UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

GEOLOGICAL SURVEY
W. C. Mendenhall, Director

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CONTRIBUTIONS TO ECONOMIC GEOLOGY
1940

SHORT PAPERS BY

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MANGANESE CARBONATE IN THE BATESVILLE DISTRICT ARKANSAS

BY

HUGH D. MISER

WITH A CHAPTER ON MINERALS OF THE ORES

BY D. F. HEWETT AND H. D. MISER

Contributions to economic geology, 1940
(Pages 1-94)

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MANGANESE CARBONATE IN THE BATESVILLE DISTRICT, ARKANSAS

By Hugh D. Miser

ABSTRACT

The deposits of manganese ore of the Batesville district, in north-central Arkansas, lie in an east-west belt 4 to 8 miles wide and 24 miles long. They have been operated over a period of 90 years, beginning in 1849, and have produced 140,277 tons of manganese ore containing 35 percent or more of manganese and 160,804 tons of ferruginous manganese ore containing 10 to 35 percent of manganese through 1938. Most of the marketed ore has consisted of manganese oxide, but since 1928, when the presence of high-grade manganese carbonate was first recognized, an appreciable amount of the carbonate ore has been marketed.

Besides manganese oxides and carbonates the ores contain relatively small quantities of manganese silicates. The manganese carbonates include rhodochrosite (pink), and also white, gray, yellow, brown, red, and reddish brown varieties; they are manganiferous calcium carbonates whose manganese content ranges from a few percent to 38 percent. The oxide minerals include psilomelane, hausmannite, braunite, manganite, pyrolusite, and wad. Hausmannite is the most abundant oxide in the carbonate deposits, and psilomelane is the most abundant oxide in the deposits that are free from carbonates. The manganese silicates, bementite and neotocite, have been recognized at several places in association with the carbonates.

The pink carbonate, rhodochrosite, contains 34 to 36 percent of manganese, the gray variety 32 to 38 percent, the chocolate brown 16 to 22 percent, the red 20 to 30 percent, and the yellow 22 to 32 percent. These carbonates occur in the two ore-bearing formations, the Fernvale limestone and the overlying Cason shale, both of Ordovician age.

The manganiferous carbonate in the Cason shale is gray, red, and reddish brown and occurs in the form of "buttons" (pebblelike masses that are fossil algae) and lenses attaining a thickness of 3 feet. It appears to have been formed while the other sediments in the Cason shale were being deposited. Through the action of ground water the carbonate lenses have been partly or completely converted to oxides, chiefly psilomelane and wad. The carbonate "buttons" in the shale have been enriched by conversion to psilomelane; and finally the shale matrix for the "buttons" has been altered to clay through which the psilomelane "buttons" are disseminated. Such residual clay and also the psilomelane

"button"-bearing shale and the carbonate and oxide lenses in the shale have been the source of much marketed ferruginous manganese and manganese ore.

The manganese carbonates that have yielded most of the carbonate ore form lenticular bodies, as much as 9 feet thick, in the topmost beds of the Fernvale limestone. Intermixed with the carbonates are varying proportions of hausmannite and minor amounts of other minerals, including braunite and manganese silicates. These lenticular bodies lie mostly in a horizontal or nearly horizontal position, parallel with the bedding of the limestone, but in addition some irregular masses as much as 2½ feet long and thin veins generally a fraction of an inch thick are distributed through the upper 40 to 50 feet of the limestone. All these bodies have been formed by replacement of the limestone.

On weathering the lenticular carbonate-oxide bodies in the Fernvale limestone are converted entirely to oxides, consisting chiefly of psilomelane, but with much unaltered hausmannite, some braunite, and a little manganite and pyrolusite. The oxide bodies thus formed may be associated with carbonate bodies in the same deposit, but in much of the districts the oxide bodies have been set free by the solution of the limestone. The oxide masses in the residual clays are for the most part broken portions of the bodies in the Fernvale limestone; they range in size from fine particles to boulders weighing as much as 27 tons. Oxide minerals mined from the residual clays of the district have made up the major part of the output of manganese ore and much of the output of ferruginous manganese ore.

The manganese deposits do not appear to bear any relation to the few known faults, but it is noteworthy, although not yet fully appreciated, that some of the largest deposits occur in synclines.

The manganiferous carbonate in the Cason shale and also that which is disseminated through the Fernvale limestone, especially its upper half, were apparently deposited contemporaneously with the sediments that formed the shale and limestone. The source of the manganese in the bodies of hausmannite and carbonate in the Fernvale limestone appears to be the limestone itself. The distribution of the localized bodies of carbonate and hausmannite, chiefly in the topmost part of the limestone, is believed to have been determined (1) by numerous fractures, (2) by the shale capping, and (3) by possible increased porosity of the limestone during exposure on an old land surface prior to the deposition of the Cason shale. To account for the concentration of manganese in the carbonate-hausmannite bodies, it seems necessary to assume the circulation of water laterally in the limestone. From what is known of the origin of other domestic ore deposits that contain a similar assemblage of minerals—hausmannite, bementite, neotocite, and manganese carbonate—it would seem that the water was warm, rather than cold.

Carbonate ores with a manganese content as low as 18 percent and as high as 35 percent occur in commercial quantity, but an admixture of hausmannite or other oxides is essential for carbonate-bearing ore in carload lots to contain more than 35 percent of manganese. Some of the carbonate ore marketed has contained little or no manganese in the oxide form, but most of it has contained a considerable proportion of manganese oxide.

The discovery in 1928 of the commercial character of the manganese carbonate ore and the consequent demonstration that the hausmannite associated with the carbonate is widespread in the bodies not affected by weathering constitute an important event in the mining industry of the Batesville district. Lenticular ore bodies of carbonate and hausmannite, like those explored from 1928 to the present time, are doubtless numerous in this region and will be discovered and developed from time to time as conditions affecting the manganese industry of the region permit.

LOCATION

The Batesville manganese district is in the southern part of the Ozark region, mostly in Independence County but partly in Sharp, Izard, and Stone Counties, in north-central Arkansas. It is an east-west belt 4 to 8 miles wide and 24 miles long. The town of Batesville, whence its name is derived, is 2 miles south of the southern border of the manganese-bearing area. (See pl. 1 and fig. 1.)

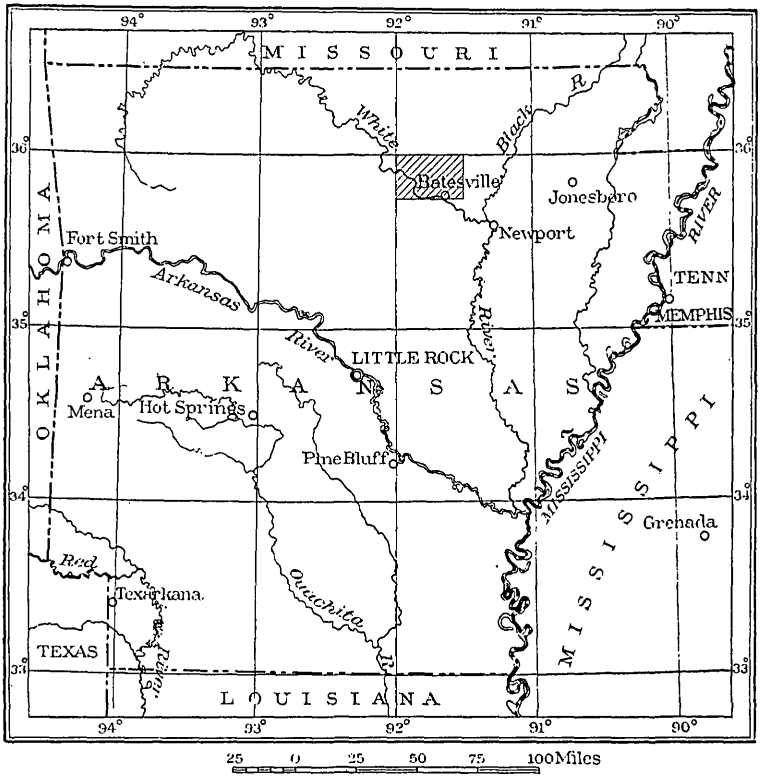

FIGURE 1.—Index map of Arkansas showing location of Batesville manganese-ore district.

PRESENT INVESTIGATION AND ACKNOWLEDGMENTS

A few occurrences of manganese carbonate were discovered during the period of mining activity of the manganese oxide ores, from 1915 to 1918. These occurrences of carbonate were studied in 1918 by the writer, who described them briefly in Geological Survey Bulletin 734,[1] published in 1922. This bulletin is now (1940) out of print and is therefore not obtainable from any official source, but its essential features have been brought up to date and are given in summarized form

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[1] Miser, H. D., Deposits of manganese ore in the Batesville district, Arkansas, with a chapter on the mining and preparation of the ores by W. R. Crane, of the Bureau of Mines.

in the present report. Bulletin 734, as well as an earlier report by Penrose,[2] describes the deposits of manganese oxides in considerable detail. Much development of the manganese carbonate deposits has taken place since 1918. It has not only led to the discovery of additional deposits of carbonate ore, but has revealed much information concerning their character and extent and also much new information concerning the occurrence, origin, and value of the oxide ores. For the purpose of keeping in touch with the development of the carbonate deposits the writer has revisited the district many times between 1920 and 1939. D. F. Hewett, of the Geological Survey, spent several days in company with the writer in the district in 1931 and has made a special study of the mineral composition of the carbonate deposits. The results of Mr. Hewett's study are incorporated in the present report.

This report is largely concerned with the deposits of manganese carbonate. Everywhere associated with the carbonate, however, there are manganese oxides, varying in relative proportion from place to place. Numerous deposits contain only the oxides, and their yield represents the major portion of the output to date of both high-grade manganese ore and ferruginous manganese ore from the Batesville district; these deposits are not described in detail here, but their features that are related to the carbonate-bearing ores are discussed.

The writer here acknowledges his appreciation of the generous cooperation of Mr. Hewett, both in the field and in the office, and also his indebtedness to E. F. Burchard, under whose direction the investigation was conducted. The cordial cooperation of the mine operators and others connected with the manganese industry in the region has made possible and has facilitated the investigation. Among these persons are W. H. Denison, Reed Denison, Alvis Denison, Louis Peterson, T. F. Shell, and the late J. S. Baker, all of Cushman, Ark.; W. G. Rinehart, R. S. Handford, and A. B. Reither, of Batesville, Ark.; and W. H. Beatty of Birmingham, Ala. Their cooperation is acknowledged with sincere appreciation by the writer.

HISTORY AND PRODUCTION

The manganese deposits of the Batesville district have been exploited for 90 years, beginning in 1849, and have yielded both manganese and ferruginous manganese ores. The output of manganese ore has been obtained largely during two periods of activity, one beginning in 1885 and ending in 1898, and the other beginning in 1915 and continuing to the present time. The greatest annual output was that recorded for 1917 and 1918, when the production was 10,140 and

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

7,731 tons, respectively. Nearly all the ferruginous manganese ore produced has been obtained in 1904 and later years.

A little manganese carbonate that is naturally intermixed with or adheres to the oxide ore was marketed incidentally to the production of oxide ore during the World War and for many years after the war. At that time rhodochrosite and the other higher-grade carbonates had not been recognized, and they, together with the associated rock, were separated from the oxide ore so far as practicable, by hand sorting. Since the recognition of the higher grades of carbonate in 1928 by Reed Denison and J. S. Baker, the production of manganese ore and ferruginous manganese ore has included a considerable tonnage of manganese carbonate, all of which is associated with varying proportions of oxides.

The production of two classes of manganese ore in the Batesville district from 1849 to 1938, inclusive, is given in the accompanying table, which is compiled mainly from Mineral Resources, published by the Geological Survey and later by the Bureau of Mines, but partly from other sources.

Manganese and ferruginous manganese ores produced in the Batesville district, Arkansas, 1849–1938, in long tons

Year	Manganese ore (35 percent or more of manganese) [1]	Ferruginous manganese ore (10 to 35 percent of manganese) [1]	Year	Manganese ore (35 percent or more of manganese) [1]	Ferruginous manganese ore (10 to 35 percent of manganese) [1]
1849–67	600		1911		2,177
1868	10		1912		1,332
1881	100		1913		9,650
1882	175		1914		1,970
1883	400		1915	1,288	2,655
1884	800		1916	6,250	3,645
1885	1,483		1917	10,140	9,100
1886	3,316		1918	7,731	9,173
1887	5,651		1919	2,558	564
1888	4,312		1920	3,445	4,403
1889	2,528		1921	728	278
1890	5,339		1922	2,264	
1891	1,650		1923	3,768	4,773
1892	6,708		1924	3,400	7,991
1893	2,020	160	1925	3,517	5,076
1894	1,934		1926	2,450	8,195
1895	2,901		1927	2,605	7,444
1896	3,421		1928	3,623	7,136
1897	3,240		1929	4,308	13,774
1898	2,662		1930	3,276	12,645
1899	356		1931	4,028	2,230
1900	145		1932	1,306	208
1901	91		1933	1,890	1,060
1902	82		1934	5,842	1,374
1904		600	1935	3,809	145
1905		3,321	1936	4,557	3,285
1906	62	8,900	1937	3,931	7,509
1907		4,133	1938	2,987	3,477
1908		4,066			
1909		3,325		140,277	160,804
1910	500	5,030			

[1] The figures for production of manganese ore for 1910 and previous years perhaps include a small amount of ore carrying less than 35 percent of manganese. The production of manganese ore and ferruginous manganese ore in west-central Arkansas, totaling several hundred tons since 1915, is included in the figures given in the table.

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 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 altitude, which is less than 250 feet above sea level, is on the White River near Batesville, and the highest, 950 feet, is on Pine Mountain, 2 miles north of Lafferty. 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. 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 streams of the Batesville district empty into the White River, which is navigable. The larger tributary streams 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 district.

A line of the Missouri Pacific Railroad passes through Sulphur Rock, Moorefield, and Batesville and thence runs near the left bank of the White River beyond the limits of the area here described. Short branches of this railroad extend to Pfeiffer and Cushman.

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 abundant.

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. They are of Ordovician, Silurian, Devonian, and Carboniferous age. The Fernvale limestone and Cason shale, of Ordovician age, and their residual clays contain the manganese ores and are consequently the only formations that require extended discussion in this report.

The rocks in the Batesville district have undergone little deformation. As a result of the general doming of the rocks in the Ozark region those of this area show 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.

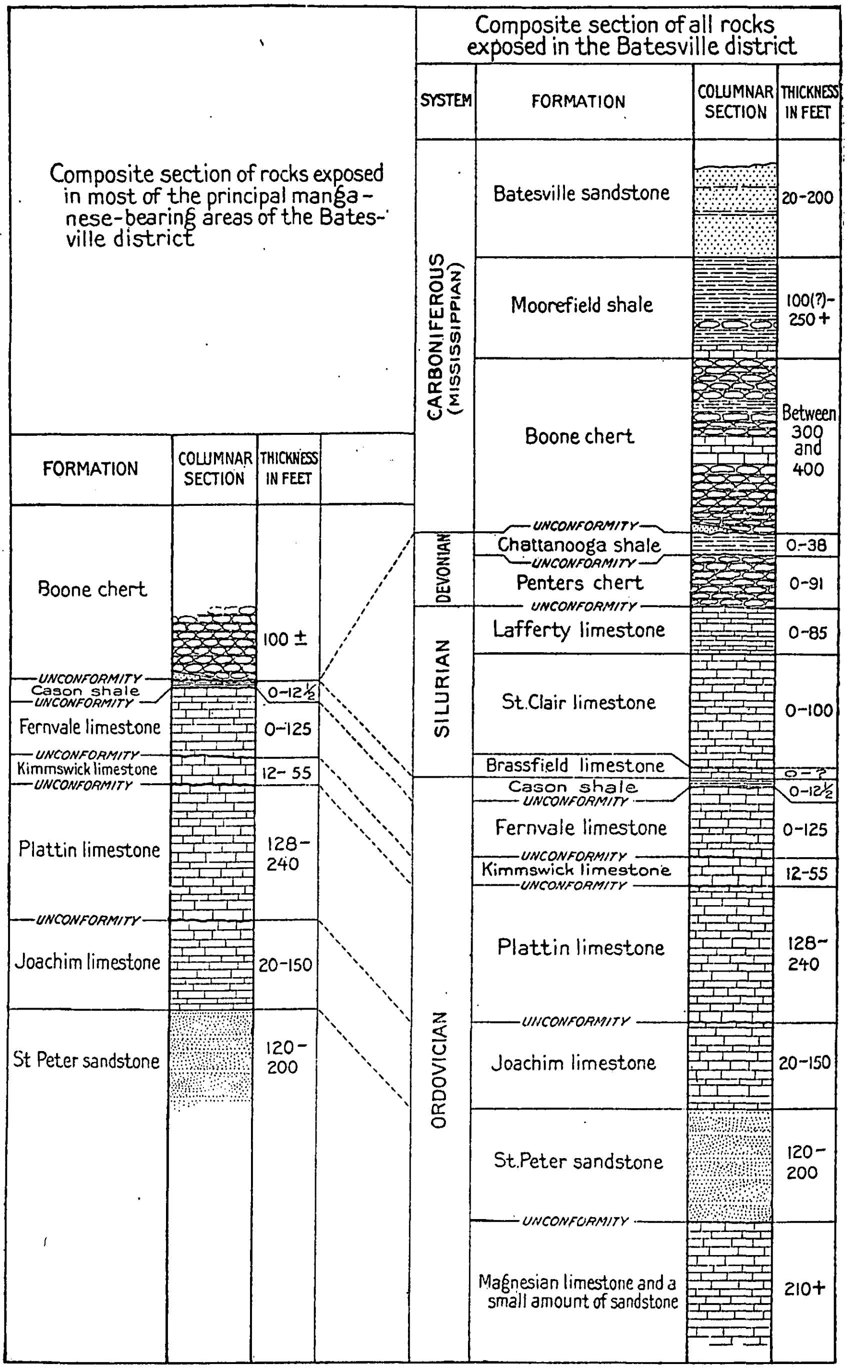

FIGURE 2.—Generalized sections of the Paleozoic rocks of the Batesville district.

The succession and thickness of the Ordovician, Silurian, Devonian, and Carboniferous rock formations are shown in figure 2, and their distribution is shown on plate 1. The principal lithologic features of these formations are set forth below, beginning with the youngest:

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 and a little sandstone and shale. Lower part caps most of hills in manganese-bearing area.

Chattanooga shale: Platy black shale. Exposed only near village of Pfeiffer. A few fossils procured from the shale are stated by E. O. Ulrich to show that it is of the same age as the Genesee group 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 lithologic character 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 Onondaga group of the northern Appalachian region.

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 lithologic character suggest that it is of the same age as the Dixon earthy limestone member of the Wayne formation 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.

St. Clair limestone: Massive coarse-grained pinkish light-gray fossiliferous limestone. Exposed in several small areas but absent from most of manganese-bearing area.

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.

Cason shale: Greenish-gray calcareous shale and smaller amounts of sandstone and phosphate rock; contains manganese and iron minerals. For a description of the Cason shale see pages 10–12.

Fernvale limestone: Coarse-grained massive cross-bedded dark-gray and pinkish-gray limestone; contains manganese minerals. For a description of the Fernvale limestone see pages 9–10.

Kimmswick limestone: Even-bedded massive light-gray fine-grained limestone. Exposed in much of manganese-bearing area.

Plattin limestone: Even-bedded dove-colored or grayish-blue compact limestone; breaks with conchoidal fracture. Exposed over a large part of manganese-bearing area.

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: Crop out at places along West Lafferty, East Lafferty, and Sullivan Creeks and Polk Bayou and are probably of the same age as named units in other parts of the Ozark region.

