the form of a thin coating around the masses of ore or as films between layers of ore.

Since the above paragraphs were written by Penrose several openings have been made in the Batesville district that reveal the presence of manganese-bearing calcite. The discovery of such calcite, together with evidence that much if not all of the manganese oxide in the Fernvale limestone and its residual clay is derived from it, supports the statement by Penrose given above, namely, that the oxidation of the manganese-bearing calcite is possibly only superficial and that the manganese may still retain its carbonate form below the water level of the country. The most noteworthy occurrences of manganese-bearing calcite are in the uppermost beds of this limestone at the Harvey mine and the recently opened Manganese Cave mine, just west of the Harvey. This calcite is a fine to coarse grained mineral which has entirely replaced parts of the limestone and which has been partly oxidized and replaced by manganese and ferruginous manganese oxides. Some of the oxide-bearing carbonate has been quarried at these mines and shipped as a low-grade ore. A few boulders of ore that were mined near the surface appeared to consist entirely of manganese and ferruginous manganese oxides, but when they were broken open they were found to contain cores of the unoxidized carbonate.

The manganese oxides and also the manganese-bearing carbonate generally occur in the upper part of the Fernvale limestone, but they are by no means uniformly distributed through this part. The oxides have been found in sufficient quantity to warrant quarrying and shipping of the limestone only at one of the Pittman mines, the Club House mine, the Henley mine, the Adler mine, the Manganese Cave mine, the W. A. Chinn cut, and one of the Walter Chinn prospects. None of the deposits at these localities have so far yielded more than a few hundred tons of manganese-bearing limestone that was found profitable to work.

RESIDUAL DEPOSITS DERIVED FROM THE FERNVALE LIMESTONE.

GENERAL FEATURES.

The manganese deposits that have been derived from the Fernvale limestone are more numerous than those of any other type and have yielded not only the greater part of the output of high-grade manganese ore from the Batesville district but also a considerable part of the output of low-grade ore. Furthermore, they contain the largest reserves of available ore in the district. The largest known deposit of this type is that at the Southern mine, which has produced 36,500 tons of ore. Other deposits of this type which have yielded about 400 tons or more each are at the W. T. Gray, Searcy, G. A. Wilson, Roberts, Denison, Sis Clark, Brooks Hill, Grubb Cut, Rogers, Polk Southard, Turner, Lassiter, Club House, Shaft Hill, Hankins Hollow, Cummins Hollow, Ruminer Rough, and Manganese Field mines.

The manganese ores consist entirely of masses of oxides and occur in residual clays that overlie not only the Fernvale limestone but also the Joachim, Plattin, and Kimmswick limestones. These masses in their shape and in the character of their component minerals are like the masses of manganese oxides in the Fernvale limestone that have been described above. In fact, they were once embedded in this limestone, and after they were set free from it by the removal of the calcium carbonate they settled by gravity to their present position in the residual clays of the Fernvale and lower limestones (see figs. 14 and 15 and Pl. VIII), or were washed to their present position by streams. Although the ores that have been thus transported by streams are of minor commercial importance they represent a class of deposits of scientific interest, and are described under the heading "Transported deposits in stream gravels."

MANGANESE-BEARING CLAYS.

The manganese-bearing clays are a residue from the decomposition of the Fernvale, Joachim, Plattin, and Kimmswick limestones. Most of the clays, however, were derived from the Fernvale limestone, although at many localities this limestone has been almost if not entirely decomposed, so that such clays rest upon the lower limestones or upon their residual clays. The decomposition of the Fernvale limestone has formed subsurface hollows and channels as much as 75 feet deep, and some of these have been widened so much that only narrow pinnacles or horses of the unaltered limestones separate them. (See figs. 14 and 15 and Pl. VIII.) Such channels and pinnacles are well displayed in open cuts at the Cummins Hollow and Club House mines. Some of the channels are straight and represent widened fissures along joints. A few caves and sinkholes have also been formed in the limestone. Manganese ore has been discovered and mined in the caves at the Manganese Cave and Club House mines.

The manganese-bearing clays vary greatly in thickness, even in a single locality, owing partly to the irregularity of the surface of the unaltered limestones upon which they rest and partly to the extensive decomposition of the limestones. They are usually thin where the chert capping has been entirely removed. At most places they are only a few feet thick, but at some places they attain an exceptional

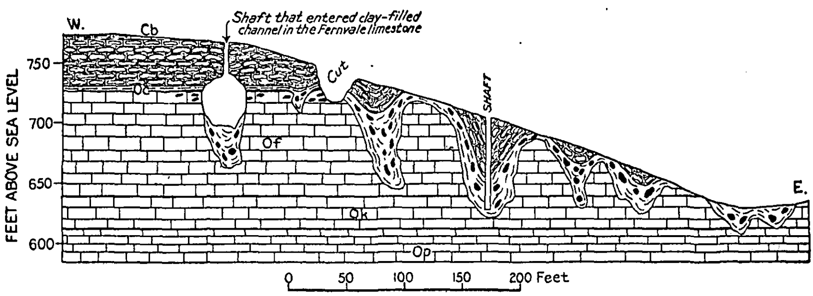

FIGURE 14.—Sketch section at the Club House mine, Batesville district, Ark., showing the occurrence of manganese ore in the Cason shale, in the Fernvale limestone, and in residual clays that lie in channels in the limestones. Cb, Boone chert; Oc, Cason shale; Of, Fernvale limestone; Ok, Kimmswick limestone; Op, Plattin limestone. Black dashes and heavy lines represent manganese ore.

thickness of 80 feet. Abundant outcrops of limestone in an ore-bearing area indicate that the ore-bearing clays occur in relatively small quantities. At such places the clays are confined almost entirely to subsurface channels and pockets in the limestone. The absence of rock outcrops, on the other hand, suggests that the clays may be relatively thick.

The clays are generally red and chocolate-colored but in places are yellow. They are usually sticky when wet and they become friable when dry, so that most of the clay that adheres to the masses of manganese ore crumbles and falls off of the ore before it is shipped. Slickensides in the clays are numerous. Besides manganese ore the clays contain loose masses of undecomposed limestone and fragments of chert which is residual from the Kimmswick and Fernvale limestones, and its surficial portions contain chert fragments that have been derived from the Boone chert and chert pebbles

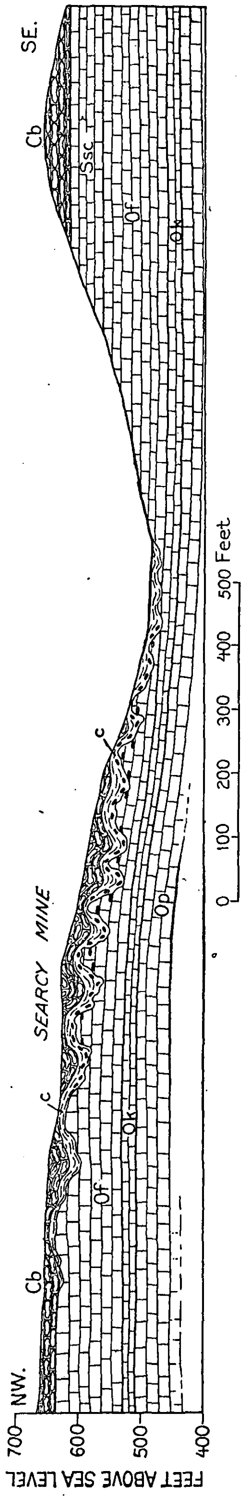

FIGURE 15.—Northwest-southeast section through the Searcy mine, Batesville district, Ark., illustrating the occurrence of the manganese-ore deposit in residual clays (c) that lie in channels in the limestones. Cb, Boone chert; Ssc, St. Clair limestone; Of, Ferndale limestone; Ok, Kimmswick limestone; Op, Plattin limestone. Black dashes represent manganese ore.

that have been derived from the gravel of Upper Cretaceous or later age, which once occurred over much of the district but which has since been almost completely eroded. At the Southern mine and a few other localities the chert is drusy, and small, doubly terminated quartz crystals are associated with it.