FERNVALE LIMESTONE

The Fernvale limestone, known to the miners as "gray rock," is the surface rock on 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, but at most places it is about 100 feet thick. It thins westward, however, so that it is only 28 feet thick three-quarters of a mile northwest of Guion, and also it thins out to the east near the east end of the district. Apparently its area of greatest thickness in the southern Ozark region is in the Batesville district.

The Fernvale consists almost wholly of limestone. The other constituents are manganese oxides and carbonates 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 weathered parts, have a pinkish cast. Parts of the limestone, especially the upper 40 to 50 feet, are very dark gray, brown, or black, owing to the occurrence of iron and manganese oxides and carbonates that are more or less uniformly disseminated through the rock. (See pl. 8, *B*.) A few fossils occur in all parts of the limestone, but they are most numerous in beds near the top and near the base. Some of the fossils are minute phosphatic shell fragments disseminated through the limestone. At some places the limestone contains nodules and thin lenses of gray and brown chert and also many irregular masses of brown chert as much as several feet in their longest dimensions.

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. Such channels and hollows, as well as the limestone pinnacles and horses that separate them, are well displayed in open cuts at the Miller-Rinehart and Club House mines. (See pl. 8 and fig. 6.) Some of the channels are straight and represent widened fissures along joints. A few caves and sinkholes 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, usually a conglomeratic or earthy material, but in a few places a gray oolitic limestone.

The Fernvale is the oldest formation of Richmond age in the Batesville district.

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 and in the portion of the manganese district west of that place but is absent at most places in the portion of the district east of Cushman. The shale at no place exceeds 12½ feet in thickness. It contains some sandstone and phosphate rock and, in addition, the manganese and iron minerals described on pages 26 to 28. Not only does the quantity of these constituents vary from place to place, but their character also varies so much that sections of the formation measured at nearby localities differ greatly.

The shale is greenish gray, platy, and calcareous; it contains flattened concretionlike masses ("buttons") the size of pebbles and also contains more or less quartz sand, phosphatic material, and glauconite. Several pieces of the shale itself, on being tested, were found to contain phosphate. At a few places the phosphatic material occurs as fine pebbles, some of which are almost 1 inch in their longest diameter. In most of its exposures the shale has been affected considerably by weathering and is yellow or brown, but most of the shale exposed in the open cuts of the Cason mine at the time of examination was red. A small part of the shale at the Cason mine, however, retains its original greenish-gray color.

A bed of greenish-gray, brown, or yellow sandstone in places several feet thick, is generally present in the Cason shale west of Polk Bayou. This sandstone contains quartz grains and some 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. It is known as "phosphate rock" on account of its high content of phosphorus. It is exposed as ledges, from which blocks have been broken away and now lie on the slopes below. These ledges are a great aid to prospectors in their search for manganese ore, for the ore is always found below them.

The basal deposits of the Cason include (1) conglomerate material, (2) shaly material containing a concentration of minute phosphatic shell fragments, apparently derived from the Fernvale limestone, and

(3) lenses and bodies of oolitic limestone as much as 8 inches thick, occupying hollows and fissures in the Fernvale. The dark-gray calcareous material cementing together the white oolites contains a great quantity of phosphatic material in the form of shell fragments. The features just described indicate that an unconformity separates the Cason shale from the underlying rocks.

The Cason is overlain at some places by the St. Clair limestone, but the fossils of the Brassfield limestone in residual clays above the altered Cason shale at the Montgomery mine show that the Brassfield once overlay the Cason shale at that locality. The Brassfield is shown by its fossils to be older than the 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 these two formations is even and does not display an abrupt change in the character of the rocks. In much of the Batesville district all the Silurian and Devonian rocks, including the St. Clair limestone, are absent, and the Boone chert, of Carboniferous age, rests unconformably upon the Cason shale.

The "buttons" mentioned above are abundant at a few localities. They are from half an inch to 1 inch in their longer diameter and from a quarter of an inch to half an inch thick, and are stated by E. O. Ulrich 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. Most of those revealed in the rock outcrops and in the residual clays have been replaced by manganese and iron oxides. (See pl. 6, *B*, and fig. 3.) The unaltered "buttons" are greenish gray, the partly oxidized "buttons" are red, the "buttons" of manganese oxides are black, and those of iron oxide are red. Many of them show concentric banding around 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. At that mine "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 its contains "buttons" whose principal constituents are manganese and calcium carbonates. This is in fact the only locality in the district where carbonate "buttons" have been found.

The *Girvanella* "buttons," 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.

STRUCTURE

The rocks of the Batesville district have undergone little deformation. They have been warped slightly by minor folds and have been broken by a few normal faults. Thus they lie in a horizontal or nearly horizontal position. The folds consist of small irregular domes or anticlines and of irregular basins or synclines.

The folding and faulting in this district affected all the beds, including those of Mississippian age, and therefore took place either late in the Mississippian epoch or at a later time. Not only was the faulting probably contemporaneous with the folding, but both were probably contemporaneous with like movements that took place near the end of the Carboniferous period in other parts of the Ozark region. There is, however, some evidence of slight folding at different times, the earliest being at the end of the Ordovician period.

The more prominent faults, those that are longest and have displacements of as much as 400 feet, lie southeast of the district and trend for the most part in an east-northeast direction. The few observed faults within the manganese-bearing district have a similar trend.

ORE DEPOSITS

MINERALS OF THE ORES

By D. F. Hewett and H. D. Miser

GENERAL FEATURES

The manganese ores of the Batesville district contain oxides and carbonates and relatively small quantities of manganese silicates. The manganese carbonates include white, gray, pink, yellow, brown, and red (reddish brown) varieties; they are manganiferous calcium carbonates whose content of manganese ranges from a few percent to 38 percent. They are widespread in the district and have constituted a considerable portion of the ore marketed since 1928, although the oxides made up the entire output prior to that date. The oxide minerals include psilomelane, hausmannite, braunite, manganite, pyrolusite, and wad. Each deposit contains two or more of these minerals, and some contain associated ferruginous manganese oxides and small quantities of brown and red oxides of iron. In some deposits ferruginous manganese ores predominate. The oxides are found in many deposits that contain no carbonates, but they are present in all the deposits of carbonates and are intermixed with the carbonates in varying proportions. Hausmannite is the most abundant oxide in the carbonate deposits, and psilomelane is the most abundant oxide in the deposits that are free from carbonates. The hydrous manganese silicates bementite and neotocite have been recognized at several places in the carbonate-bearing deposits.

MANGANESE CARBONATES

Rhodochrosite and several other carbonates of manganese and calcium are found widely and appear to be the most abundant unweathered manganese minerals in the district. These carbonates present diverse aspects. The rhodochrosite is pink and finely to coarsely crystallized. Other common varieties are white carbonate, which is coarse-grained, and gray and red (reddish-brown) carbonates which have replaced the Fernvale limestone and thus largely retain its texture. The distribution and form of the carbonate bodies are discussed on pages 26–32.

To aid in describing the ore deposits, five main groups of carbonates are here recognized:

1. Rhodochrosite; pink carbonate; 33.8 to 36.3 percent of manganese (analyses 4 and 5, below).
2. White carbonate, manganese content low.
3. Gray carbonate; 32.6 to 38.5 percent of manganese (analyses 1–3, below).
4. Red or reddish-brown carbonate; 20 to 30 percent of manganese.
5. Mottled carbonate, a mixture of red and black carbonates, generally with some pink and white carbonates.

Analyses of specimens of manganese carbonate from the Batesville district

[R. C. Wells, analyst]

	Gray carbonate			Rhodochrosite	
	1	2	3	Fine 4	Coarse 5
MnO	45.2	49.8	42.20	43.7	46.9
FeO	.3	.3	.4	.2	.7
Lime (CaO)	8.2	7.9	11.6	13.8	7.9
Magnesia (MgO)	.4	.6	1.7	1.5	.3
Carbonic acid (CO_2)	35.4	35.7	37.0	39.6	38.2
Insoluble	3.7	4.8	2.2	.4	.5
Phosphoric acid (P_2O_5)	.50	.50	.80	.10	.50
Total	93.7	99.6	95.9	99.3	95.0
Manganese	34.9	38.5	32.6	33.8	36.3
Calculated constitution					
$MnCO_3$	73.21	80.67	68.36	70.79	75.98
$FeCO_3$	.48	.48	.64	.31	1.11
$CaCO_3$	12.85	12.32	17.85	24.27	12.32
$MgCO_3$	.84	1.25	3.55	3.13	.63
Insoluble	3.70	4.80	2.20	.40	.50
$Ca_3(PO_4)_2$	1.51	1.51	2.42	.30	1.51
Total	92.59	101.03	95.02	99.20	92.05

1. From carbonate core of oxide mass in Fernvale limestone at Miller-Rinehart mine.
2. From carbonate cores of several masses of oxides in Fernvale limestone at Miller-Rinehart mine.
3. From top portion of Fernvale limestone at Walter Chinn prospect.
4. From carbonate ore body in top of Fernvale limestone at Club House mine.
5. From carbonate ore body in Fernvale limestone at Woodpecker Hollow mine.

The rhodochrosite is dense in texture, and some of it is fine-grained, but much is coarse-grained. Although much of it has replaced the Fernvale limestone, only the coarse-grained carbonate retains some of the texture of the limestone. Some of the coarse-grained carbonate grades into the gray carbonates described below. As shown in analyses 4 and 5 in the preceding table, the composition of the rhodochrosite closely resembles that of the gray carbonate. Small quantities of rhodochrosite are rather widely distributed in the Batesville district, but it is generally associated with hausmannite and with the gray and red carbonates.

Some varieties of carbonates range from pale pink to white. No analyses of these have yet been made, but blowpipe tests indicate that they all have a low manganese content, the amount being roughly indicated by the depth of the pink color.

The manganese content of the gray carbonate, as shown by analyses 1 to 3 in the table, ranges from 32.6 to 38.5 percent and the lime content from 7.9 to 11.6 percent. Etching tests of polished surfaces indicate that this material is not homogeneous but contains at least two distinct carbonates. The more abundant mineral resists attack by dilute acid and is rhodochrosite. Within this mineral there are irregularly rounded patches, in part fragments of fossils, that are readily attacked by dilute acid and undoubtedly are nearly pure calcium carbonate. Much of the carbonate has a rusty gray color because of the presence of very small disseminated areas of iron oxide and of a brown carbonate. (See pl. 2.)

The red or reddish-brown carbonate is widely distributed in the Fernvale limestone and occurs at places in the Cason shale. Analyses are stated to show the presence of 20 to 30 percent of manganese. A high iron content of some of the red carbonate is suggested by the high iron content—25 percent—of the oxidized ore derived from the carbonate. Some of the red carbonate replacing the Fernvale limestone appears to be largely a calcium carbonate that contains disseminated fine-grained iron oxide and manganese oxide (hausmannite?). The grains of black carbonate, generally found with the red carbonate and hausmannite, contain disseminated hausmannite.

In addition some fine-grained chocolate-brown carbonate is present at many places, and analyses of it are stated to show the presence of 16 to 22 percent of manganese. A yellow carbonate found at some places is said to contain 22 to 32 percent of manganese.

MANGANESE OXIDES

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, is only 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 chemical composition is expressed by the formulas Mn_3O_4 and $MnO.Mn_2O_3$ This mineral is one of the most abundant in the Batesville district, being present at most of the 200 mines and prospects. In 1891 Penrose[3] described as a silica-free braunite the mineral that is now recognized as hausmannite. The identification of the hausmannite was established by the study of its optical properties by E. S. Larsen and by chemical analyses by J. G. Fairchild.[4]

Chemically pure hausmannite contains 72 percent of manganese. Analyses 1 and 2, below, show the presence of 70.76 and 70.00 percent of manganese, respectively, in samples of hausmannite 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. Analysis 3 shows 69.37 percent of manganese.[5]

Analyses of hausmannite from the Batesville district, Arkansas

	1	2	3
Manganese protoxide (MnO)	91.38	90.40	[1] 89.58
Oxygen (O)	7.78	8.878	[1] 7.90
Iron (Fe)	None	[2]	----------
Silica $(SiO)_2$	None	.10	Trace
Alumina (Al_2O_3)	None	[3] .48	----------
Lime (CaO)	Trace	Trace	----------
Magnesia (MgO)	Trace	Trace	----------
Baryta (BaO)	.26	None	.43
Total water (H_2O)	.62	1.03	1.21
Total	100.04	100.88	99.12
Manganese (Mn)	70.76	70.00	69.37
Specific gravity at 15.5° C	4.836	4.778	[4] 4.782

[1] Calculated from Thiel's figures.
[2] Included with alumina.
[3] Plus a trace of iron.
[4] Temperature not stated.

1. Sample from W. T. Gray mine; J. G. Fairchild, analyst.
2. Sample from Club House mine; J. G. Fairchild, analyst.
3. Sample from unnamed locality; G. A. Thiel, analyst; polished surface showed a few very small gains of psilomelane.

Hausmannite is the most abundant mineral in parts of some manganese carbonate ore bodies in the Club House and Club House extension mines near Cushman, in several openings of the Pittman and Woodpecker Hollow mines, and at other mines. In other parts of such ore bodies the amount of hausmannite is exceeded only by that of the manganese carbonates, although wherever weathering affects the hausmannite and the carbonates psilomelane and wad occur in considerable quantity.

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[3] Penrose, R. A. F., Jr., Manganese—its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol 1, pp. 148–153, 1891.

[4] Miser, H. D., and Fairchild, J. G., Hausmannite in the Batesville district, Arkansas: Washington Acad. Sci. Jour., vol. 10, pp. 1–8, 1920.

[5] Thiel, G. A., The manganese minerals—their identification and paragenesis: Econ. Geology, vol. 19, p. 111, 1924.

Hausmannite is recognized at most places by the chestnut-brown color of its streak or powder, which differs from that of the iron oxides and other manganese oxides of the district. When viewed under the microscope, the crystal form, cleavage, and red-brown color aid in its recognition. As typically developed in the carbonate-bearing deposits hausmannite forms aggregates of interlocking grains largely 1 to 2 millimeters in diameter in a matrix of manganese carbonate or silicate. (See pl. 3.) Here and there these aggregates contain terminated crystals that extend into the matrix and seem to have grown by replacing the carbonate or other constituents of the matrix. In other places the borders of the aggregates, especially those which are enveloped in bementite, are vague and poorly defined. As some thin sections show minute pseudoöctahedrons of hausmannite in various stages of replacement by bementite, it is concluded that much of the bementite has formed at the expense of the earlier hausmannite. (See pl. 4, *A*.) Most of the polished specimens of the hausmannite-bearing material show sporadic aggregates of bladed crystals of barite, and many of these are either deeply corroded by masses of hausmannite or replaced by crystals. (See pl. 4, *B*.) It seems quite clear that the hausmannite has developed later than the barite but earlier than the bementite.

In close proximity to the bodies characterized by coarsely crystalline hausmannite there are bodies in which several distinct types of manganese carbonates, including rhodochrosite, appear in mottled pattern. One of these carbonates is black and at first glance appears to be pure hausmannite. On closer examination, however, it becomes quite clear that this is a carbonate mineral through which minute dark grains of a manganese oxide are scattered. (See pl. 5.) Since these grains appear reddish under transmitted light, they are here considered to be hausmannite.

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 $MnO.(Mn.K,Ba)O.nH_2O$ and H_4Mn_5, the composition is not definite, as the percentage of manganese ranges from 50 to 57 and the amounts of minor accessory ingredients, such as barium, potassium, and water, show a wide range.

The derivation of psilomelane from hausmannite and from the manganese carbonates and silicates is well shown at numerous places. Also almost every specimen of the oxides contains two minerals. The following combinations are the most common: Psilomelane and hausmannite, psilomelane and braunite, and psilomelane and manganite.

Braunite.—Braunite is a 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. The composition is usually expressed by the formula $3Mn_2O_3.MnSiO_3$, and the percentage of manganese ranges from about 63 to 66.

The braunite occurs in different associations as aggregates of small octahedral crystals. Some of it forms small irregular granular masses in red manganese carbonate, which is in part replaced by hausmannite and bementite; coatings of braunite crystals line cavities in psilomelane; and some granular braunite, free from manganese carbonates or other oxides, occurs as widely scattered masses in the Fernvale limestone.

Manganite.—Manganite ($Mn_2O_3.H_2O$) is a steel-gray granular or or crystalline mineral with a dark-brown or nearly black streak. It contains 62.4 percent of manganese and 10.3 percent of water. Although it is present at several localities in the Batesville district it forms a very minor part of the manganese ores. Manganite is associated with psilomelane but not with hausmannite, braunite, nor with the manganese carbonates and silicates. Nodules from some of the deposits are made up of alternate layers of psilomelane and radiating needles 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 contains 63.2 percent of manganese. Pyrolusite is present in small quantity at a few localities in the Batesville district, in association with manganite, psilomelane, and wad.

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 it is more abundant than the higher-grade manganese minerals. During and after the World War, 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 percent of manganese.

MANGANESE SILICATES

The presence of bementite and neotocite in the Batesville district is definitely established on the basis of their properties as viewed under the microscope and by simple tests. According to present usage neotocite should be confined to the amorphous material having the approximate chemical composition $MnO.SiO_2nH_2O$, whereas bementite is the crystalline mineral ($8MnO.7SiO_2.5H_2O$).[6] Although the two minerals can be readily distinguished under the microscope, and their presence has been definitely proved in several deposits, they are so similar in appearance to the unaided eye that in the field it is not possible to distinguish one from the other with confidence. Bementite is assuredly abundant at the W. A. Chinn mine, on Cave Creek, the Miller-Rinehart mine, on Polk Bayou, and the Pittman and Woodpecker Hollow mines, near West Lafferty Creek. In most of these places it forms pale-brown veinlike or irregular masses that break with a conchoidal fracture and do not reveal the fact that they are made up of myriads of minute interlocking micaceous plates. These masses are most abundant near bodies of hausmannite but they also are intergrown with carbonate material, which they have replaced. In a few places, such as the Pittman mine, in Hankins Hollow, bementite forms clusters of spherical aggregates of radiating micaceous gray plates which, with hausmannite, have replaced shaly limestone. The material at the Pittman mine possesses the physical and optical properties of the bementite of Franklin Furnace, N. J., where the mineral was first found and described.[7] Elsewhere in the United States and in this district the known bementite is a massive brownish mineral that breaks with conchoidal fracture.

Neotocite has been definitely identified in abundance in material from the Woodpecker Hollow mine but is probably more widespread. Most of it, like bementite, is pale brown and massive and breaks with a conchoidal fracture. Some of it is nearly black.

No analyses of either of these two minerals from Arkansas have been made.

Some manganese silicates whose identity has not been determined but which may include either bementite or neotocite or both or other manganese silicates occur at the Adler prospect and Adler mine, on Cave Creek; the Rutherford mine, near Polk Bayou; and the Club House mine, near Cushman.

OTHER MINERALS

Iron oxides.—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. The limonite occurs in large quantities as irregular bodies in the residual clays and other surface materials in the district. At most places it contains some manganese oxides. The hematite is not only associated

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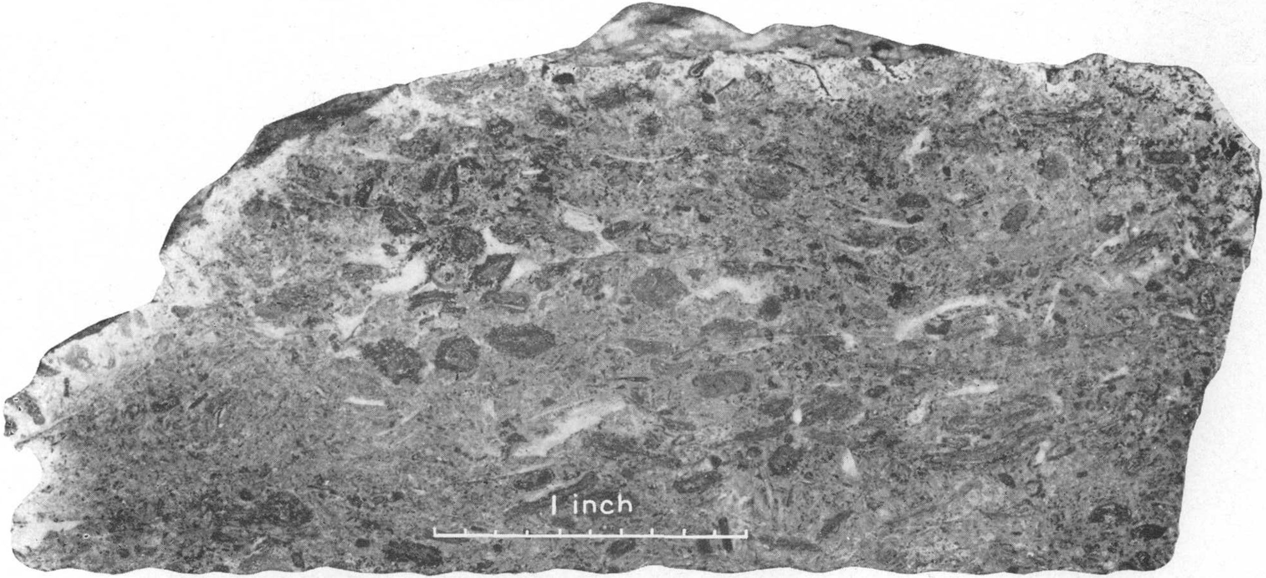
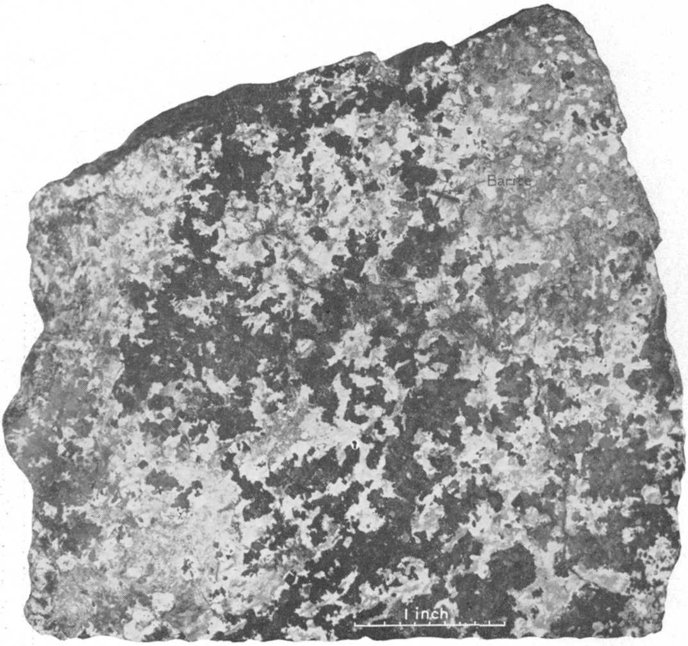
[6] Pardee, J. T., Larsen, E. S., Jr., and Steiger, George, Bementite and neotocite from western Washington, with conclusions as to the identity of bementite and caryopilite: Washington Acad. Sci. Jour., vol. 11, p. 31, 1921.

[7] Koenig, G. A., Preliminary note on a new mineral species from Franklin, New Jersey: Acad. Nat. Sci. Philadelphia Proc., 1887, pp. 310–311.



POLISHED SURFACE OF GRAY CARBONATE FROM MILLER-RINEHART MINE.

Shows pseudomorphs of fossils and other textural features.

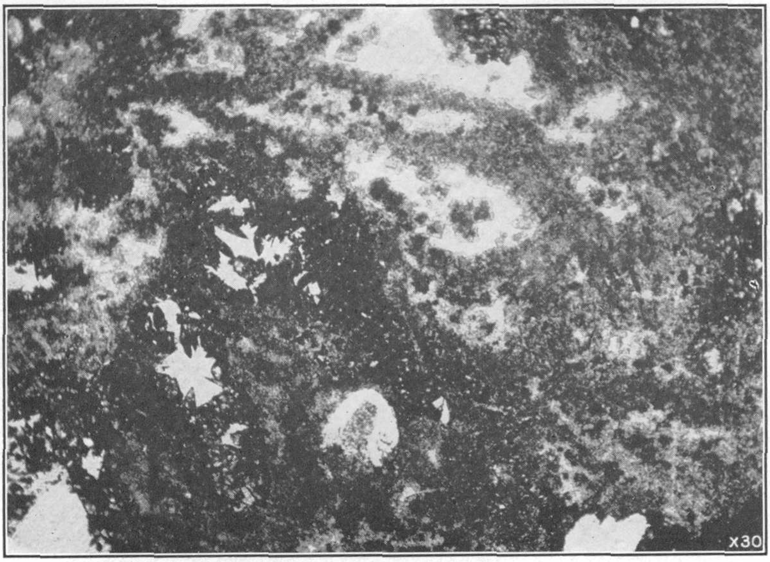


A. POLISHED SURFACE OF ORE FROM CLUB HOUSE MINE.

Black grains are hausmannite crystals in matrix of carbonate (gray) that contains also a few crystals of barite.

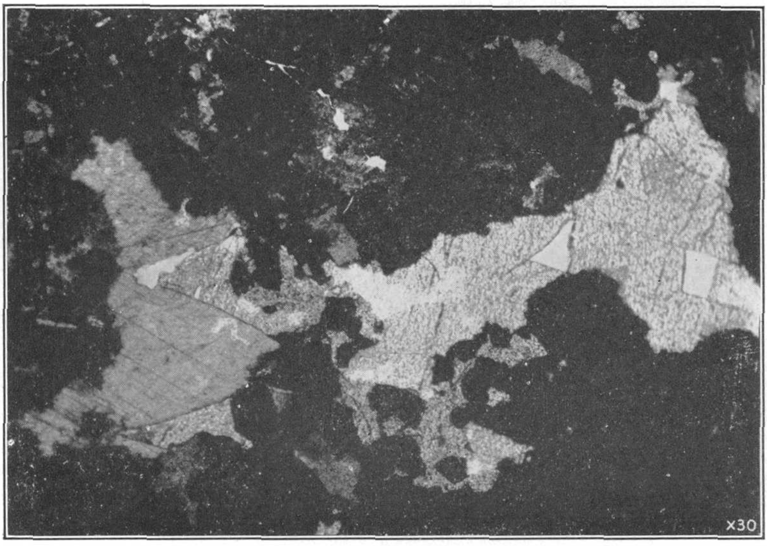
B. POLISHED SURFACE OF ORE FROM WOODPECKER HOLLOW MINE.

Black grains are hausmannite in matrix of carbonate (light gray) and bementite (dark gray) in which are a few coarse crystals of barite (*b*). White areas are rhodochrosite.



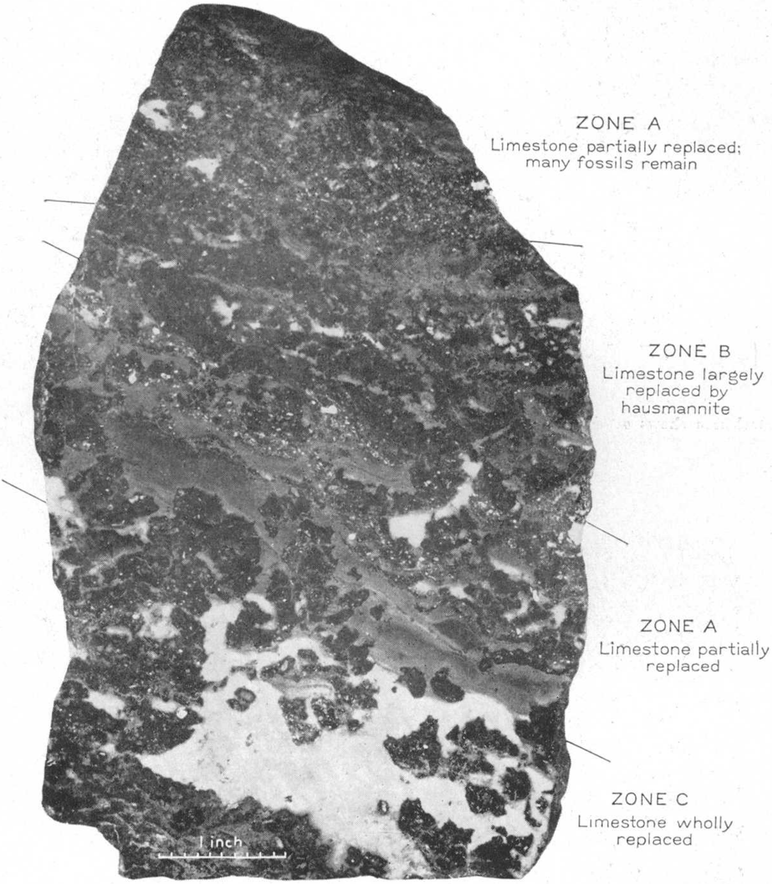
A. THIN SECTION OF ORE FROM WOODPECKER HOLLOW MINE.

Central area shows octahedral crystals of hausmannite (black) largely replaced by bementite (gray) in carbonate matrix (white).



B. THIN SECTION OF ORE FROM PITTMAN MINE.

Shows hausmannite (black) replacing calcite (left, gray) and barite (right, gray).



POLISHED SURFACE OF ORE FROM W. A. CHINN MINE, CAVE CREEK.

Shows transition from partially replaced limestone (top) to mixed hausmannite and rhodochrosite (bottom).

in places with the limonite and with manganese oxides but, like some limonite, occurs in association with the manganese carbonates. The soft earthy forms of limonite and hematite are present, but some of the hematite has a foliated or micaceous structure. Minute disseminated grains of hematite and limonite, chiefly hematite, in some portions of the Fernvale limestone give it a rusty color.

At many openings in the district the normally gray Fernvale limestone is altered to mottled red or reddish-brown manganiferous carbonate. This color is due, in part at least, to disseminated iron oxide. In a few places a bluish-black hematite in irregular and plumose masses is embedded in white and red manganiferous carbonates; it is later than some of the white and red carbonates but is earlier than banded veinlets of white carbonates. Grains of pyrite are common in the hematite and also in the associated rock.

Barite.—The manganese ores contain barite at many places. As almost every specimen of unweathered manganiferous material that has been studied closely contains some barite, it is now considered to be almost as widespread as the manganese deposits of the district. Some of the barite consists of tabular crystals 3 inches or less in their longest dimension or of coarsely granular aggregates embedded in the masses of manganese oxides. These crystals and aggregates are generally colorless or white, but some are amethystine. Barite is most common in the midst of the masses of mixed hausmannite and manganese carbonates, where it occurs as clusters of thin tabular crystals from a quarter to half an inch long. In many of these masses barite has been partly replaced by hausmannite and where bementite is abundant this mineral also has replaced barite. (See pls. 3, *B* and 5.) At the O'Flinn prospect nearly spherical fossil Girvanellas from a quarter of an inch to 1 inch in diameter in the St. Clair limestone have been replaced by fluorite alone or by fluorite in which tabular crystals of barite are embedded. Barite has also replaced Girvanellas in the St. Clair limestone at the Cason mine. Another form of barite occurring as white hairlike crystals, one-tenth of an inch or less in length, lines cavities in masses of psilomelane and wad.

Fluorite.—Fluorite is not common in the district. Near the head of Hankins Hollow it forms small irregular particles a fraction of an inch across in a body of brown manganiferous carbonate. Here it is colorless and amethystine. The other occurrence which is mentioned above, under the heading "Barite," is at the O'Flinn prospect. There it is amethystine.

Sulphides.—Specimens of the Cason shale that were found at the Cason mine by D. F. Hewett show films and crystals of arsenopyrite.

Small quantities of galena (PbS), the largest piece the size of a man's fist, were found in the lower part of the St. Clair limestone at the Cason mine while this limestone was being quarried from above the Cason shale. The galena observed by H. D. Miser occurred in cavities formed by the solution of fossil Girvanellas and in thin veinlets in the parts of the limestone that contain the Girvanellas. Galena has also been found in the Montgomery mine, and a specimen of it weighing a few ounces was given to Mr. Miser.

Pyrite in small quantities occurs rather widely in the district and is present in the limestone, in the hematite, and in the masses of manganiferous carbonates, both gray and mottled, but is nowhere near hausmannite or bementite.

Other minerals.—Recently deposited calcite and gypsum, which are the products of weathering, occur in small amounts and are associated with the manganese oxides.

Some masses of porous chert in the ore-bearing clay contain drusy quartz, and doubly terminated quartz crystals have been found on a few of the old mine dumps. These crystals are most abundant at the Southern mine, where they are as much as half an inch long. Although many are transparent, most of them are brown from the presence of minute inclusions of a manganese oxide.

PARAGENESIS OF THE MANGANESE MINERALS

Most of the above-mentioned minerals were recognized many years ago by Mr. Miser,[8] but, as a result of the recent joint examination of the district by Messrs. Hewett and Miser, it is now known that the manganese carbonates are more widespread in the Fernvale limestone and Cason shale than was at first thought and that the uncommon minerals bementite and neotocite are present in considerable quantity at many places. The minerals now known and their relations have led to new conclusions concerning their origin. These conclusions, as discussed beyond, have a direct bearing on the economic features of the manganese ores of the Batesville district.

The minerals that have been recognized fall readily into two groups on the basis of the origins that are assigned to them—supergene and hypogene.[9] It is widely believed that supergene minerals have been deposited by cool waters of surface origin and that their constituents have been derived from local sources, usually at or above the general level at which they are now found. It is further believed that hypogene minerals have been deposited by warm or even hot waters and that their constituents have been derived from remote and generally deeper sources, though the sources in some areas, as in the Batesville

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[8] Miser, H. D., Deposits of manganese ore in the Batesville district, Arkansas: U. S. Geol. Survey Bull. 734, 1922.

[9] Ransome, F. L., Copper deposits near Superior, Ariz.: U. S. Geol. Survey Bull. 540, pp. 152–153, 1914.

district, appear to be local. The assignment of the minerals of this district to these groups is based upon the accumulated knowledge of their general distribution, their mutual relations, and their chemical characteristics.

The hypogene minerals of the Batesville district include rhodochrosite and other manganese carbonates, hausmannite, braunite, barite, fluorite, bementite, neotocite, hematite, and pyrite. The remaining minerals worthy of mention—psilomelane, manganite, wad, and questionably some braunite—are classed as supergene. Many specimens of the early manganese minerals—the manganese carbonates, hausmannite, bementite, and neotocite—show stages of alteration to psilomelane and wad, which are the two most common supergene minerals.

The spatial relations of most of the hypogene minerals are sufficiently clear in the polished and thin sections to permit confident conclusions concerning the order in which they were formed. These include rhodochrosite and other manganese carbonates, barite, fluorite, hausmannite, bementite, neotocite, and pyrite.

The gray manganese carbonate appears to have been the first or earliest mineral to form, for it occurs in the Fernvale limestone as isolated masses that retain all the minute textural details of the limestone, it forms a border zone between the hausmannite-bementite masses and the enclosing limestone, and it is replaced by both hausmannite and bementite. The rhodochrosite and the red and white carbonates that retain no trace of the texture of the limestone which they replace are confined largely to the inner parts rather than the borders of the deposits and are undoubtedly later than the gray carbonate.

Fine crystal aggregates of braunite and also hematite are distributed through and have replaced these mottled carbonates at some places, and the hematite and braunite-bearing material has been in turn replaced by barite crystals, and these in turn by hausmannite and bementite. It thus appears that some braunite and hematite are earlier than barite, hausmannite, and bementite.

Barite is widespread, and its relations to the other minerals are clear, but fluorite is known only in association with barite. Apparently the fluorite was deposited after the barite.

In many polished as well as thin sections hausmannite and bementite have replaced barite crystals. (See pls. 3, *B*, and 4, *B*.) Also in many places hausmannite presents crystals toward the earlier carbonates which it has replaced. Similarly, bementite is invariably associated with hausmannite and has replaced it. In many thin sections crystal forms characteristic of hausmannite are now bementite except for an inner sponge or core. (See pl. 4, *A*.) In some specimens rhodochrosite has replaced barite crystals, indicating a second generation of such carbonate, and veinlets of banded carbonates cut bodies consisting of earlier carbonates and hausmannite.

The relations of bementite and neotocite are obscure.

The following table summarizes the data concerning paragenesis:

	Hypogene	Supergene
Gray carbonate	▬	
Rhodochrosite, red, and white carbonates	▬	
Braunite	▬	
Hematite	▬	
Barite (tabular crystal aggregates)	▬	
Fluorite	▬	
Hausmannite	▬	
Rhodochrosite, white, and red carbonates	▬	
Pyrite	▬	
Bementite	▬	
Neotocite	▬	
Manganite		▬
Psilomelane		▬
Braunite?		▬
Wad		▬
Barite (needlelike crystals)		▬
Calcite		▬
Gypsum		▬

CHEMICAL COMPOSITION OF THE ORES

The chemical composition of the manganese carbonate ores varies greatly, especially in their content of manganese, iron, and lime. Analyses of samples of the rhodochrosite and gray carbonate given on page 13 show a manganese content ranging from 32.6 to 38.5 percent, a low iron content, not exceeding 0.5 percent, and a lime content ranging from 7.9 to 13.8 percent. The red carbonate, as shown by analyses of many samples, has a manganese content ranging from 20 to 30 percent and also has a high iron content, which in places equals that of manganese.

Carbonate ores having a manganese content as low as 18 percent and as high as 35 percent occur widely, but carload lots that contain more than 35 percent of manganese include an admixture of hausmannite or other oxides. Some of the shipments of carbonate ore have contained little or no manganese oxide, but most of them have contained considerable.

The analysis of the first shipment of manganese carbonate, which was made in 1928 and which consisted of gray and brown carbonates and of oxides from the Club House Mine, is given below.

Analysis of first shipment of manganese carbonate ore from Batesville district

Manganese (Mn)	31.56
Iron (Fe)	5.14
Silica (SiO_2)	2.41
Alumina (Al_2O_3)	1.15
Moisture (H_2O)	2.12

The shipments of manganese carbonate ore from the Club House mine, the largest producer of such ore, have contained an average manganese content of 37 or 38 percent. These shipments have consisted of manganese oxides and carbonates, which were intermixed in part naturally and in part artificially.

Shipments of intermixed carbonate and oxide ore from the Ozark mine have contained 47 percent of manganese. A carload lot of carbonate oxide ore from the Rutherford mine is stated to have contained between 20 and 25 percent of manganese. A carload of similar ore from the Adler prospect contained 32 percent of manganese. Analyses of carload-lot shipments of manganese carbonate and oxides naturally intermixed from the W. A. Chinn mine are given below.

Analyses of manganese ore from the south cut of the W. A. Chinn mine

	1	2	3
Manganese (Mn)	17.24	36.15	24.65
Iron (Fe)	7.0	10.0	9.20
Phosphorus (P)	.44	.54	.58
Silica (SiO_2)	3.60	8.50	4.90
Calcium carbonate ($CaCO_3$)	52.70	25.30	32.83
Moisture	1.60	2.10	.60

The marketed carbonate oxide ore from the Stark Spring mine had a manganese content of 38 percent. Carload lots of similar marketed ore from the Martin No. 1 mine had a manganese content that ranged from 34.07 to 41.58 percent and averaged 36 percent.

Carload-lot shipments of carbonate oxide ore from the Manganese Cave mine in 1920 had a manganese content ranging from 34 to 36 percent; in 1925 the carload lots of high-grade ore contained 35.10 to 42.52 percent of manganese; and in the same year the shipments of low-grade ore averaged 32 percent of manganese. The manganese content of the marketed ore from this mine in 1934 averaged 27 percent. Analyses of shipments in 1929 and 1930 of ore from this mine mixed with ore from nearby mines are given on page 24.