MANGANESE ORES.

The manganese ores are, as previously stated, a residue from the weathering of the Fernvale limestone, having been set free by the removal of the inclosing calcium carbonate through solution. This source is shown by the similarity in shape of the masses of ore in the clay and those of the manganese oxides in the limestone, by the occurrence of the same manganese oxides in the same relations in both the clay and the limestone, and by the presence of casts of fossils in some of the ore that is in the clay. Some of the masses of fossiliferous chert that have been derived from the weathering of the Fernvale limestone have been partly replaced by manganese oxides, and the casts of the fossils they contained are preserved in the ore, but the purity of much of the ore that shows casts of fossils, together with the absence of fossiliferous chert at most places, indicates that at least much of the fossil-bearing ore has not replaced fossiliferous chert but fossiliferous limestone. The chert may have been replaced before it was set free from the limestone or afterward. No evidence bearing on this point was observed. Penrose[15] says:

> The distribution of manganese ore in the clay, as would be expected from its unequal distribution in the limestone, is irregular and is the principal cause of the uncertainty in mining it. In some places, though rarely, it is

[15] Penrose, R. A. F., jr., op. cit., pp. 184–186.

evenly distributed throughout a large body of clay, but in most places it is in numerous pockets surrounded by clay containing no ore. These pockets vary greatly in character; sometimes they are comparatively solid bodies, separated only by thin films or seams of clay and containing from 50 to 500 tons or more of ore; sometimes they consist of large and small masses of ore embedded together in greater or less quantities in certain places in the clay; at other times they are composed of small nodules or grains (called "wash dirt" or "shot ore" by the miners) disseminated throughout the clay. The mass of these pockets of "wash dirt" contain from 5 to 25 per cent of manganese ore. Sometimes large areas of clay contain little or no ore, just as large areas of the original limestone often hold enough insoluble material to form a clay bed yet contain no manganese.

As the bodies of ore in the original limestone tended, in a general way, to follow the almost horizontal bedding of the rock and often had an oblong, flat shape, it would be expected that they would retain something of that shape in the residual clay. In most cases, however, the horizontal position has been considerably disturbed by the unequal decay of the limestone, and the flat bodies of ore have been broken into angular fragments or crushed together in a shapeless, shattered mass. Sometimes the fragments of ore have been separated in the unequal sinking of the clay and have been carried to different depths. Where the ore originally existed in the limestone as separate nodules, the same agencies have tended to scatter them, thus still further dividing the deposits as they orginally existed in the limestone. This action has undoubtedly, in many places, caused a more general distribution of manganese in the clay than was the case in the St. Clair [Fernvale] limestone. Of course the aggregate amount of ore has not been increased, but the original pockets have been broken up and separated.

In some places, however, where the decaying limestone has retained a comparatively even surface, the pockets of ore preserve their general horizontal position. Such is the case at the Southern mine, near Cushman, where, though the ore bodies sometimes pitch at high angles, a characteristic mode of occurrence is as almost horizontal pockets, gently undulating and of variable thickness.

It is also a noteworthy fact that where the surface of the St. Clair [Fernvale] limestone has been worn into the domes and peaks [pinnacles] already described the clay and its accompanying ore have a distinct dip, pitching away from such protuberances on all sides. This feature is a natural consequence of the sinking of a soft, plastic clay on an uneven surface, and a knowledge of it will prove of value in the practical mining of the ore. When a body of ore is found in the clay at or near the surface of one of these limestone peaks, its dip will be found to conform more or less closely to the angle of slope of the surface of the limestone.