Carload lots of carbonate ore with a very minor amount of oxide from the Smith mine had a manganese content ranging from 28 to 33 percent. The carbonate oxide output from the Hinkle cut of the Pittman mines in 1928 contained an average manganese content of 35 percent. Many analyses of carload lots of manganese carbonate ore from these and other mines near Penters Bluff in 1929–31 are given below.

Analysis of carload-lot shipments of manganese carbonate ore from mines near Penters Bluff in 1929–31

[Many carloads contained ore from two or more mines]

	1	2	3	4	5	6	7	8	9	10
Manganese (Mn)	30.25	28.08	37.94	25.52	34.34	29.80	27.30	28.50	30.28	30.52
Iron (Fe)	6.45	4.82	4.32	5.30	3.81	8.32	6.35	7.45	5.42	6.45
Phosphorus (P)	-------	-------	-------	.97	-------	-------	-------	-------	-------	-------
Silica (SiO_2)	2.41	3.02	3.03	3.55	-------	5.34	5.24	4.86	3.82	5.02
Alumina (Al_2O_3)	1.11	1	.84	2.12	-------	1.58	1.45	2.21	1.17	1.25
Moisture (H_2O)	1	1.25	1.90	1	2.5	5	5	3.75	2.87	2.40

	11	12	13	14	15	16	17	18	19
Manganese (Mn)	28.76	28.73	26.50	30.58	25.95	25.61	29.50	31.06	41.51
Iron (Fe)	13.18	6.42	6.52	7.62	7.55	8.98	9.58	-------	-------
Phosphorus (P)	-------	-------	-------	-------	-------	1.	.82	-------	-------
Silica (SiO_2)	20.40	5.48	6.89	6.98	4.65	[1] 8.70	[1] 5.60	-------	-------
Alumina (Al_2O_3)	9.16	2.75	2.66	2.67	1.61	-------	-------	-------	-------
Moisture (H_2O)	4.15	2.75	3.05	5.65	2.75	2.82	3.85	2.20	6.32

[1] Insoluble matter.

1. Carbonate from Manganese Cave, Smith, and Pittman mines.
2. Carbonate from Manganese Cave and Pittman mines.
3. High- and low-grade carbonates from Pittman mine.
4–5. High-and low-grade carbonates and some dark "gray rock" from Pittman and Woodpecker Hollow mines.
6–7. Carbonate from Manganese Cave and Penters Bluff mines.
8–9. Carbonate and black rock (limestone) from Woodpecker Hollow mine.
10. Carbonate from Pittman and Woodpecker Hollow mines.
11–12. Carbonate and dark "gray rock" from Pittman and Woodpecker Hollow mines.
13. Carbonate and some dark "gray rock" from Parker and Woodpecker Hollow mines.
14. Carbonate from Woodpecker Hollow and other mines near Penters Bluff.
15. Red and green carbonates from Manganese Cave and Smith mines.
16. High-grade No. 2 carbonate from different mines near Penters Bluff.
17. Carbonate and black rock (limestone) from Smith mine.
18. Carbonate from Woodpecker Hollow mine.
19. High-grade carbonate from Pittman and Woodpecker Hollow mines.

Many analyses of samples of manganese carbonate are given in the descriptions of the mines and prospects.

Most of the high-grade oxide ores contain from 45 to 52 percent of manganese, although some carload lots contained as much as 62.67 percent. They generally contain from 3 to 8 percent of iron, 0.15 to 0.30 percent of phosphorus, and 2 to 8 percent of silica. Some of the ore that has been marketed contained more than 0.30 percent of phosphorus, and a very little contained 0.50 percent or more. Most specifications for ores that are used for metallurgic purposes state that the phosphorus should not exceed 0.25 percent, but it is evident that some of the shipments contain more than this. Phosphorus is the most harmful ingredient in the ores of the district, but in many places it can be reduced by properly sorting the ore. At some places the silica content is high, exceeding 8 percent.

The two analyses given represent the approximate average composition of the greater part of the high-grade manganese oxide 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 percent or more of manganese.

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

	1917 (231 carloads)	1918 (165 carloads)
Manganese (Mn)	47.60	45.72
Iron (Fe)	[1] 5.77	[2] 5.59
Phosphorus (P)	[3] .24	[4] .36
Silica (SiO_2)	[5] 6.79	[6] 8.68
Alumina (Al_2O_3)	[7] 2.98	----------

[1] Iron was determined in 194 cars.
[2] Iron was determined in 125 cars.
[3] Phosphorus was determined in 193 cars.
[4] Phosphorus was determined in 91 cars.
[5] Silica was determined in 135 cars.
[6] Silica was determined in 130 cars.
[7] Alumina was determined in 125 cars.

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

TYPES OF DEPOSITS

The workable deposits of manganese and ferruginous manganese ores may be grouped into several types, according to their character, their enclosing rocks, and their origin:

- Sedimentary deposits:
  - Manganiferous carbonate in the Cason shale.
  - Manganese oxides in stream gravel.
- Hypogene deposits:
  - Rhodochrosite and other manganese carbonates with hausmannite.
- Supergene deposits:
  - Manganese oxides replacing Cason shale.
  - Manganese oxides in residual clays:
    - From Fernvale limestone.
    - From Cason shale.
  - Manganese oxides replacing residual clays.

Rhodochrosite, the other manganese carbonates, and the associated hausmannite are widely distributed and have formed a considerable proportion of the output of manganese ores since 1928, when appreciable quantities of the carbonates were first marketed. The manganese oxides in clays residual 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 of deposit is represented, but at some two types and at a few three types are present and have been mined on a commercial scale.

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

SEDIMENTARY DEPOSITS

MANGANIFEROUS CARBONATE IN THE CASON SHALE

Gray and red manganiferous carbonates are revealed in the Cason shale at several places, notably the Cason mine, near Batesville; the Meeker mine, near Cushman; and several mines on East and West Lafferty Creeks and near Penters Bluff. Some or all of the carbonate-bearing material appears to have been formed by the deposition of manganese compounds in the sea during the accumulation of the sediments for the Cason shale.

The character of the shale varies greatly in different portions of the district, as stated in the description of the Cason on page 10–12. Besides the manganiferous and ferruginous minerals the Cason shale contains phosphate, glauconite, and quartz. In addition, there are small bodies of oolitic limestone at the base; and flattened pebblelike masses or "buttons" of fossil algae (*Girvanella*) 1 inch or less in diameter are disseminated through the shale at many places in the district.

A red manganiferous carbonate accompanied by a little pyrite forms a bed, 36 inches in maximum thickness, which has been revealed in workings at several places between Cushman and Penters Bluff. At some places the bed rests directly upon the Fernvale limestone and is overlain by the ledge-making phosphate rock; at other places it lies between beds of phosphate rock; but at still other places the carbonate occurs as thin layers in the shale in which there is no phosphate rock. The carbonate is said to contain as much as 25 percent of manganese. On weathering this carbonate changes to porous seams of red and brown oxides of iron and oxides of manganese. These seams lie parallel with the bedding. The oxides derived from the weathering of the Cason shale contain as much as 20 percent of manganese and 25 percent of iron and are widespread in the district. Their presence suggests an equally widespread occurrence of manganiferous ferruginous carbonates in the Cason shale in the areas where the shale has not been weathered.

The "buttons" in the Cason shale, as shown at most places, are weathered to oxides of iron and manganese. Extensive quarrying of manganese ore at the Cason mine indicates that such "buttons" away from the influence of weathering are a manganiferous carbonate. There the "buttons" measure as much as 1 inch in their smaller diameter and as much as half an inch in thickness; they lie parallel with the bedding, and they are rather uniformly distributed through the shale, which, as shown in and near the quarry, is a lenslike body ranging in thickness from a feather edge to 10 feet. The shale at that mine is red to brown, hard, platy, sandy, and slightly calcareous, but its original color, a greenish-gray, is shown through a thickness of several feet in the deepest portion of the quarry. The buttons were originally spherical, like the Girvanellas in the massive portions of the overlying St. Clair limestone; but they were flattened by pressure, which at the same time appears to have compressed the shale to about one-third its original thickness. (See pl. 6 and fig. 3). A few of the "buttons" in the greenish-gray shale are gray, but parts of some are reddened. Other "buttons" in both the greenish-gray and red shales are red, whereas in much of the red shale they are composed of hard black oxide. The red "buttons," as shown by analysis 3 in the table on page 28, are composed of a manganese-lime carbonate with a manganese content of 5.85 percent. The gray shale matrix (analysis 1) in which such "buttons" lie also contains a manganese-lime carbonate and, in addition, much fine sand, as shown by the presence of 32.73

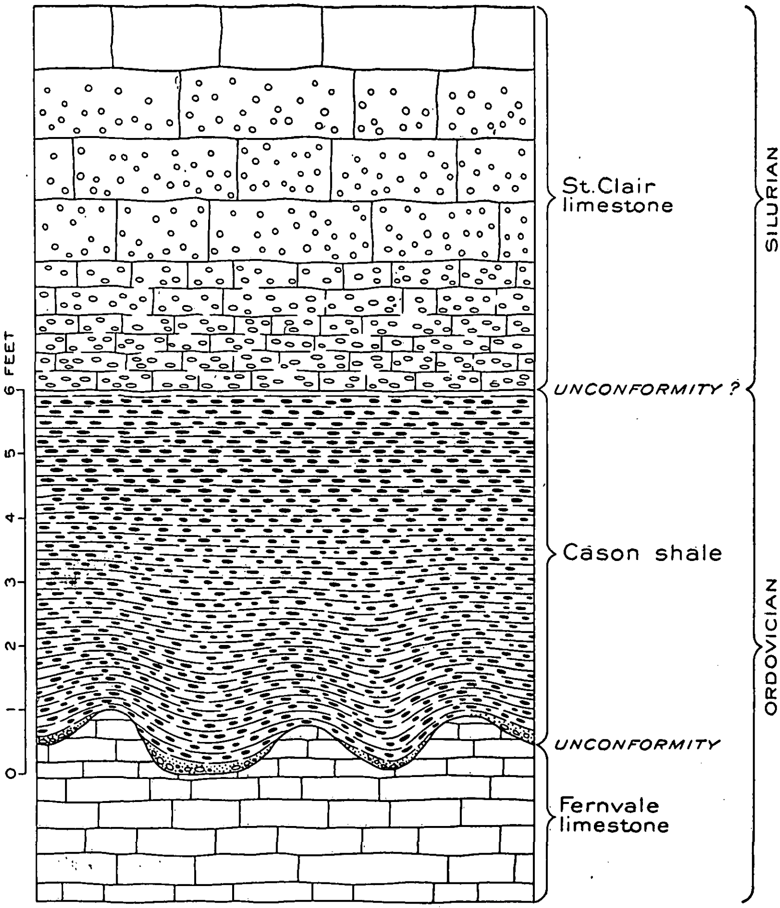

FIGURE 3.—Section in Cason mine showing relations of manganese-bearing Cason shale. The spherical to flattened fossil Girvanellas in the St. Clair limestone are composed of manganiferous carbonate, and the much flattened Girvanellas ("buttons") in the Cason shale are composed of oxidized manganese carbonate.

percent of silica; but the manganese content—5.87 percent—is essentially the same as that of the "buttons" enclosed in the shale.

The quarry walls as well as small specimens show a gradation from gray shale with gray or slightly reddened "buttons" to red shale with red "buttons" and then to dark-brown shale with oxide "buttons." In this gradation the carbonate has increased in amount and has undergone first a partial and then a complete change to manganese oxide. These changes are illustrated by the analyses in the table given below. The gray shale matrix (analysis 1) and the enclosed red "buttons" (analysis 3) contain manganese in the carbonate form only. The dark-brown shale matrix (analysis 2) and the enclosed buttons of the same color (analysis 4) contain both the carbonate and oxide of manganese, and the percentage of manganese is greater than in the gray shale and the red buttons. The black "buttons" (analysis 5) are hard psilomelane containing 50 percent of manganese, none of which occurs in the carbonate form.

The Girvanellas (analysis 6) in the St. Clair contain the same amount of manganese as the red "buttons" (analysis 3) in the underlying Cason shale. The limestone matrix (analysis 7), however, contains a smaller percentage of manganese (1.52 percent) than the gray shale matrix (analysis 1). This occurrence of manganese in the Girvanellas (algae) that flourished during the deposition of the Cason shale and St. Clair limestone seems to suggest that the algae facilitated the deposition of the manganese. This suggestion conforms to the conclusion concerning the precipitation of manganese by algae at a locality near Harpers Ferry, W. Va., discovered by the late Dr. David White.[10]

Analyses of Cason shale and St. Clair limestone, Cason mine

	Cason shale					St. Clair limestone	
	1	2	3	4	5	6	7
Manganese (Mn)	5.87	6.1	5.85	26.9	50.41	5.94	1.52
Iron (Fe)	4.98		3.08		7.56	1.56	
Phosphorus					.06		
Silica (SiO_2)	32.73		2.73		12.67	.29	
Alumina (Al_2O_3)	8.22		5.68		1.37	4.06	
Lime (CaO)	14.22		29.85		2.09	42.80	
Magnesia (MgO)	3.38		1.45			.87	
Barium (Ba), SO_4, CO_3	Present		Present			Present	
Manganese as carbonate (estimated)	5.87	3.9	5.85	14.2	None	5.94	1.52

1. Greenish gray shale matrix containing no manganese oxide. R. C. Wells, analyst. Miser, H. D., op. cit. (Bull. 734), p. 139.
2. Dark-brown shale matrix; contains both manganese carbonate and oxide. E. T. Erickson, analyst.
3. Red "buttons"; contain manganese carbonate but no oxide. R. C. Wells, analyst. Miser, H. D., op. cit., p. 140.
4. Dark-brown "buttons," nearly black; contain both manganese carbonate and oxide. E. T. Erickson, analyst.
5. Black manganese oxide "buttons"; contain no manganese carbonate. R. N. Brackett, analyst. Penrose, R. A. F., Jr., op. cit. (Arkansas Geol. Survey Annual Report for 1890, vol. 1), p. 221.
6. Gray pebblelike *Girvanella;* R. C. Wells, analyst. Miser, H. D., op. cit., p. 137.
7. Gray limestone matrix.

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[10] Howe, M. A., The geologic importance of the lime-secreting algae, with a description of a new travertine-forming organism: U. S. Geol. Survey Prof. Paper 170, pp. 61–64, 1932.

MANGANESE OXIDES IN STREAM GRAVEL

Stream gravel contains hard manganese oxide at many places on the tributaries of East and West Lafferty Creeks in the western part of the district. The gravel consists of the hard, compact masses of manganese oxides that have been set free by the decomposition of the Fernvale limestone and Cason shale and have been transported by streams. Some deposits that have been formed in this way occur in the beds of wet-weather streams that drain hollows on whose slopes the manganese-oxide-bearing clays and loams are exposed; others occur in alluvial cones at the mouths of some of such hollows. 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 examples of manganese-bearing alluvial cones are at the mouth of Cummins Hollow and at the mouth of Hankins Hollow. The drainage from both these hollows empties into West Lafferty Creek.

HYPOGENE DEPOSITS

RHODOCHROSITE AND OTHER MANGANESE CARBONATES WITH HAUSMANNITE

Rhodochrosite and the other manganese carbonates with which hausmannite is associated form lenticular bodies lying in the topmost portion of the Fernvale limestone. They have yielded most of the output of carbonate ore from the district; the smaller part has been obtained from the Cason shale. Most of the carbonate ore bodies in the Fernvale lie in a horizontal or nearly horizontal position, parallel with the bedding of the limestone and the overlying rocks. The ore in such bodies is locally known as "ledge" ore and has been formed by replacement of the limestone, which the miners call "gray rock." Although the ore contains many other minerals, hausmannite is the most abundant manganese oxide. The proportion of hausmannite ranges from practically none to nearly 100 percent. Nearly all marketed carbonate ore has included some oxides; some carload lots contain practically none, whereas others are mostly oxides.

AREAL DISTRIBUTION OF DEPOSITS

The manganese carbonate and hausmannite deposits in the Fernvale limestone are widely distributed in the district, as is shown by their presence in a considerable number of openings. (See pl. 1.) The mines and prospects that show carbonates may be grouped into three areas—one on and near Cave Creek, a few miles northwest of Pfeiffer; another extending from Cushman westward to Penters Bluff; and the third on the northeast side of the White River a few miles southeast of Guion. Further prospecting for manganese ore of this type will reveal other deposits in these three areas and doubtless also in the intervening territory.

Many parts of the district, however, do not contain carbonate deposits, because the rocks have been exposed to weathering sufficiently long to change all the manganiferous carbonates and some of the hausmannite to psilomelane, wad, and manganite. There are thus numerous deposits of manganese oxides with which there are no associated manganese carbonates. Such deposits include those in the vicinity of Cave City, Sandtown, Mount Pleasant, and Lafferty and those worked by the group of highly productive mines a few miles northeast of Cushman—the Southern, Grubb Cut, Polk Southard, Turner, and Blue Ridge mines.

The distribution of the mines containing known deposits of manganese carbonate and also the mines containing only manganese oxides is shown on the accompanying map (pl. 1).

FORM AND CHARACTER OF DEPOSITS

The deposits of manganese carbonate, as shown in the numerous openings, assume several forms. The largest and most extensive, however, are the lenslike bodies that occur at the top of the Fernvale limestone. They are best revealed in the cuts and extensive tunnels of the Club House and Club House extension mines. Other bodies are (1) irregular or lens-shaped masses distributed through the upper 40 to 50 feet of the Fernvale and (2) thin horizontal layers and vertical veinlets a fraction of an inch thick that follow joints in the limestone. These masses, layers, and veins are best shown in the large open cuts at the Miller-Rinehart mine, though they are known elsewhere. They are not large enough nor abundant enough to yield manganese ore in commercial quantities.

The lenslike bodies at the top of the Fernvale yield the "ledge ore" of the miners, so called because of the bedded character of the deposits. They lie next to the overlying Cason shale, but in the eastern part of the district, at places on and near Cave Creek, they are overlain directly by the Boone chert, a formation younger than the Cason. They are underlain by the miners' "gray rock," the portions of the Fernvale limestone that have not been replaced by manganese minerals. That the ore bodies have been formed by the replacement of the limestone is shown by the preservation of textural features of the limestone in much of the manganese ore—both carbonates and oxides. These features include especially the casts of fossils, minute phosphatic shells, and the outlines of the different kinds of calcium carbonate particles in the limestone. In addition some of the lenslike bodies contain unreplaced areas of limestone, and some bodies are branching veins that extend as much as 10 feet below the top of the limestone.

Pinnacles or "horses" of "gray rock" are present at some places and rise as much as 6 feet above the base of the ore bodies. Many of the "horses" project upward to the base of the Cason shale and the ore bodies do not therefore extend over such "horses." The ore bodies are thus thickest in the hollows surrounding the "horses."

The usual maximum thickness of the carbonate ore bodies in a working face ranges from 2 to 4 feet, though thicknesses of as much as 9 feet are reported at the Club House mine and 10 feet at the Manganese Cave mine.

The character of the ore bodies, as well as of the Cason shale and "gray rock," varies from place to place. The differences appear to be due mainly or entirely to the action of ground water. These differences include (1) oxidation of the manganese carbonates and their transformation to oxides; (2) a change in the color of the Cason shale from the usual green to brown where the carbonates in the underlying limestone have been converted into oxides; this change in color is accompanied by the oxidation of disseminated pyrite in the shale; (3) solution of the limestone and consequent formation of residual clays through which masses of manganese oxide ore are distributed; (4) settling of the ore-bearing residual clays and the superjacent rocks into channels and even caves of large and small size that are formed by the solution of the limestone; and (5) removal of some managenese from the deposits through solution by ground water.

The manganese carbonates are found chiefly in those portions of the lenticular ore bodies that are covered by Cason shale where there has been no slumping and settling of the shale and higher rocks, including the Boone chert. On the other hand, oxides either alone or accompanied by a small amount of carbonate are found in the portions of the deposits where there has been settling of the Boone chert in consequence of the solution of the Fernvale limestone.

The lenslike carbonate ore bodies are composed of manganese carbonates, oxides, and silicates. The carbonates are chiefly rhodochrosite and the white, gray, and red varieties; the oxides are hausmannite and braunite; and the recognized silicates are bementite and neotocite. Associated minerals include barite, pyrite, and hematite. The weathered portions of the ore bodies contain little or no carbonate, but much psilomelane and wad are present in places as a result of the action of ground water on the several manganese minerals.

At some places the Fernvale limestone immediately underneath the carbonate ore bodies is either gray or red. Apparently the red color is due to the presence of hematite and manganiferous carbonate. The limestone also contains veinlets of white and pinkish carbonates and some disseminated pyrite.

The irregular masses of carbonates occur in the upper 40 to 50 feet of the Fernvale limestone below the lenslike bodies and are irregularly distributed both horizontally and vertically. They reach a length of about 2½ feet and a thickness of 1 foot. Their longer dimensions lie horizontal, parallel with the bedding of the limestone. Most of the manganese carbonate is the gray variety and retains the textural features of the limestone which the carbonate has replaced. (See pl. 2.) Other varieties—rhodochrosite and white and red carbonates—are present in small quantity. Although these carbonate masses are embedded in limestone, their peripheral portions, as revealed at the Miller-Rinehart mine, are commonly surrounded by a layer of psilomelane, 1 to 2 inches thick. The psilomelane was obviously formed by the surficial oxidation of the carbonates and doubtless decreases in amount and disappears in depth. These carbonate masses are doubtless the source of much of the psilomelane that occurs in the form of rounded and nodular bodies at many mines in the district. The aggregate amount of psilomelane originating in this way, however, is very small in comparison with the oxide masses derived by weathering from the lenticular carbonate bodies at the top of the Fernvale. Besides these irregular carbonate masses there are horizontal layers of brown manganiferous carbonate, a fraction of an inch thick, lying along the bedding planes, and veinlets of similar thickness that occupy cracks parallel with the vertical joints in the limestone. On weathering these veinlets and layers have changed to manganese oxide on the surface of the limestone and as much as an inch away from the surface. They are especially well displayed at the Miller-Rinehart mine, where large areas of the limestone have been exposed by the removal of the surface mantle of clay and rock debris during mining operations.

SUPERGENE DEPOSITS

MANGANESE OXIDES REPLACING CASON SHALE

At numerous places in the Batesville district manganese and iron oxides have replaced the Cason shale, but only at the Cason mine have commercial quantities of the manganese oxide psilomelane formed in this way. This mine has produced more low-grade manganese ore than any other in the district. Here the oxide occurs in the shale chiefly as "buttons" or flattened concretionlike masses about an inch in their longest diameter. (See pl. 6, *B*, and fig. 3.) At the Cason mine the "buttons" are so numerous that much of the shale has been quarried and shipped. The average manganese content of the ore shipped has been about 20 percent, and the iron content has ranged from 6 to 10 percent. Only a part of the shale at the Cason mine contains "buttons" of manganese oxide; the rest contains red and gray "buttons" of manganese and lime carbonate. 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 walls of the quarry. The gray shale matrix also contains a manganese-calcium carbonate, and the stages in its transition to red and dark brown shale are well shown. The analyses on page 28 show that the gray shale matrix and the red carbonate "buttons" contain practically the same amount of manganese—5.87 percent (analysis 1) and 5.85 percent (analysis 3). The dark-brown shale matrix (analysis 2) and its enclosed dark-brown "buttons" (analysis 4) contain manganese in both the carbonate and oxide forms, though the amount of manganese in both the shale matrix (6.1 percent) and the "buttons" (26.9 percent) is greater than that in the gray shale matrix and in the red "buttons." The increase of percentage in the "buttons" is, however, several times greater than the increase in the shale matrix. Presumably this is due to the greater facility with which manganese oxide replaces the carbonate of the "buttons" than it does the rather large amount of quartz sand in the shale matrix. The manganese content of the black "buttons," in which there is no carbonate, as shown by analysis 5, is 50.41 percent.

The above-described transition from material containing manganese-calcium carbonate to material composed of manganese oxide appears to indicate clearly that the manganiferous carbonate is the source of the manganese that now occurs as oxides. The relations of the oxide- and carbonate-bearing parts of the deposit to the topographic features in the vicinity indicate that the oxide-bearing material decreases with depth. In addition to manganese in the oxide form the marketed ore also contained some carbonate. In fact, analyses 2 and 4 represent material from a portion of the deposit that was mined and shipped.

Generally the dark-brown to black "buttons" form about one-third of the rock, but in some places they make up more than half of it, and in some others they form so small a part that such rock has to be discarded as waste. The shale that contains enough oxide "buttons" to be classed as ore ranges in thickness from 3 to 8 feet and averages about 5 feet.

Manganese and iron oxide "buttons" occur at other places in the district, and their origin is doubtless similar to that of the manganese oxide "buttons" at the Cason mine, but at some places they are composed of red iron oxide.

MANGANESE OXIDES IN CLAYS RESIDUAL FROM FERNVALE LIMESTONE

The deposits of manganese oxides in clays that are residual 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. The largest known deposit of this type is that at the Southern mine, which has produced about 45,000 tons of ore through 1936.

The manganese ores are masses of oxides that occur in residual clays above not only the Fernvale limestone but also older limestones. These masses have been derived from the manganese carbonate-oxide bodies in the Fernvale limestone. Most of the oxide masses have been derived from the lenslike bodies of manganese carbonate and hausmannite in the topmost part of the Fernvale, but some of them, apparently a very few, have been derived from the irregular and rounded masses that are distributed here and there through the upper 40 to 50 feet of the Fernvale limestone.

The ores consist mainly of the hard oxides psilomelane, hausmannite, and braunite, and the soft oxide wad. The braunite is least in quantity. The hard oxides occur mostly as irregular masses ranging in size from fine particles to boulders that weigh as much as 27 tons. The wad occurs as irregular bodies of large and small size and as lenses and beds, and hard masses of oxides are distributed through many of these.

The oxides in the clays are formed by the action of weathering on the manganese carbonates and silicates and on the oxides hausmannite and braunite in the Fernvale limestone. The oxide masses in the clays are mostly broken portions of the original carbonate-oxide ore bodies, but some of the smaller ones retain the shapes of the original masses. They have been set free from the limestone by solution and have settled by gravity to their present position in the residual clays.

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 underlying Kimmswick limestone and even a part or all of the Plattin limestone also have been completely decomposed. At many places, therefore, the chert and shale have settled far below their original positions, and during the settling they have been shattered, faulted, and bent so as to conform with the irregular surface of the underlying limestones. (See figure 6.) 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," and their thickness ranges from less than 10 to more than 60 feet.

MANGANESE OXIDES IN CLAYS RESIDUAL FROM CASON SHALE

The deposits of manganese oxides in clays that are residual from the Cason shale are widely distributed, and their character and form differ greatly from place to place. All the deposits have been formed by the weathering of manganiferous carbonates in the shale.

The ores include both iron and manganese oxides, which are in places rather intimately mixed. The manganese oxides are mainly psilomelane and braunite, and the iron oxides include both red and brown varieties. These minerals occur as "buttons," as irregular masses, and as thin horizontal seams and beds.

The "buttons" are so abundant in the shale at the Cason mine that the "button"-bearing residual clay was mined and shipped in the early history of the mine. Later the "button"-bearing shale was quarried. Analysis 5 on page 28 shows 50.41 percent of manganese in the "buttons." At the Montgomery and Ball mines the deposits include "buttons" and irregular masses of manganese oxides, distributed through the residual clay of the Cason shale. The irregular masses are generally porous and have rough surfaces, but a few have smooth botryoidal surfaces. Much of the material contains grains of sand and pebbles and particles of phosphate.

A bed of ferruginous manganese oxide ore, as much as 36 inches thick, in the weathered Cason shale has been mined at several places between Cushman and Penters Bluff, It has been derived from the weathering of the bed of red manganiferous carbonate described on page 26. In some places it lies in a horizontal position, but in others it lies in solution channels and on "horses" of the Fernvale limestone. Locally as at the Meeker mine, it occurs at the base of the Cason shale, but elsewhere, it occurs between beds of phosphate rock. The ore consists of seams of porous red and brown oxides of iron and oxides of manganese that lie parallel with the bedding. It contains as much as 20 percent of manganese and 25 percent of iron.

MANGANESE OXIDES REPLACING RESIDUAL CLAYS

In some places manganese from exotic sources has replaced clays to a sufficient extent to be minable. These deposits are not numerous, and even though some probably contain 10,000 tons or more of ore, their aggregate tonnage is not great. The original source of the manganese in such deposits was probably the Cason shale or the Fernvale limestone, but deposits of this type occur only where these formations have been so completely decomposed that nothing but residual clay remains. The clays contain more or less sand and pebbles and fragments of chert.

The manganese content of such ore is usually 35 percent or less and the iron, silica, and alumina contents are high. The manganese minerals form large irregular masses, veins several feet in their longest dimension, and also 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 psilomelane, manganite, and iron oxide are present. Such masses are cut by many joints, which show deeply striated slickensided surfaces. The smaller masses contain a larger proportion of psilomelane and manganite.

Most of the deposits of this type are at the McGee, Hawkins, Chapel Hill, Montgomery Hill, and Roach mines.

OUTCROPS OF THE DEPOSITS

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

Manganese oxides crop out at many places, and although the manganese carbonate bodies do not crop out, the occurrence of the oxides may be used as a helpful guide to locate carbonate bodies in parts of the district. Generally fine particles and large masses of manganese oxides lie loose on the hill slopes and in the beds of small streams. At some places the presence of unexposed masses of manganese oxides is indicated by 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 exposed on the surface.

In many parts of the district, where all the tabular bodies of manganese carbonate or "ledge ore" have been changed to the oxides, the ore-bearing clays and any overlying rocks have settled into underground channels and over limestone pinnacles. The result is that the chert layers of the Boone have been much deformed. Where the chert has been so deformed, it is useless to expect manganese carbonate ore beneath. Ledge ore may be expected only in the parts of the district or of a property where the Boone chert and locally the Cason shale and St. Clair limestone lie in an essentially horizontal position, and also where the Cason, if present, retains its fresh, unweathered green and red colors. A single property, like that on which the Club House mine is located, may display not only manganese carbonate bodies above which the Boone chert lies horizontal or nearly horizontal, and the Cason remains gray and red; but also oxide bodies which, with the overlying rocks, have settled into solution-formed channels.

Where the phosphate rock of the Cason shale is present in the western part of the district it is a helpful guide in the search for manganese carbonate. At places the phosphate rock crops out, but where blocks of the rock lie on the hill slopes, prospecting may be started at or near the highest blocks. The "ledge" carbonate ore at the top of the "gray rock" lies a few feet below the phosphate rock, and the ore in the Cason shale lies immediately below or in the bed of phosphate rock.

RELATION OF THE DEPOSITS TO STRUCTURAL FEATURES

The carbonate-hausmannite deposits do not appear to bear any relation to the few known faults of the district, for nearly all of them are from a fraction of a mile to many miles away from the known faults. The rocks are sufficiently well exposed to fortify the conclusion that faults are probably not numerous in the region, although more detailed studies will doubtless lead to the discovery of minor faults that are not now known. The ore-bearing Fernvale limestone and the other exposed rocks are, however, cut by many vertical joints that are especially conspicuous in the limestone because at numerous localities their positions are marked by solution channels. These channels are, for the most part, underground hollows reaching 50 feet or more in depth and are filled with manganese-bearing clays and other materials that have been washed or have settled into them. From such channels much of the manganese oxide ore is mined. Some channels that have been partly excavated in the course of mining operations are especially well shown at the Club House, Miller-Rinehart, and Cummins Hollow mines.

A noteworthy feature, whose significance is not now fully appreciated, is that some of the largest deposits occur in synclines. The Southern, Grubb Cut, Rogers, Wren, Polk Southard, Turner, and Blue Ridge mines, which have produced only oxide ores, are in a single syncline; the Barksdale, Ruminer Rough, Manganese Field, Sand Field, and Earl Collie mines, which have produced similar ore, are likewise in a single syncline; the W. T. Gray mine, which has produced oxide ore, and the Cason mine, which has produced both oxide and carbonate ore are in synclines. These are only a few of the mines in the district, but their aggregate production of both high-grade and low-grade ores is more than twice that of all the other mines and prospects. It seems therefore that the occurrence of large deposits in synclines is not accidental, but that the synclines have favored the accumulation of the ores.

How and when the manganese minerals accumulated in these synclines are undetermined questions. The concentrations of manganese carbonate in the Cason shale and Fernvale limestone appear to have been derived from the disseminated manganese that was deposited at the same time as the other sediments that now form these rocks. The occurrence of the ores in synclines indicates that the concentration took place before the present valleys of the district were eroded.

In the vicinity of the Cason mine both the Cason shale and the ore body are lenticular and thin out to the north, northeast, and northwest, so that they are essentially coextensive. The materials that formed the shale body at that locality were either deposited in a small embayment of the sea, or they were eroded from the adjoining areas before the calcareous deposits that later formed the St. Clair limestone were laid down.

ORIGIN OF THE ORES

PREVIOUS VIEWS

The different views as to the origin of the manganese ores of the Batesville district are not numerous. They are briefly outlined in the following paragraphs.

Owen [11] described them as occurring in veins in the "cavernous sub-Carboniferous limestone," but he said nothing concerning the source of the manganese.

Penrose,[12] who made a detailed examination of the deposits almost 50 years ago, concluded that manganese, derived from the pre-Cambrian crystalline rocks of the Ozark region of Missouri, was deposited contemporaneously with the calcareous and detrital material that forms the rocks now known as the Cason shale and Fernvale limestone. According to Penrose, the present oxide deposits in the clays were derived from the limestone by its recent decay and by the removal of its more soluble parts, the masses of oxide being thus set free. He believed that the manganese in the rocks of the region was originally in the form of a carbonate and that it was subsequently oxidized into its present condition. According to him "this oxidation may be only superficial, and below the water level of the country the ore may still retain its carbonate form."

Van Ingen,[13] in describing the ore body in the Cason shale at the Cason mine, concluded that there the manganese appeared to be in the form in which it was originally accumulated and that elsewhere in the district the marketable ore, which forms large irregular masses in the residual clays, has been recrystallized.

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[11] Owen, D. D., First report of a geological reconnaissance of the northern counties of Arkansas made during the years 1857 and 1858, pp. 39, 136, 1858.

[12] Penrose, R. A. F., Jr., Manganese—Its uses, ores, and deposits: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 1, pp. 167, 586–595, 1891.

[13] Van Ingen, Gilbert, The siluric fauna near Batesville, Ark., I: School of Mines Quart., vol. 22, pp. 324–325, 1901; Columbia Univ. Geol. Dept. Contr., vol. 9, No. 76, pp. 324–325, 1901.

Harder[14] expressed the opinion that the manganese was deposited as oxide in the Cason shale and that it has subsequently undergone concentration in the shale and in the residual clays on the hill slopes below it.

Woodbridge[15] says: "Throughout the greater portion of that part of the district of economic value the Cason shale and the Fernvale lime have decayed into a series of siliceous clays, and in these clays is the manganese that has been freed from those rocks and left as a minable residuum."

The writer[16] concluded from his investigation of the manganese ore deposits of the district in 1918 that (1) the manganiferous carbonates in the Cason shale were formed contemporaneously with the shale; (2) the Cason shale was probably the local source of all the manganese found in the district, the bodies of manganiferous carbonates then known in the Fernvale limestone having been formed by downward migration of manganese from the overlying Cason shale; (3) all the manganese oxides—hausmannite, braunite, psilomelane, manganite, and wad—whether in the unweathered Fernvale limestone and Cason shale or in the clays resulting from the decomposition of those formations, were formed by weathering and local migration of manganese from bodies of carbonates in the two formations.

RESULTS OF PRESENT INVESTIGATION

The discovery in recent years that lenticular bodies of hausmannite and gray carbonate of manganese, with or without accessory bementite or neotocite, persist under hard unweathered layers of the Fernvale limestone and the Cason shale, requires a modification of the views summarized above. The present conclusions are stated below.

The earlier view that the manganiferous carbonates in the Cason shale were formed contemporaneously with the deposition of the shale is maintained. It is now concluded that the Fernvale limestone is the source of the manganese in that limestone. Another conclusion is that the hausmannite, one of the most abundant oxide minerals, was formed not by the weathering of the manganiferous carbonates in the Fernvale but at essentially the same time as the carbonate bodies in the limestone. The bodies of manganese oxides in the residual clays have been formed by the weathering of the carbonate bodies in the Cason shale and the carbonate-hausmannite bodies in the Fernvale limestone. The processes of weathering affecting the numerous

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[14] Harder, E. C., Manganese deposits of the United States, with sections on foreign deposits, chemistry, and uses: U. S. Geol. Survey Bull. 427, pp. 117–118, 1910.

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

[16] Miser, H. D., Deposits of manganese ore in the Batesville district, Arkansas: U. S. Geol. Survey Bull. 734, 1922.

bodies and the associated rocks have included (1) the oxidation of the manganiferous carbonates, (2) a partial alteration of the hausmannite, (3) the formation of the oxides psilomelane, manganite, and wad, and (4) the solution of the limestone adjacent to the manganese bodies, with the resulting accumulation and settling of the oxide masses in the residual clays. At only a comparatively few places have the manganese oxides replaced residual clays.

If the bodies of manganese carbonate, hausmannite, and some associated bementite in the Fernvale limestone were distributed along faults or were associated with persistent fractures that pass through the Fernvale limestone and into the underlying rocks, it would seem probable that the manganese were derived from some remote deep source. Although there are northeastward-trending faults in the district, the concentrations of the manganese minerals bear no distinct relations to them. In several parts of the district, however, notably at the Miller-Rinehart mine, irregular small bodies of manganese carbonate are closely associated with local fractures in the Fernvale limestone that do not persist more than 10 or 20 feet vertically. It seems clear that these local fractures have determined the position of these small bodies of carbonate, but in the larger bodies of hausmannite and carbonate at the top of the limestone, such as that explored by the Club House mine, no definite persistent fractures have been found. Such fractures as those at the Miller-Rinehart mine could not have served to conduct manganese in solution from greater depth, but they and the bedding planes could have permitted the solution and transfer of manganese that was contained in the nearby limestone in some areas; and the manganese thus dissolved may then have traveled long or short distances along bedding planes before it was deposited by replacement of the limestone. Some assurance is added to this interpretation by the fact that a considerable thickness of the limestone, especially its upper half, contains disseminated manganese in the carbonate form in much of the Batesville district, and is therefore an adequate source. Analyses of four samples of such limestone in widely separated localities show the presence of 1.39, 1.48, 4.49, and 5.82 percent of manganese. (See table of analyses, p. 41.) If it were assumed that the manganese carbonate so widely disseminated through the upper half of the Fernvale was introduced from distant or remote sources, it would be expected that noteworthy concentrations of manganese minerals would occur along bedding planes and fractures through the upper half of the Fernvale limestone. The concentrations in such places are, however, so small below the topmost few feet that they have yielded no appreciable quantity of minable ore.