The manganese ores consist mainly of the hard oxides, psilomelane, hausmannite, and braunite, with braunite in the least quantity, and of the soft oxide wad. The hard oxides occur partly as slabs and nodules but mostly as irregular masses ranging in size from fine particles to boulders that weigh as much as 22 tons, though boulders so large are rare. The wad occurs as irregular bodies of large and small size and as lenses and beds, and there are masses of hard oxides distributed through many of these bodies. Some deposits contain two or even three different grades of ore. The larger masses generally contain a higher percentage of manganese and a lower percentage of iron than the finer particles. This means that the "lump ore" is, as a rule, higher in grade than the "wash ore." The first-grade ore at some of the mines is hard and compact and contains 50 per cent or more of manganese; the second grade is porous, light, and soft, though firm, and contains 30 to 35 per cent of manganese, and the lowest or third grade is light, earthy, and soft and contains 20 to 25 per cent of manganese. At some places there is as much of the second grade as of the first grade and twice as much of the third grade as of the other two grades combined. The character and relative proportions of the several grades of ore, however, differ in different deposits.

Much of the highest-grade ore produced in the district—that containing 55 per cent or more of manganese—has been obtained from areas (called "roughs") over which outcropping boulders and ledges of the Joachim and Plattin limestones abound, but in such areas the manganese-bearing clays occur in comparatively small quantity. Such ore is farther from its source than most of the other ore in the region, and the chert covering has been entirely removed from above the ore-bearing clays. As a consequence this ore has been more easily attacked by weathering than most of the other ores, and it has lost its more porous soft parts by erosion or solution or both processes, so that only the hardest and most compact parts remain. Some of the occurrences of these high-grade ores are at the Denison, Hankins Hollow, Cummins Hollow, Johnson Hill, Ruminer Rough, Manganese Field, Barksdale, Sand Field, and Earl Collie mines. Analyses of ore of this grade are given on page 121.

CAPPING OF THE DEPOSITS.

The clays containing residual deposits derived from the Fernvale limestone are capped at many places by the Cason shale, by the Boone chert, and by gravels and sand.

Where the Cason shale is present, its shaly parts and the phosphatic sandstone that it contains in much of the western part of the district have been broken up during the decomposition of the Fernvale limestone, and, as stated by Penrose,[16] they have in places "been disintegrated into a more or less sandy clay and mixed with the other residue from the limestone; in other places they have not as yet been entirely decomposed and are associated with the clay as soft, earthy, honeycombed, and partly disintegrated masses commonly known as 'ocher.'" Although in places this weathered shale overlies the manganese-bearing clays and is in turn generally overlain by the Boone chert, in most of the eastern part of the Batesville district this chert rests directly upon the manganese-bearing clays, the Cason shale being absent except in small areas.

[16] Penrose, R. A. F., jr., op. cit., p. 175.

The Boone chert and the weathered Cason shale overlie the manganese-bearing clays at many places, not only where the Fernvale limestone has been partly or entirely decomposed but where the Kimmswick limestone has been completely decayed and even where a part or all of the Plattin limestone has been decayed. The chert and shale have therefore at many places settled far below their original position. (See figs. 14 and 15 and Pl. VIII.) The amount of the settling of the chert is equal to the thickness of the limestones that have been removed less the thickness of the residual clays that separate the chert from the undecomposed limestones. The beds of the chert have settled 75 feet or more at the Club House mine, at least 150 feet at the Polk Southard and Turner mines, and at least 250 feet at the Lassiter mine, but probably at no place have they settled more than 300 feet. During the settling of the beds they have been shattered, faulted, and bent so as to conform with the irregular surface of the underlying limestones, and at such places they now dip at angles that range from a few degrees to 60°. In general they dip away from the limestone pinnacles or horses, toward the subsurface hollows or channels in the underlying limestones. These displaced masses of chert are known by the miners as flint bars. The thickness of the chert capping ranges from less than 10 to more than 60 feet.

Surficial beds composed of well-rounded chert pebbles and quartz sand not only overlie some of the ore-bearing clays, but at a few places, as at the W. T. Gray mine, they occur as lenses and irregular masses in the clays. These lenses and masses are known as sand and gravel bars and were probably formed in underground channels in limestones that have since decomposed, leaving their residual clays, in which the gravel and sand are now found. The sand and gravel have been derived from beds of Upper Cretaceous or later age which once covered much if not all of the Batesville district, and which have since been almost completely eroded. Much if not all of the sand and gravel has settled below its original level or has been carried below that level by streams.