Analyses of Fernvale limestone

	1	2	3	4
Manganese (Mn)	4.49	1.39	5.82	1.48
Ferrous oxide (FeO)	1.3	.9		
Lime (CaO)	47.3	51.2		
Magnesia (MgO)	1.0	1.0		
Carbonic acid (CO_2)	42.0	40.4		
Insoluble	.9	2.2		
Phosphoric acid (P_2O_5)	.60	.10		

1. Rusty gray limestone from Club House mine. R. C. Wells, analyst.
2. Brown limestone from Miller-Rinehart mine. R. C. Wells, analyst.
3. Rusty gray limestone from depth of about 240 feet in drill hole at northeast corner NW¼SE¼ sec. 26, T. 14 N., R. 6 W., 4 miles northeast of Batesville. Chase Palmer, analyst. Miser, H. D., op. cit. (Bull. 734), p. 44.
4. Rusty gray limestone from depth of 102 to 135 feet in drill hole in SW¼NW¼ sec. 24, T. 14 N., R. 6 W., near Pfeiffer. Chase Palmer, analyst. Miser, H. D., op. cit., p. 45.

The source of the manganese that is contained in the bodies of hausmannite and carbonate appears therefore to have been the Fernvale limestone itself. The manganese-bearing area coincides with the area of the greatest known thickness of the Fernvale limestone in the southern Ozark region and to such an area the upper part of the Fernvale limestone, which contains a greater manganese content than the lower part, may be restricted. Many large deposits, as noted on pages 37–38, occur in synclines, and their concentration took place before the erosion of the valleys of the region, which have been cut in the horizontal or slightly dipping Fernvale limestone.

The concentration of manganese minerals in the topmost bed of the Fernvale limestone may have taken place during the deposition of the Fernvale, but, as will be noted from the following discussion, most if not all of the concentration to form the workable deposits in the top of the limestone appears to have occurred after the limestone was buried beneath the younger formations of the region.

If the concentration took place during Fernvale time, it seems likely that the topmost beds of the Fernvale limestone contained a greater original quantity of manganese minerals than the lower beds, and that these beds were eroded from anticlinal areas and are present only in the synclines. Slight folding to form such anticlines and synclines in the limestone probably took place at the end of Fernvale time, when the area was uplifted and became land. The exposure of the manganese-bearing limestone to erosion at the end of Fernvale time would have resulted in the oxidation of manganese carbonates and the formation of psilomelane and wad; but no concentrations of these two oxide minerals that can be assigned to that time have been noted. Available evidence appears to indicate that the psilomelane and wad in the region are entirely the result of relatively recent alteration of the carbonate-hausmannite bodies in the Fernvale limestone and the manganiferous carbonate in the Cason shale. Possibly any such concentrations of psilomelane and wad on a land surface of the Fernvale were completely removed by erosion before and during the deposition of the Cason shale; indeed, it appears from available evidence that the Fernvale was the source of the manganese in the manganiferous carbonate in the Cason.

Many if not all of the deposits of commercial interest in the topmost beds of the Fernvale appear, however, to have been formed after the deposition of the Cason shale and the Boone chert, which overlie the Fernvale in different parts of the region. This hypothesis seems to be supported by the argument that the localization of most of the bodies in the topmost coarse-grained beds of the Fernvale limestone was, it is believed, determined either by the shale capping (Cason shale) in the areas where the Cason rests upon the Fernvale or by a shale and compact limestone at the base of the Boone chert in the areas where the Boone rests directly on the Fernvale. The localization also may possibly have been influenced by increased porosity of the top of the Fernvale during its exposure on a land surface prior to the deposition of the Cason. Such an increase in porosity would have facilitated the circulation of manganese solutions, and the shale and compact limestone above the Fernvale would have served as a relatively impervious capping to confine the circulation of such solutions to the Fernvale. To account for the concentration of manganese in the carbonate-hausmannite bodies, it seems necessary to assume the circulation of water laterally in the Fernvale over rather large areas. The source and causes of such a circulation are obscure. From what is known of the origin of ore deposits elsewhere in the United States that contain a similar assemblage of minerals—hausmannite, bementite, neotocite, and manganese carbonate—it would seem that the water would have had to be warm rather than cold. The source of the heat for the warm water may have been related to concealed igneous rocks or to high temperatures arising from a former possible thick cover of sedimentary rocks during Pennsylvanian time. There are, however, no known exposed igneous rocks in the Batesville district, and the nearest known igneous rocks that are younger than the manganese-bearing rocks are the nephelite syenites and related rocks of Cretaceous age in central and southwestern Arkansas. The most recent study of the zinc and lead deposits that occur in northern Arkansas outside but near the Batesville district has led McKnight[17] to conclude that the zinc and lead ore solutions were, in part at least, derived from igneous sources.

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[17] McKnight, E. T., Zinc and lead deposits of northern Arkansas: U. S. Geol. Survey Bull. 853, pp. 138–150, 1935.

DISCOVERY OF CARBONATE ORE AND ITS COMMERCIAL USES

At the time of the detailed investigation by Penrose[18] mining in the Batesville district had been devoted entirely to the types of manganese oxide deposits that are found in the residual clays of the limestones and shales. Accordingly, none of the carbonate-bearing deposits appear to have been prospected up to that time, though Penrose suspected the presence of manganese carbonate as an original source for the oxide ores. During the World War and the attendant period of high prices for manganese ore, prospecting and even mining included the quarrying on a small scale of the solid unweathered manganese-bearing rocks, the Fernvale limestone and Cason shale. Manganese carbonate minerals were thus revealed, and a small quantity of carbonate-bearing ore was shipped.[19] This ore was known as "ledge ore." It consisted mostly of oxides and was freed as far as possible from the associated rock, for the opinion was held by the mine operators that oxide ore would be reduced too much in manganese content if it were shipped with an admixture of country rock. Accordingly, ore consisting of masses of manganese oxide ore with such rock adhering to them was considered to be worthless.

Subsequent to the war, a considerable quantity of low-grade "ledge ore" containing both oxides and carbonate was mined at a few places, especially the Club House and Manganese Cave mines. The practice was, however, continued of obtaining and shipping salable manganese ore that was freed so far as practicable from the associated country rock. The first specimens, weighing a few pounds each, of rhodochrosite were found in 1924 by R. S. Handford, who submitted them to the United States Geological Survey for identification.

The existence of the carbonate ore in commercial quantity was first determined in 1928 by Reed Denison and J. S. Baker, superintendents for W. H. Denison, ore buyer and operator, when a gray carbonate that appeared to be limestone was analyzed and found to have a high manganese content. Their attention was attracted to it by its weight and by the black color that appeared in a short time when freshly broken surfaces were exposed to the weather.

The first shipment of manganese carbonate from the Batesville district was made in May 1928. It consisted of one carload, half of which was carbonate ore and the other half oxide ore, from the Club House mine. The carbonate ore, consisting of a mixture of the gray and brown varieties, was loaded in the car separately from the oxide ore. An analysis of a sample of the gray carbonate showed the pres-

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

[19] Miser, H. D., Deposits of manganese ore in the Batesville district, Arkansas: U. S. Geol. Survey Bull. 734, pp. 59–61, 1922.

ence of 38 percent of manganese, and that of the brown variety 22 percent. The carload lot was found on analysis by the purchasing company to contain 31.56 percent of manganese, 2.12 percent of water, 5.14 percent of iron, 2.41 percent of silica, and 1.15 percent of alumina. The remainder consisted essentially of lime and carbon dioxide. Because of the low content of moisture, silica, and alumina and the high content of lime, a market immediately became available for Arkansas carbonate ore for use in the making of high-manganese pig iron, for which it is stated to be excellent.

The oxide ores from the Batesville district have been used for making ferromanganese, spiegeleisen, and high-manganese pig iron.

ECONOMIC POSSIBILITIES

The output of manganese ore from the Batesville district from 1849 to 1938, inclusive, was 140,277 long tons, and that of ferruginous manganese ore for the same period was 160,804 tons. Mining in the district was especially active during the World War, when the restriction of imports of foreign ores caused high prices for domestic ores.

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 at that time he conservatively estimated that "the deposits of the region perhaps include at least 250,000 tons of available ore containing 40 percent or more manganese."[20] This estimate included only oxide ore; it included no manganese ore in the carbonate form. It was based on such factors as (1) the geologic information then available concerning the deposits, (2) mining costs and methods employed at that time, and (3) the prices then paid for manganese ores.

The low-grade oxide ore of the district was estimated by the writer in 1918 at "170,000 tons of available ore containing less than 40 percent of manganese." It was recognized then, as now, that the amount of low-grade oxide material in the district, not now economically recoverable, is really many times this estimate. The recovery and sale of such low-grade ore are naturally controlled by the cost of its mining and preparation for the market, by its usual high percentages of silica and moisture, and by the limited market for it.

The mining of oxide-ore deposits in the region since the World War has shown extensions of many deposits that were known in 1918 and has also revealed some new deposits that were not then known. This mining has not only resulted in the continued production of ore but has brought to light additional reserves of oxide ore whose quantity has exceeded the total production of the district since 1918. The

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[20] U. S. Geol. Survey Press Bull., September 1918.

oldest mines of the district, among them the Southern and Woodpecker Hollow, are still producers of manganese ore.

The deposits that have been developed and have produced manganese ore in commercial quantity lie in an irregular belt from 4 to 8 miles wide and about 24 miles long, extending in an east-west direction across Independence County and the adjacent portions of Stone and Izard Counties. Guion is at the west end of the belt, Cave City and Mount Pleasant are on its north border, and Pfeiffer, Cushman, and Walls Ferry are on its south border. In this belt the Fernvale limestone is apparently thicker, and the Cason shale is present in larger areas than elsewhere in the southern part of the Ozark region. Manganese ore is not present everywhere in this belt, either in these formations themselves or in their residual clays. The manganese carbonate deposits are widespread in the belt and extend from a point near its east end to its west end, but they are confined to the southern part of the belt, where the carbonate-bearing rocks, the Fernvale limestone and Cason shale, have been least subjected to weathering. It is only in areas where this shale and the topmost portion of the Fernvale have not been weathered that carbonate deposits with varying proportions of hausmannite may be expected.

The Fernvale and the Cason have a general southerly dip, and in this direction they pass beneath younger formations of Silurian, Devonian, and Carboniferous age, none of which contain manganese ores. Lenticular bodies of carbonate and hausmannite, like those explored from 1928 to the present time, are doubtless numerous in the Batesville district and will be discovered and developed from time to time as conditions affecting the manganese industry of the district permit. Search for carbonate-hausmannite bodies is most likely to succeed in the many localities of the district where there are minable quantities of oxide ore, for such ore, if it contains hausmannite, is derived from the weathering of carbonate-hausmannite bodies. Also, synclines appear to be favorable for the occurrence of such bodies, because many of the larger deposits of oxides of the district are found in synclines. The location of such synclines will, for the most part, require very detailed geologic work based partly on drilling.

The portion of the district in which the carbonate-hausmannite deposits may be sought lies in general south of the irregular east-west belt that contains the well-known oxide deposits in the residual clays, but some isolated areas lie within the belt of oxide deposits. The total extent in square miles of the portions of the district in which carbonate-hausmannite deposits are to be expected may equal that of the belt containing the oxides. If this is true, it follows that the aggregate size of such carbonate-hausmannite bodies, expressed in tons, would perhaps equal the aggregate quantity of oxide minerals in the residual clays. Thus far the tunneling and drilling for such bodies have been too slight to permit an estimate by tons of the different grades of manganese ore that could be produced from the carbonate-hausmannite bodies. It is noteworthy that the experience so far in mining such bodies indicates that for every ton of ore containing 40 percent or more of manganese there is about 10 tons of manganese-bearing limestone that contains between 18 to 40 percent of manganese. Naturally the future output of carbonate-hausmannite ore will be determined by the size and extent of the ore bodies, the character of the ore, the cost of mining and marketing, and the demand for such ore. The Batesville district will, however, doubtless continue to produce both oxide ore and carbonate ore under normal conditions in the future, as it has in the past.

MINES AND PROSPECTS CONTAINING MANGANESE CARBONATES

OZARK MINE

Several groups of openings on the Ozark property, owned by the American Ore Corporation, in sec. 11, T. 14 N., R. 6 W., 3½ miles north of Pfeiffer, have yielded high-grade oxide ore. Of these groups the North Line opening and the Cricket tunnel have, in addition, yielded carbonate ore.

The North Line opening is in the SE¼NW¼ sec. 11, in the head of a steep-sided hollow that drains north and is near the north line of the property. It has been visited three times by the writer, in 1924, 1935, and 1939.

The Boone chert caps the east-west ridge just south of the North Line opening, and chert fragments derived from it strew the hill slopes of the vicinity. The workings, which are pits and tunnels, reveal horselike masses of Fernvale limestone and overlying beds of Boone chert that have been bent during their settling from their original position on the hillside. The limestone and chert are separated by clay that is residual from the solution of the Fernvale limestone. From this clay, within an area measuring 75 by 150 feet, the Ozark Manganese Co. mined and shipped, in 1918, about 5 carloads of high-grade oxide ore. Mining operations by W. H. Denison in 1934 and 1935 yielded 148 tons of inter-mixed carbonate and oxide ore, whose average manganese content was about 47 percent. The carbonate-oxide ore that was mined and shipped in those years is said to have been obtained from the upper 5 or 6 feet of the Fernvale limestone.

In 1939 the face of a small cut in which work was being done by Mr. Denison revealed the top 7 feet of the Fernvale limestone and also the overlying limestone that here forms the basal part of the Boone chert. A horizontal body, 24 to 27 inches thick, composed mainly of brown and pink carbonates of manganese and some hausmannite, lies in the topmost beds of the Fernvale. The 5 feet of limestone underneath this body is brownish red from the presence of disseminated manganese carbonate. The average manganese content of the 7-foot face, thus exposed in the cut, is reported to be 17 percent. The Josh Williams tunnel, about 50 feet west of the above-described cut, was driven in a southwesterly direction into the hill for a distance of 40 feet. At its end it exposes the topmost 4 feet of the Fernvale limestone and also the overlying limestone at the base of the Boone chert. The 4 feet of Fernvale limestone in the tunnel is brown from the presence of disseminated manganese carbonate and is reported to contain less than 10 percent of manganese.

The ore at the North Line opening is composed of several intermixed manganese minerals, which occur in diverse proportions. As it contains fossils that are characteristic of the Fernvale limestone, it is obvious that the manganese minerals have replaced the limestone. The chief manganese oxide is hausmannite; psilomelane appears to be confined to the parts of the deposit that are free from carbonate or to the parts of the carbonate-bearing rock that have been exposed to the action of ground water. The manganese carbonates include rhodochrosite and the white, gray, red, and black varieties, and there is some calcite. A few veins, as much as 3 inches thick, show a banded arrangement of calcite and manganese carbonate. Dense hard hematite and white barite occur sparingly in the bodies of hausmannite and manganese carbonates.

The Cricket tunnel was driven in 1936 by Amos Palmer for W. H. Denison in the head of a northward-draining hollow a quarter of a mile west of the North Line opening and about 200 yards south of the north boundary of the Ozark property. It was driven in a southwesterly direction in chert debris and clay, and the Fernvale limestone was encountered at a few places in the floor. The clay is residual from the limestone, but the chert fragments were derived from the Boone chert that caps the ridge to the south. In driving the tunnel 3 tons of oxide ore (psilomelane) in the form of boulders weighing as much as 300 pounds was obtained, but in addition it is stated that some manganese carbonate was found near the end of the tunnel, and a mass of gray manganese carbonate about a foot square was observed near the entrance.

Fragments of brown manganese carbonate were noted on the dumps adjacent to several shafts at other groups of workings—the No. 2 mine, in the S½NW¼ sec. 11, T. 14 N., R. 6 W., and the No. 1½ mine, in the SE¼NW¼ sec. 11. These fragments were brought to the surface in the course of the mining of the residual high-grade oxide ores.

SEARCY PROSPECT

The Searcy prospect, which is on land owned by Columbus Searcy, is on a steep north hill slope in the N½NW¼ sec. 11, T. 14 N., R. 6 W., about 4 miles north of Pfeiffer. It is about one-eighth of a mile northwest of the North Line opening of the Ozark mine. The prospect at this locality consists of an open cut which was made 2 or 3 years prior to the time of visit (Oct. 24, 1939). The cut extends into the hill for a distance of 10 feet and reveals in its face, which is 20 feet long, the lower few feet of the Boone chert and below it the topmost part of the Fernvale limestone. As shown in the cut, a brown carbonate of manganese has largely replaced the upper beds of the Fernvale through a vertical range of 4½ feet and for the full distance along the face of the cut. This 4½-foot manganese-bearing zone, according to samples that have been obtained from it, is said to contain 15 percent of manganese.

SEARCY CAVE HILL PROSPECT

The Searcy Cave Hill prospect, which is on land belonging to the N. A. Adler estate, is about 100 yards north of the Searcy Cave, in the SW¼ sec. 11, T. 14 N., R. 6 W., 3 miles north-northwest of Pfeiffer. A very small amount of work was done here in 1939 by Dave and Ad Dunegan, and 2 tons of manganese ore said to contain 15.80 percent of manganese was marketed. The openings are small pits, alined in a northwest direction through a distance of 100 feet, on a southwest hill slope. They have been made in a manganese-bearing zone at the contact of the Fernvale and St. Clair limestones, which crop out on the slope. These limestones at and near the openings dip toward the northeast, at angles that increase from 10° to 40° as the beds are followed toward the southeast. The manganese-bearing zone along the contact of the two limestones as revealed in the pits attains a thickness of 3 feet, though the full thickness at some places exceeds this amount, for its base is not exposed in all the pits. The zone lies chiefly in the topmost beds of the Fernvale limestone, but at one place it extends upward 1 foot into the St. Clair limestone. The upper surface of the portion of the zone in the St. Clair displays rounded forms. The manganese-bearing parts of these two limestones, from which the marketed ore was obtained, are mottled and contain brown manganese carbonate, hausmannite, specular hematite, rhodochrosite, and calcite.

A small outcrop of the St. Clair limestone about 100 yards northwest of the pits displays rounded areas of brown manganese carbonate like those in one of the pits. This is an isolated exposure, and the topmost portion of the Fernvale, which may here contain manganese carbonates and oxides, is not exposed.

SILBERSTEIN PROSPECT

Although an opening on the east side of Davis Hill, which is southeast of Searcy Spring and 3 miles north-northwest of Pfeiffer, is reported to show the presence of manganese carbonate in the Fernvale limestone, little or no mining has been done at this locality. The opening is on property that is owned by E. A. Silberstein.

WALTER CHINN PROSPECT

The Walter Chinn prospect is half a mile east of Chinn Spring and 2½ miles west-northwest of Pfeiffer, on land belonging to the N. A. Adler estate in the SW¼NW¼ sec. 22, T. 14 N., R. 6 W. A northwestward-trending cut 60 feet long and a few feet deep is on the southwest side of a small hollow one-eighth of a mile south of Cave Creek and 140 feet above the creek. It has been blasted in horizontal rocks, of which the following section was measured in 1918 soon after the cut had been made:

Section in cut of Walter Chinn prospect

	Feet
Boone chert:	
Massive chert interbedded with a small quantity of clay	6
Red clay, containing a few chert layers	1½–2½
Hard, compact greenish-gray limestone	Few inches–2½
Weathered shale; contains nodules that appear to be phosphatic	Few inches
Fernvale limestone: Cross-bedded gray limestone; contains very small pockets and lenses of manganese oxide near the top; at the northwest end of the cut the limestone is red and contains red iron oxide and hausmannite and thin veins of calcite	4

Rhodochrosite and the gray and red varieties of manganese carbonate are present here in the Fernvale limestone, and fragments of them lying on the surface from 1918 to 1931, the two dates of visit by the writer, had become blackened from the oxidation of the carbonates. When broken the fragments showed the fresh carbonates underneath the surface film of oxide and calcite distributed irregularly through dark-gray limestone. An analysis (No. 3, p. 13) of a sample of the gray carbonate shows the presence of 32.6 percent of manganese.