REPLACEMENT DEPOSITS IN CLAYS.

Manganese deposits that have been formed by the replacement of the clays by manganese minerals that have been introduced by ground waters from outside sources are not numerous in this district and their aggregate tonnage is not great, though some deposits probably contain 10,000 tons or more of this ore. The original source of the manganese in such deposits was probably the Cason shale or Fernvale limestone, but at all localities where deposits of this type occur these formations have been completely decomposed and if any of their constituents remain it is clay.

The clays in which these deposits occur contain more or less sand and pebbles and fragments of chert, and as some of the clay has been replaced by manganese ore these materials are present in much of the ore. Furthermore, the replacement of much of the clay has not been complete, and irregular areas of clay are included in parts of the ore. The ore is a low-grade ferruginous manganese ore, the manganese content usually being 35 per cent or less and the iron, silica, and alumina contents high. It occurs in large irregular masses and as veins several feet in their longest dimension and also in small masses many of which are nodular and have botryoidal surfaces. Most of the larger masses are composed mainly of a soft, earthy compact black wad but partly of psilomelane, manganite, and iron oxide and are cut by many joints whose faces are black and show deeply striated slickensides. The smaller masses contain a larger proportion of psilomelane and manganite.

Most of the deposits of this type examined by the writer are at the McGee, Hawkins, Chapel Hill, Montgomery Hill, and Roach mines and at the Cochran, Eliza Patterson, E. W. Roach, Jeff Weaver, and Pool prospects.

TRANSPORTED DEPOSITS IN STREAM GRAVELS.

Some of the hard, compact masses of manganese oxides that have been set free by the decomposition of the Fernvale limestone and Cason shale have been transported by streams and laid down in gravel beds. Some deposits that have been formed in this way occur in the beds of wet-weather streams that drain hollows on whose hill slopes the manganese-bearing clays and loams are exposed at the surface; others occur in alluvial cones at the mouths of some of such hollows. The deposit at the Sand Field prospect is on a terrace standing about 100 feet above East Lafferty Creek, but this terrace is perhaps the remnant of an old alluvial cone. The deposits of this class that have been worked have been formed by small streams only, and the masses of ore in them have not been transported far from their source, but much ore has doubtless found its way into the larger streams and has been carried by them out of the district.

The best example of a manganese-bearing alluvial cone is at the Pittman mine, at the mouth of Cummins Hollow, though another fairly good example is at the mouth of Hankins Hollow. Manganese ores have been mined from the beds of small streams in hollows at the Hankins Hollow, Cummins Hollow, Johnson Hill, Pugh, Adler Hollow, Earl Collie, and McConnell mines, and the O'Gilsby and Rudolph prospects.

The manganese ore of these deposits consists of hard, compact masses which have been partly rounded by abrasion and which range in size from fine pebbles to cobbles weighing 30 pounds, though at the Sand Field prospect the occurrence of boulders weighing 1,000 pounds is reported. The Pittman mine, at the mouth of Cummins Hollow, has produced 200 tons of ore, which is the largest output from a deposit of this type. The ore marketed there as well as at the other places named consisted of high-grade lump ore. The wash ore, which includes the finer pebbles, is usually a ferruginous manganese ore. The high percentage of iron is due to the occurrence of small pebbles of iron oxides mixed with those of manganese oxides.

OUTCROPS OF THE DEPOSITS.

The outcrops of the deposits are especially important to the prospector, for they generally present certain features that have served as guides in the discovery of the many deposits of the district.

The manganese ore itself, regardless of the type of deposit to which it may belong, is exposed at most places. The exposures generally consist of fine particles and large masses lying loose on the hill slopes and in the beds of small streams, and such ore is usually of the same quality as that below the surface. At places where the ore is not exposed its possible presence may be indicated by exposures of reddish-brown or chocolate-colored clays and by the occurrence of manganese and iron stains in and on chert that overlies the ore-bearing clay. At a few places the iron oxides with which the manganese ores are associated are revealed on the surface.

The brown loamy soil that overlies the manganese-bearing clays is usually very fertile where it does not contain too many chert fragments, and it supports a good growth of white oak, hickory, walnut, and other hardwoods.

RELATION OF THE DEPOSITS TO ROCK STRUCTURE.

Although most of the manganese deposits bear no definite relation to the structure of the rock formations, several of them, including a few of the largest deposits in the district, occur in synclines. The Southern, Grubb Cut, Rogers, Wren, Polk Southard, Turner, and Blue Ridge mines are in a single syncline; the Barksdale, Ruminer Rough, Manganese Field, Sand Field, and Earl Collie mines are in a single syncline; the W. T. Gray mine is in a syncline; and the Cason mine is in a syncline. Most of these synclines are described on page 105. The above-named mines are only a few of those in the district, but their aggregate production of both high-grade and low-grade ores is more than twice the combined production of all the other mines and prospects. The writer is therefore led to believe that the occurrence of large deposits in synclines is not accidental, but that the synclines have been favorable places for the accumulation of the ores. This subject will be discussed more fully in the final report.

RELATION OF THE DEPOSITS TO SURFACE FEATURES.

The manganese ores occur at all elevations from the bases of the hills to their crests, or from about 300 to about 800 feet above sea level, but most of the ores are found on and near the summits of even-crested hills, many of which mark the approximate elevation of a peneplain of Upper Cretaceous or Tertiary age, now dissected. A fuller discussion of the relation of the deposits to the surface features is given in the final report.

CHEMICAL COMPOSITION OF THE ORES.

The manganese ores may be grouped according to composition into two general classes—high-grade ores and low-grade or ferruginous manganese ores.

Most of the high-grade ores contain 45 to 52 per cent of manganese, though some of the ore that has been shipped contained as much as 60.80 per cent in carload lots. They generally contain from 3 to 8 per cent of iron, 0.15 to 0.30 per cent of phosphorus, and 2 to 8 per cent of silica. Some of the ore that has been marketed contained more than 0.30 per cent of phosphorus, and a very little contained 0.50 per cent or more. As the usual requirements of ores that are used for metallurgic purposes specify that their phosphorus content should not be in excess of 0.25 per cent, it is evident that some of the ores are too high in phosphorus. Phosphorus is, in fact, the most harmful ingredient in the ores of the district, but as it is not uniformly disseminated through the ores it can generally be avoided in mining. Also the high phosphorus content is in places due to the large amount of phosphorus in the material associated with the ore, and in such places it can be largely reduced by properly preparing the ore for the market. At some places the silica content is high, exceeding 8 per cent, which is the maximum amount that is usually accepted by buyers without deducting penalties, but at some such places the silica content can be materially reduced by properly treating the ore. During the last few years, when the demand for domestic manganese ores was especially great, much ore was shipped from the Batesville district that contained very high percentages of both silica and phosphorus.

The two analyses given below represent the approximate average composition of the greater part of the high-grade manganese ore that was shipped during 1917 and 1918. They were computed from the available analyses, supplied by W. H. Denison, of carload shipments that contained 35 per cent or more of manganese. The computation consisted in adding together the percentages of each constituent in the analyses of the carload shipments and dividing the sums by the number of carload shipments in which each constituent was determined. The analyses used in the computation do not include any shipments from the Montgomery mine in 1917, but all the shipments from this mine in 1918 were included. This accounts in part for the high percentage of phosphorus in the ore that was shipped in 1918, for the ore from that mine has averaged approximately 0.40 per cent of phosphorus.

Approximate average composition of the high-grade ores that were shipped from the Batesville district, Ark., in 1917 and 1918.

	1917 (231 carloads).	1918 (165 carloads).
Manganese (Mn)	47.60	45.72
Iron (Fe)	a 5.77	b 5.59
Phosphorus (P)	c .24	d .36
Silica (SiO_2)	e 6.79	f 8.68
Alumina (Al_2O_3)	g 2.98	....

a Iron was determined in 194 cars.
b Iron was determined in 125 cars.
c Phosphorus was determined in 193 cars.
d Phosphorus was determined in 91 cars.
e Silica was determined in 135 cars.
f Silica was determined in 130 cars.
g Alumina was determined in 125 cars.