Almost a carload of manganese ore was obtained at this locality during the World War. Apparently it was mostly hausmannite, which was blasted away from solid rock and freed so far as possible from the associated limestone and manganese carbonates. After this ore was mined the manganese content of the remaining material was too low to justify further mining.

ADLER PROSPECTS

Two prospects from which manganese carbonate has been recovered are on property of the N. A. Adler estate, in secs. 16 and 21, T. 14 N., R. 6 W.

The prospect in sec. 21 is in the northern part of the section, on the west side of Sawmill Hollow, 3 miles west-northwest of Pfeiffer. It is on the south point of a hill which is west of the W. A. Chinn mine. Development work was done here in 1934 by W. H. Denison, and one carload of ore containing 32 percent of manganese was shipped. The prospect is a cut 35 feet long that runs in a northeasterly direction, following the contact between the Boone chert and the Fernvale limestone, both of which lie horizontal. The following section was measured in the face of the cut at the time of visit in 1935:

Section at Adler prospect in sec. 21

	Ft.	*in.*
Boone chert:		
Chert.		
Gray limestone	2	8
Green shale		5
Fernvale limestone: Reddish-brown rock, which is limestone largely replaced by manganese carbonate. Exposed to the floor of the cut, which is formed by "gray rock" (Fernvale limestone comparatively free from manganese minerals)	2	4

The ore body at the top of the Fernvale limestone is revealed for the full length of the cut and thus lies horizontal and parallel with the bedding of this limestone and the overlying chert. The manganese minerals include hausmannite, rhodochrosite, red carbonate, and also a manganese silicate.

The Adler prospect in sec. 16 is on the north point of a hill in the N½SW¼ of the section. Some work was done here in 1937 by Jess Harkelroad, who recovered and marketed from a small pit 10 tons of carbonate ore that contained 22 percent of manganese. The pit was made in the upper few feet of the horizontal Fernvale, and its face shows 4 feet of St. Clair limestone above the Fernvale and then 4 to 5 feet of limestone that appears to be the basal bed of the Boone chert. The topmost 2½ feet of the Fernvale contains brown and red carbonates of manganese. No manganese oxides were noted.

An opening said to show manganese carbonate lies in the southeast corner of sec. 16, T. 14 N., R. 6 W., on the property of the N. A. Adler estate. A specimen of a pink carbonate, shown to the writer in 1935, is reported to show a manganese content of 31.51 percent, but the opening was not visited.

W. A. CHINN MINE

The W. A. Chinn mine is on the W. A. Chinn tract, in Sawmill Hollow, on the north side of Cave Creek in the NE¼ sec. 21, T. 14 N., R. 6 W., 3 miles west-northwest of Pfeiffer. The mine was operated by S. W. Deener in 1915 and by W. H. Denison and N. A. Adler in 1916. The total production by these operators was 400 tons, but further work was done in 1927 and 1928, and some low-grade ore was marketed.

The mine consists of two open cuts, one south of the other. The south cut is on a steep slope on the east side of Sawmill Hollow and 60 feet above the bottom; it is a few feet deep and 125 feet long. It was blasted in beds which lie horizontal, and the following section was measured in 1918:

Section in south cut of W. A. Chinn mine

	Feet
Boone chert:	
Thick-bedded gray chert and cherty gray limestone	3
Fine-grained gray limestone; contains small nodules of phosphate rock	3
Platy red and green shale; contains soft dark-colored pebblelike masses which may be phosphatic	Few inches to 1
Fernvale limestone: Ferruginous and manganiferous fossiliferous limestone; red in some parts and dark gray in others. Calcareous oolites and pebbles occupy small fissures and pockets in the upper part of the limestone	7

When the cut was visited in 1931 the north end of the cut exposed a horizontal body of carbonate-oxide ore more than 3 or 4 inches thick at the top of the Fernvale limestone, and the south end exposed a similar body of ore ranging in thickness from a few inches to 2 feet. The ore consists of hausmannite, rhodochrosite, and white, brown, gray, and black varieties of manganese carbonate. Mixed with the ore are much calcite and some bementite and white barite. The hausmannite is irregularly distributed through the carbonate-bearing rock. The ore body represents a partial replacement of the top of the Fernvale limestone. (See pl. 5.) The portions of the limestone that contained the largest percentages of oxide-carbonate ore have been quarried and shipped. Analyses of three carload lots of manganese ore shipped from this mine are given on page 23. Analysis 3 is said to represent approximately the average composition of the marketed ore.

The north cut is on the south point of a hill on the east side of Sawmill Hollow, about 100 yards north of the south cut. The opening shows the bottom part of the Boone chert and the topmost part of the Fernvale limestone, both of which, here as at the south cut, lie horizontal. A lens of red manganese carbonate containing much hausmannite lies at the top of the Fernvale limestone and is exposed for the full length of the cut, a distance of 75 feet. At only one place is the full thickness of the body, 3½ feet, shown. The underlying ledge of gray rock is exposed here.

Fragments of ore lying on the mine dump in 1931 and 1935 were coated with a film of manganese oxide, but when broken they showed the manganese carbonates and associated hausmannite. It is reported that the carbonate-oxide ores at this locality contain as much as 27.90 percent of manganese, although analyses of picked specimens of hausmannite containing a little carbonate show as much as 55.29 percent.

Masses of dark brownish-gray oolitic limestone as much as 2 to 3 feet across are conspicuous features at this locality, especially because of the white roelike oolites in the dark calcareous matrix. The poor exposures do not show fully the relation of the oolitic limestone, but it appears that the limestone lies in pockets on the top of the Fernvale limestone or in solution cavities in the Fernvale. The matrix for the oolites is mottled green and brown and contains phosphatic shell fragments. Veinlets of brown manganese carbonate have penetrated and replaced both the oolites and the matrix.

SHELL-REITHER PROSPECT

The Shell-Reither prospect is in the S.½NW¼ sec. 21, T. 14 N., R. 6 W., on the west side of Sumac Hollow, 3½ miles west-northwest of Pfeiffer, on land owned by T. F. Shell and A. B. Reither.

A small amount of work has been done here. During the World War 20 tons of high-grade oxide ore was obtained from rock ledges, and in 1934, 10 tons of oxide-carbonate ore averaging about 40 percent of manganese was obtained by blasting the ore-bearing ledge.

The larger of the two openings at this locality is a small cut whose face shows the following sequence of horizontal rock strata:

Section in cut of Shell-Reither prospect

	Ft.	*in.*
Boone chert: Chert and shale	10	
St. Clair limestone: Gray limestone	1	4
Cason shale: Green shale		12–18
Fernvale limestone:		
Mottled green and pink limestone		9
Ledge composed of gray and red manganese carbonates and hausmannite in which there are veinlets and pockets of the white and pink (rhodochrosite) varieties of manganese carbonate		22–24
"Gray rock," containing no notable amount of manganese minerals, forms floor of cut.		

About 10 feet south of the cut described above a small pit reveals the top of a ledge of carbonate-oxide ore.

As shown in the two openings, the manganese ore occurs as a horizontal ledge that has been formed by the replacement of limestone near the top of the Fernvale limestone by manganese minerals. Hausmannite forms a considerable proportion of the ore. (See fig. 4.) Fragments of the carbonate-oxide ore mined in 1934 and left lying on the surface until April 1935 had become blackened from the formation of an oxide film. Only the fragments of carbonate containing the high percentages of manganese had thus changed their color in this short period of time. The fragments containing low manganese had changed color little, if any.

In 1931, at the time of the first visit by the writer to the locality, the larger opening showed masses of manganese oxides embedded in clay adjacent to and above the Fernvale limestone. The clay and also the oxide masses are a residue from the solution of the calcium carbonate of the limestone.

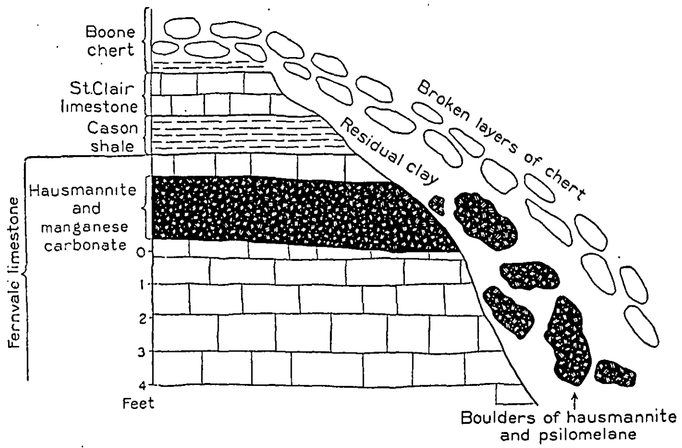


FIGURE 4.—Sketch at Shell-Reither prospect showing occurrence of horizontal hausmannite-carbonate ledge near top of Fernvale limestone and occurrence of oxide masses in residual clay.

RUTHERFORD MINE

The Rutherford mine, on property owned by Bill and M. A. Rutherford is 3 miles north of Batesville. It was operated in the late eighties or early nineties and again during the World War. The marketed ore included chiefly oxides, but one lot contained some intermixed carbonate and oxide.

The workings consist of four or more groups of shallow pits and cuts and a few short drifts. One of these on the south side of Rutherford Hollow, which is drained westward into Polk Bayou 1½ miles away, yielded carbonate ore. This group of openings is on a steep north slope in sec. 34, T. 14 N., R. 6 W., and is northwest of the Cason mine.

The hill is capped by the Boone chert, and the slopes are strewn with chert fragments. The small cuts on the lower slope disclose pinnacles of Fernvale limestone, and the oxide and carbonate ores were obtained from clay surrounding the pinnacles. The ores and the clays are residual from the limestone. At the time of the writer's last visit, in 1931, it was not clear whether the ore bodies formed masses irregularly distributed at different levels in the limestone, as at the Miller-Rinehart mine, or horizontal lenses at the top of the limestone, as at some of the other mines of the district.

Several tons of carbonate ore was observed on the mine dump in 1931. It contained psilomelane, hausmannite, rhodochrosite, some brown to red manganese silicate, and a little barite. These minerals are all intimately mixed, even in a hand specimen, and the marketed carbonate ore doubtless included much manganese oxide. One carload lot is said to have contained 20 to 25 percent of manganese.

CASON MINE

The Cason mine, on property belonging to the estate of Mrs. K. P. Gregory, is in the S½SW¼ sec. 34, T. 14 N., R. 6 W., 3 miles northeast of Batesville. The main productive period of the mine extended from 1904 to 1918, when about 61,000 tons of ore was shipped, in which the manganese content ranged from 11 to 25 percent and averaged about 20 percent. Some ore, probably not more than several hundred tons, was shipped about 1890, and some again in 1927 and 1928.

The Cason mine has yielded more low-grade manganese ore than any other mine in the district. Its ore body is of special interest because the manganese oxide disseminated through the Cason shale represents replacement and enrichment of manganese carbonate and because much of the marketed ore contained manganese both as oxide and as carbonate.

ROCK FORMATIONS

In the vicinity of the mine the rocks are well exposed and their distribution is shown on plate 7. The Cason shale, which contains the ore, is described below, under the heading "Occurrence and character of the ore."

The Fernvale limestone, which underlies the Cason shale, is a pinkish-gray or gray coarsely granular limestone and varies in thickness from 30 feet to more than 75 feet, in the vicinity of the mine.

The character of the lower part of the St. Clair limestone and of the underlying Cason shale in the north cut is shown in the following section, but it varies from place to place, owing in part to different stages of weathering and in part to original differences in the beds from place to place:

Section in north cut at Cason mine

	Feet
St. Clair limestone:	
Pinkish-gray granular fossiliferous limestone containing a few gray scattered pebblelike masses (*Girvanella*) about 1 inch in diameter. Dendrites are present on the surface of some of the numerous fossils	Several
Red limestone like that above, except that it contains a few "buttons" of manganese oxide in its lower, shaly part. This limestone is not a separate bed but is a colored phase of the limestone described above	1–3
Calcareous hard red shale; contains a few "buttons" of manganese oxide. Appears to grade into the overlying limestone bed; not mined	1¼
Cason shale: Red sandy shale; contains manganese oxide "buttons"; mined. Within 2 inches of its top there is a lenticular horizontal vein 1 inch thick and 2 feet long of white barite and rhodochrosite. The lowermost 1 or 2 feet of shale that rests upon the Fernvale limestone has not been mined because of its low manganese content or because of the absence of oxide "buttons"	7

The pebblelike *Girvanella* mentioned in the above section are a conspicuous feature of the lower several feet of the St. Clair limestone. (See pl. 6, *A*, and fig. 3.) They range from one-eighth of an inch to 1½ inches in diameter and show concentric banding. The centers of many contain angular fragments of gray earthy phosphatic material. The minerals in them are crystalline and, as may be inferred from the character of the specimens and the analyses given on page 28, contain a calcium, manganese, and magnesium carbonate. The Girvanellas also contain much pyrite as fine crystals and small irregular replacement masses. One pebblelike *Girvanella* has been replaced by crystalline barite. Galena occurs as minute quantities in some cavities left by the solution of the fossil *Girvanella* and as fine veins in the parts of the limestone that still contain *Girvanella.* The largest mass of galena found in quarrying the St. Clair limestone is reported to have been the size of a man's fist.

The rocks at the Cason mine lie horizontal or dip at low angles in the area shown on plate 7, but south of the mine they are broken by a normal fault with a north of east trend and a downthrow of perhaps 400 feet on its south side. (See fig. 5.) The surface rocks immediately south of the fault in this vicinity are the Moorefield shale and Batesville sandstone. Just north of the fault the rocks dip 15°–20° SE., toward the fault. In the mine the rocks lie in a shallow syncline whose axis trends northwestward. In the west cut, which is on the west side of the syncline, the St. Clair limestone and Cason shale dip 15°–20° NNE., into the hill; in the north cut, which is on the east side of the syncline, they dip at about the same angle to the southwest.

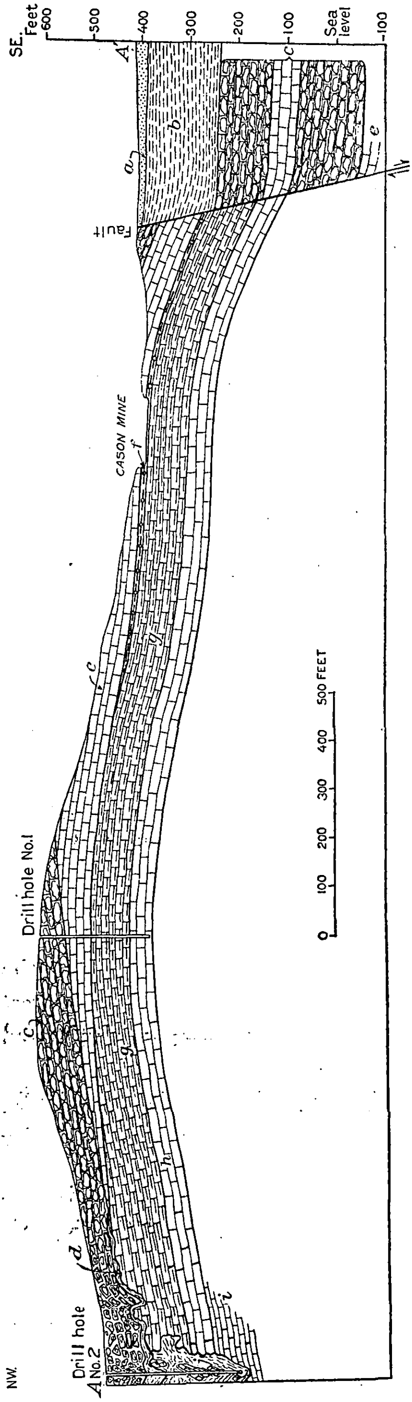


FIGURE 5.—Structure section through the Cason mine along line *A–A′* on plate 7. *a*, Batesville sandstone; *b*, Moorefield shale; *c*, Boone chert; *d*, Chattanooga shale; *e*, St. Clair limestone; *f*, Cason shale; *g*, Fernvale limestone; *h*, Kimmswick limestone; *i*, Plattin limestone; *j*, clay derived from weathering of limestones.

OCCURRENCE AND CHARACTER OF THE ORE

All the Cason shale at this locality contains some manganese, and half or more of it contains enough manganese to warrant mining and shipment from time to time.

The extent of the Cason shale was not definitely determined, as soil and rock fragments conceal it or its horizon at most places, but it probably thins out to the west, north, and east, as shown on the map (pl. 7), and it may extend southward to the fault, south of which the shale, if present, is possibly 400 feet below the surface. (See fig. 5.) The area underlain by the unmined shale is therefore comparatively small; it is at least 3 acres and may be 6 acres or more. The shale ranges in thickness from a feather edge to about 10 feet. The contact between the Cason shale and Fernvale limestone, as shown by exposures in the north cut, is irregular, so that an unconformity is indicated. (See fig. 3.)

The Cason shale is hard, platy, sandy, and slightly calcareous and ranges from its original color, greenish gray, through red to dark brown. The greenish-gray color is retained by as much as 3 feet of the top of the shale in the bottom of the syncline near the junction of the cuts. A conspicuous constituent of the shale consists of its "buttons," flattened pebblelike masses that lie parallel with the bedding and are more or less uniformly distributed through the shale in all parts of the mine. Most of the "buttons' are half an inch to an inch in their longer diameter and a quarter to half an inch thick. (See pl. 6, *B*, and fig. 3.) The colors of the "buttons," like those of the shale matrix, become darker near the outcrops. They range from gray through red and dark brown to black. A few of the "buttons" in the greenish-gray shale are gray, but parts of some are reddened. Other "buttons" in both the greenish-gray and red shales are red, and those in the dark-brown shale are dark brown to black, as they contain psilomelane.

The analyses on page 28 demonstrate that the manganese content and also the oxidation of both the shale matrix and the "buttons" increase as the ore is followed from the junction of the cuts—the deeper part of the mine—toward the outcrops. The analyses (Nos. 1 and 3) of the green shale matrix and red "buttons" show the presence of 5.87 and 5.85 percent of manganese, respectively, all of which is in the carbonate form.

Most of the marketed ore has consisted of dark-brown shale with dark-brown to black "buttons." The shale of this color, as shown by analysis 2 (p. 28), contains 6.1 percent of manganese, of which 3.9 percent is estimated to occur as carbonate. The dark-brown "buttons" (analysis 4) contain 26.9 percent of manganese, of which 14.2 percent is estimated to occur as carbonate. The black "buttons" (analysis 5) contain 50.41 percent of manganese all of which is oxide. The thickness of the dark-brown shale and its enclosed dark-brown to black "buttons" that contain enough manganese to be classed as ore is said to range from 3 to 8 feet and to average about 5 feet.

The mine has not been worked for many years, and the manganese-lime carbonate, as revealed in the walls of the quarry, has become black from the formation of a film of manganese oxide. This film has formed alike on the gray and red shale matrix and on the gray and red "buttons."

MINING

The Keystone Iron & Manganese Co., which first operated the mine, shipped the ore as it occurred in the surficial clay, but made an unsuccessful attempt to improve its quality by washing it. Much of the ore shipped by later operators was soft surficial material, which was shoveled into wagons without treatment and hauled to the railroad. The ore being mined at the time of the visit in 1918 was the hard, unaltered shale. It was simply quarried by blasting after the overburden of St. Clair limestone was removed. The limestone overburden was as much as 15 feet thick at some places, and its thickness will be found to increase as the ore bed is followed away from the outcrop.