The highest-grade ores of the district consist of compact or nearly compact, very hard masses of psilomelane, hausmannite, and braunite ranging in weight from about a pound to several hundred pounds. The first analysis given below represents the approximate average composition of 39 carloads of lump manganese ore from the Ruminer Rough, Manganese Field, Sand Field, Johnson Hill, Earl Collie, Barksdale, Cummins Hollow, Hankins Hollow, and Denison mines, and the second represents the composition of 250 tons that was shipped from the Cummins Hollow mine in 1918. All of this ore was hand picked. "Wash ore," consisting of pieces that weigh less than a pound, is also present at these mines, but it generally contains a higher percentage of iron than the "lump ore," because there are so many small particles of iron oxide which can not be profitably separated from the manganese minerals.

Average composition of the highest grade of manganese ore produced in the Batesville district, Ark.

	1	2
Manganese (Mn)	56.32	58.11
Iron (Fe)	a 2.80	1.63
Phosphorus (P)	b .13	....
Silica (SiO_2)	c 6.18	6.90
Alumina (Al_2O_3)	d 2.41	....
Moisture	....	1.10

a Iron was determined in 34 cars.
b Phosphorus was determined in 28 cars.
c Silica was determined in 32 cars.
d Alumina was determined in 11 cars.

The most common type of high-grade ore is represented by the bulk of the ore at the Southern, Grubb Cut, Rogers, Turner, Polk Southard, Wren, Lassiter, Club House, Searcy, Ozark, Brooks Hill, and other mines. The ore at these mines occurs as loose masses varying greatly in size, from the "wash ore" to masses of "lump ore," some of which weigh several tons. The masses are generally compact, irregular in shape, and black on weathered surfaces but have a bright luster on fresh surfaces. They are composed mainly of black and steel-blue psilomelane and fine to coarse grained hausmannite, which may or may not occur in equal proportions. Tests at some places show about equal quantities of wash ore and lump ore. Analyses of ore of this type follow:

Analyses of the most common type of high-grade manganese ore.

	1	2	3	4
Manganese (Mn)	47.927	48.183	53.685	49.41
Iron (Fe)	6.875	6.550	2.850	5.43
Phosphorus (P)	.197	.255	.186	.21
Silica (SiO_2)	3.220	2.985	2.400	5.52
Alumina (Al_2O_3)	....	....	....	2.91
Moisture	6.490	7.179	4.229	....

1. Analysis by A. S. McCreath of 5 cars of wash ore from the Southern mine.
2. Analysis by A. S. McCreath of 3 cars of wash ore from the Southern mine.
3. Analysis by A. S. McCreath of 15 cars of lump ore from the Southern mine.
4. Approximate average composition of 56 cars of lump ore from the Rogers, Polk Southard, Southern, Ozark, Searcy, and Brooks Hill mines. The percentage of iron is the average of 55 cars; that of phosphorus is the average of 53 cars; that of silica is the average of 28 cars; and that of alumina is the average of 23 cars. These constituents were not determined for the other cars.

The wash ore at any particular mine generally contains at least a few per cent less of manganese than the lump ore, and some of it contains more iron, phosphorus, and silica than the lump ore.

Most of the low-grade or ferruginous manganese ores contain 20 to 35 per cent of manganese, 8 to 20 per cent of iron, and 5 to 26 per cent of silica. The phosphorus content is about the same as that of the higher-grade ores.

USES OF ORES.

The ore from the Batesville district has been used for making ferromanganese, spiegeleisen, and high-manganese pig iron. Very little if any of it has been found suitable for chemical uses, because the amount of manganese dioxide is as a rule less than 80 per cent—the minimum usually required of such ores—and it is not likely that commercial quantities of chemical ore will be discovered. Penrose[17] states that the dark-brown manganiferous clay at the Brooks Hill mine has been successfully used in St. Louis in the manufacture of artificial brownstone and colored bricks. Similar clays occur at other localities. They could be used to produce the spots of some varieties

[17] Penrose, R. A. F., jr., op. cit., p. 251.

of speckled bricks and could be mixed with red-burning clay for brown bricks and with buff-burning clay for gray bricks.

ECONOMIC POSSIBILITIES.

Very little manganese ore has been mined in the Batesville district since November, 1918, except to fill a war-time contract of 2,000 tons. As stated under the heading "History and production" the output of manganese ore was 75,985 tons from 1849 to 1918, inclusive, and that of ferruginous manganese ore for the same period was 69,237 tons. Mining in the district was especially active during the World War, when the restriction of imports of foreign ores caused a great demand for domestic ores, for which very high prices were paid.

The manganese deposits of the Batesville district were examined by the writer in the spring and summer of 1918, during the period of increased activity, and as a result of his examination the following statement concerning available ore reserves was issued in September of that year:[18]

> An estimate of the quantity of available manganese ore of all grades in this region, where mining is not preceded by systematic prospecting, is difficult to make. Of the 180 deposits examined about half contain an estimated available reserve of 200 tons or less. Only about one-third contain about 1,000 tons or more, and only a few contain more than 5,000 tons, though certain of these contain many thousand tons. A small number of prospects and mines, however, were not visited, and these and the unexplored deposits may considerably increase the reserve. The deposits of the region perhaps include at least 250,000 tons of available ore containing 40 per cent or more of manganese and 170,000 tons of available ore containing less than 40 per cent of manganese.

It is impossible to make any estimate of the available ore that can be mined and marketed at a profit under normal or nearly normal conditions, when the ores command much lower prices than they did during the war, because there are a number of factors that affect the domestic production of manganese ores in normal times. The comparatively high cost of producing the ores and the high percentages of phosphorus and silica in some of them are a few of the factors that will retard the manganese-mining industry in this district, though the district can doubtless produce some ore under normal conditions in the future just as it has at times in the past. The quantity, however, will probably be considerably less than the above estimates of total available ore.

Whenever conditions in the future again cause an abnormal demand for domestic manganese ores, mining in the Batesville district will doubtless be stimulated and the result will be an increased production.

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[18] U. S. Geol. Survey Press Bulletin, September, 1918.

LIMITS OF THE ORE-BEARING AREA.

The manganese deposits that have been developed and have produced ore in commercial quantity occur in an eastward-trending though irregular belt 4 to 8 miles wide extending from Lafferty Hollow, near Williamson, eastward to the Ball mine, 2 miles east of Hickory Valley, a distance of 20 miles. (See Pl. VI.) Cave City and Mount Pleasant are near the irregular north border of the belt, and Hickory Valley, Pfeiffer, the Cason mine, Cushman, and Walls Ferry are on or near the south border. Manganese minerals have, however, been found in small quantity as far west as Guion. It is in this belt that the Fernvale limestone, one of the ore-bearing formations, is apparently thicker than it is elsewhere in the southern part of the Ozark region, and that the Cason shale, the other ore-bearing formation, is present in larger areas than it is elsewhere in the southern Ozark region. Although manganese ore is not present in these formations or in their residual clays everywhere in this belt, it occurs in commercial quantity only in the areas that contain outcrops of one or both of these formations or their residual clays. At many places, as in the vicinity of Cave City, Sandtown, and Mount Pleasant, the ore-bearing residual clays have escaped erosion, although the Fernvale limestone and Cason shale have been entirely decomposed, but such clays occur only in areas where either one or both of the Joachim and Plattin limestones have not been eroded. It is therefore useless to look for large quantities of manganese ore in areas where the St. Peter sandstone and lower formations are exposed.

The Fernvale limestone and Cason shale have a general though low southward dip, and in this direction they pass beneath rock formations of Silurian, Devonian, and Carboniferous age. None of these younger rocks contain manganese ores, and probably no workable deposits will be discovered by deep drilling in the Fernvale and Cason where they are overlain by younger rocks, because the manganese has been concentrated into minable deposits only at and near the surface.