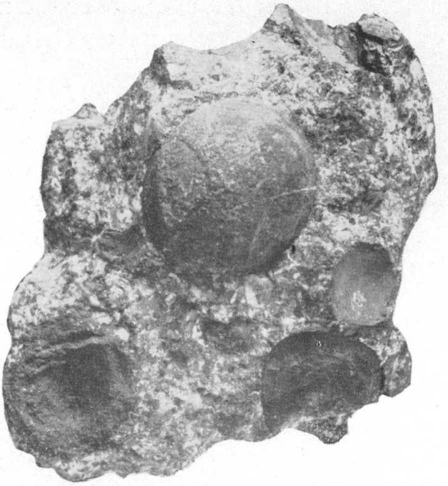
The ore that was marketed in 1927 and 1928 consisted of the oxide psilomelane, which was separated from the enclosing carbonate-bearing shale by treating the ore in a small mill equipped with roll crushers and jigs. It is reported that the manganese content of carload lots of this product ranged from 35 to 40 percent.

MILLER-RINEHART MINE

The Miller-Rinehart mine is near Blowing Cave, on Polk Bayou, 3½ miles north of Batesville. It is on a tract which comprises the SW¼SE¼ sec. 29 and the NW¼NE¼ sec. 32, T. 14 N., R. 6 W. In 1918, at the time of the writer's first visit, little mining had been done, and the property was described by him in Geological Survey Bulletin 734 under the heading "Weaver-Dowdy prospect." Since then much work has been done by L. B. Miller and W. G. Rinehart, who operated an experimental concentrating plant in 1927 and 1928 for the recovery of manganese ore in the manganese-bearing clays. The small amount of ore recovered in this plant and marketed consisted of oxides that occurred as fine particles disseminated through the chocolate-colored residual clay of the Fernvale limestone. In the course of mining operations on a steep west hill slope the surficial overburden of chert fragments derived from the Boone chert that caps the hill at this locality was stripped from this clay over an area of 1 to 2 acres, and then the clay was partly removed from above and around numerous large pinnacles of Fernvale limestone. (See pl. 8, B.)

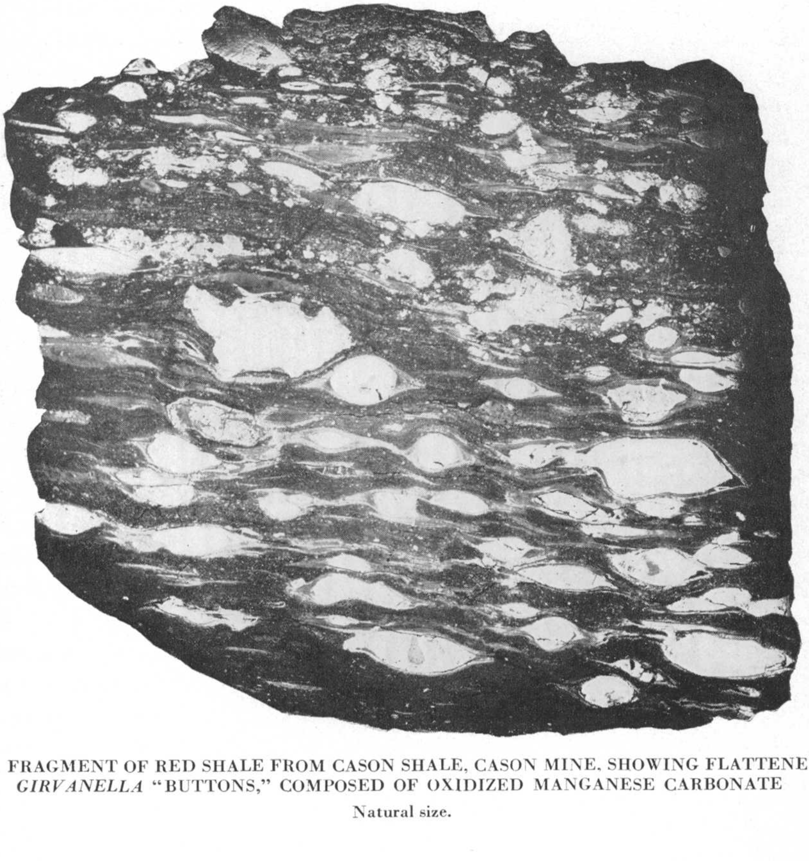
In the large open cuts the upper 40 to 50 feet of the Fernvale limestone, which is here between 80 and 100 feet thick, contains both large and small irregularly-shaped masses of manganese carbonate. The carbonate masses are irregularly spaced both horizontally and vertically, and some are as much as 2½ feet long and 1 foot thick. Their longer dimensions lie horizontal, parallel with the bedding of the limestone.

The gray variety of carbonate is the most abundant. It retains the texture of the Fernvale and contains the minute phosphatic shell fragments and small areas of reddish-brown earthy hematite observed in portions of the limestone. (See pl. 2.) Two samples of it contain 34.9 and 38.5 percent of manganese (analyses 1 and 2, p. 13). Rhodochrosite and white and red varieties of carbonate are also present. A little barite and some manganese silicate (bementite) were noted in the carbonate masses. Hausmannite was not observed in any of the carbonate masses, but as it was noted with psilomelane in some masses of oxide, it appears to have formed a part of some unweathered car-



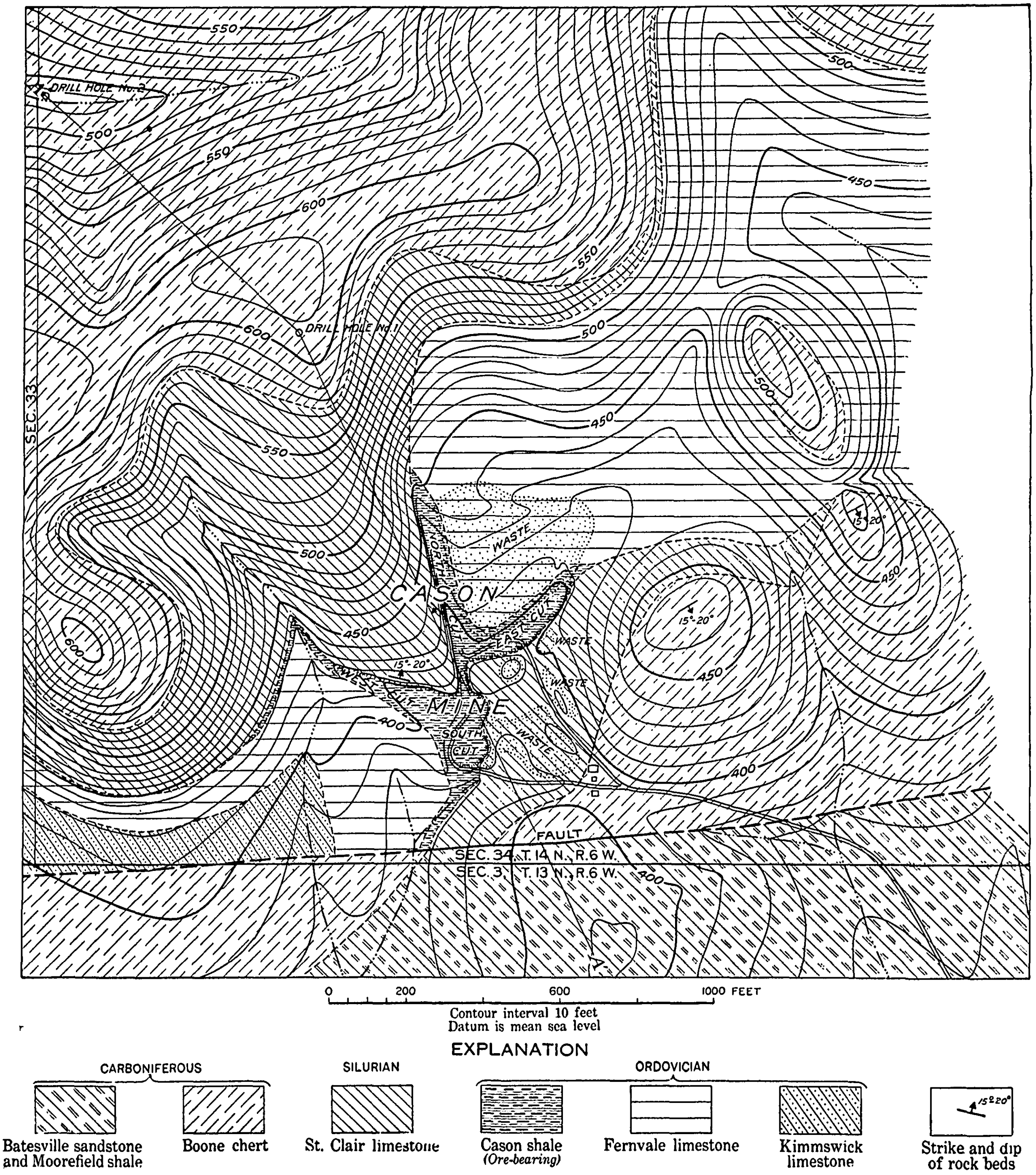
A. SPHERICAL GIRVANELLAS, COMPOSED OF MANGANIFEROUS CARBONATE, IN FRAGMENT OF LIMESTONE FROM LOWERMOST BED OF ST. CLAIR LIMESTONE, CASON MINE.

Natural size.



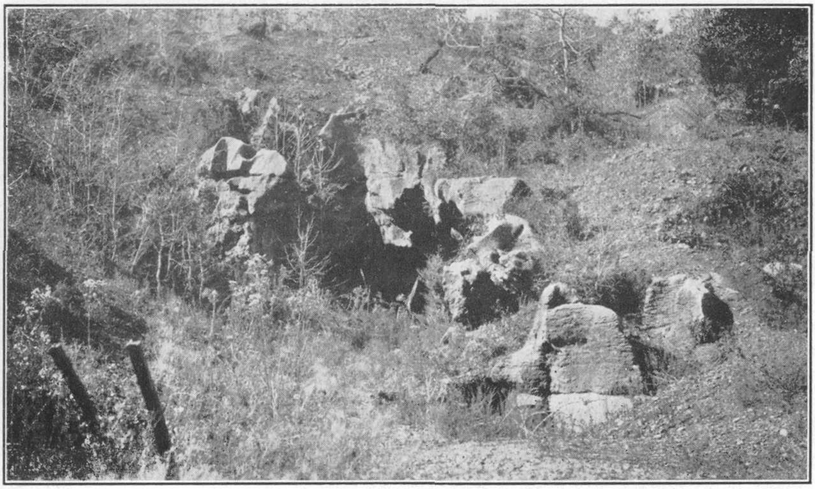
B. FRAGMENT OF RED SHALE FROM CASON SHALE, CASON MINE, SHOWING FLATTENED *GIRVANELLA* "BUTTONS," COMPOSED OF OXIDIZED MANGANESE CARBONATE

Natural size.

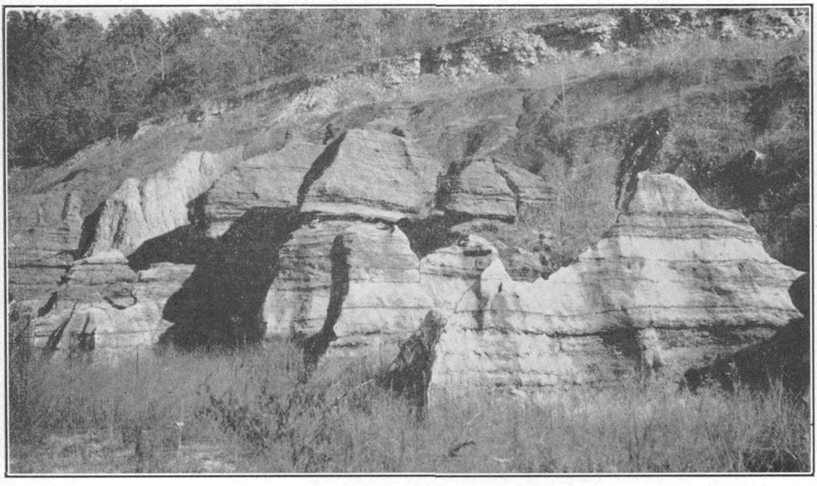


GEOLOGIC MAP OF CASON MINE.

Surveyed by H. D. Miser in 1918. *A–A'* is line of section in figure 5.



A. CLUB HOUSE MINE.



B. MILLER-RINEHART MINE.

Exposed surface of upper part of limestone has been darkened by the oxidation of disseminated manganese carbonate.

PINNACLES OF FERNVALE LIMESTONE THAT HAVE BEEN REVEALED BY THE REMOVAL OF RESIDUAL CLAY CONTAINING MASSES OF MANGANESE OXIDE.

bonate. The alteration of manganese carbonate to psilomelane is described below.

Although the observed carbonate masses are embedded in limestone, they are surrounded by a layer of psilomelane 1 to 2 inches thick. The psilomelane was obviously formed by the oxidation of the carbonates, and it will probably be found to decrease in amount away from the weathered surface of the limestone. When these carbonate masses are broken, a film of manganese oxide soon forms on the exposed surface, and a similar film also forms on the surface of the limestone immediately adjacent to the carbonate.

Besides the partly oxidized carbonate masses there are horizontal layers of oxide a fraction of an inch thick along the bedding planes and in cracks that are parallel with the solution channels in the limestone. These channels have been formed by the widening of cracks along vertical joints. The oxide layers and veinlets are remarkably displayed on the weathered surfaces of the limestone, and when they are broken so as to reveal the limestone as much as an inch away from the surface they are found to grade into a brown manganese carbonate.

Ferruginous manganese oxides are especially abundant in a reef or colony of massive bryozoans just north of the concentration plant. The reef is a horizontal lens that measures 25 feet long, 1 to 2 feet thick and more than 15 feet wide. The oxides occur as branching veinlike bodies penetrating in all directions not only the reef but the underlying limestones as far as 3 feet below it. When the limestone is broken away from the surficial weathered portions, the oxides are found to disappear and a brown manganese-bearing carbonate is revealed. The bryozoan portions of the limestone at other places in the mine contain more manganese and iron than are found in the immediately adjacent rock. These relations suggest that the reefs offered a favorable environment for the deposition of manganese and iron carbonates, whose concentration may have taken place at the time of deposition of the limestone or subsequently.

The manganese carbonate at the Miller-Rinehart mine is of special interest, for it occurs in masses, layers, and veinlets in different portions of the Fernvale limestone, and the inference seems reasonable that manganese carbonate is the source of psilomelane occurring in similar positions in the limestone at other mines in the district. Here the limestone, having been stripped of its overburden of chert and clay, is better exposed than elsewhere.

STARK SPRING MINE

The Stark Spring mine is on a small western tributary of Polk Bayou 4 miles north of Batesville. It includes two groups of workings. The group near Stark Spring, in the W½NW¼ sec. 29, T. 14

N., R. 6 W., was described as the Allen mine in Geological Survey Bulletin 734, and the group three-eighths of a mile northwest of the spring, in the NE¼ sec. 30, T. 14 N., R. 6 W., was described as the Roberts mine in the same report. The mining of oxide ore at these two localities has been carried on intermittently since 1889. A small amount of manganese carbonate was found in the course of mining operations about 1920 at the southern locality, as is shown by the occurrence of masses of manganese carbonate on the mine dumps, but the marketed ore, so far as known, consisted of oxides. At the northern group of workings about 40 tons of carbonate-oxide ore was mined and marketed in 1934 by W. H. Denison.

The southern group of workings, formerly designated the Allen mine, consists of shafts, pits, open cuts, and short tunnels that have been made here and there on the steep slopes on both sides of a southeastward-trending hollow for a distance of half a mile near Stark Spring and at different altitudes up to 120 feet above the spring branch. They penetrate the residual clay of the Fernvale limestone, exposures of which are found at many places on the slopes. This clay, which contains the masses of oxide ore, is red or chocolate colored and lies in pockets and channels in the limestone or surrounds limestone horses. The clay, in fact, forms a blanket of irregular thickness dipping at high to low angles and lying between the channeled limestone and an overburden of debris derived from the Boone chert. In the course of mining operations about 1920 on the hill east of the spring branch some oxide ore was recovered by blasting the irregular masses found in the Fernvale limestone. The caving and slumping between 1920 and the times of visits in 1924 and 1931 did not permit a determination of the relation of the manganese carbonate to the Fernvale limestone. Masses of oxides that had been partly removed by blasting were, however, observed at different levels in the limestone. The masses of both oxides and carbonates are similar to those so well displayed at the Miller-Rinehart mine. It is inferred that the manganese-carbonate found thus far near Stark Spring occurs as irregular bodies in the Fernvale limestone and that much of the oxide ore—the psilomelane—has been formed by the oxidation of the peripheral portions of the carbonate bodies.

At this locality oxide masses that range from fine particles to boulders weighing 8 tons have been disclosed by blasting. These masses are largely psilomelane that shows botryoidal surfaces and is made up of wavy thin layers—a type that has not been observed except where it is associated with the manganese carbonate from which it has been derived.

The northerly group of workings, formerly designated the Roberts mine, consists of pits and tunnels in a belt that extends 1,000 feet along both sides of a hollow, but most of them are on the southwest side, where carbonate-oxide ore has been mined. The major part of the output is oxide ore that consists of large and small masses of psilomelane, braunite, and some hausmannite that are irregularly distributed through the reddish-brown residual clay of the Fernvale limestone. The clay lies on the uneven surface of the limestone and is overlain by debris from the Boone chert. The tunnels on the southwest side of the hollow were driven into the hill near the top of the Fernvale limestone. Two of them, driven in 1934 by W. H. Denison, obtained carbonate-oxide ore. One of them, 30 feet long, is said to have encountered in the limestone a horizontal body, 2½ feet thick, of intermixed manganese carbonate and hausmannite. In a second tunnel, 80 feet away, the oxide boulders show cores of manganese carbonate. At the time of the writer's last visit (1935) the tunnels showing the carbonate-oxide ore were caved and could not be entered. Small specimens showing gray and brown varieties of carbonate and some hausmannite were found near their portals. The marketed carbonate-oxide ore is said to have had a manganese content of 38 percent.

CROSSER PROSPECT

The Crosser prospect is on land owned by Jess Crosser in the SE¼ sec. 19, T. 14 N., R. 6 W., half a mile north of Stark Spring. Some work was done here in 1936 and subsequently by E. A. Crosser, who marketed 3½ tons of oxide ore including 1 ton of the gray variety of manganese carbonate. The opening visited by the writer in 1939 is a drift 8 feet long on the east slope of a hill. After it passed through several feet of debris consisting of chert fragments it entered residual clay of the Fernvale limestone. This clay contained irregular fragments of manganese oxide that was recovered and included in the marketed ore from the prospect. Associated with the clay are ledges of the Fernvale limestone, some of which are brown. In the bottom of the drift the limestone contains rounded masses of gray manganese carbonate, one of which measured 16 by 10 inches. It is from such masses that the ton of carbonate ore from this locality was obtained. Both in their form and in their occurrence below the top of the limestone these masses resemble the manganese carbonate bodies in the upper half of the Fernvale limestone at the Miller-Rinehart mine, about 1½ miles southeast of the Crosser prospect.

CLUB HOUSE MINE

The Club House mine, which is owned by W. H. Denison, is in the E½NE¼ sec. 8, T. 14 N., R. 7 W., half a mile north of Cushman. It was first operated about 50 years ago by Skinner & Abbot. The next work was done in 1909 and 1910 by the Martin Manganese & Mining Co., and the next, for a period of several years, beginning in

1915, by the Independence Mining Co. In 1916 some work was done by Denison & Adler. Since the World War the operators have included R. S. Handford, W. L. Hogg, J. B. Jones, T. F. Shell, Denison & Peterson, and W. H. Denison. The production during and before the War was over 4,000 tons of manganese ore; from 1928 to 1935, inclusive, 5,485 tons; and for the few years prior to 1928, 1,500 tons. The total output of the mine through 1935, therefore, exceeds 11,000 tons. Before 1928 the shipments consisted entirely of oxides, but beginning in that year they have included oxides and carbonate.

Explorations for oxides include pits, open cuts, shafts, and tunnels at all altitudes on the east and north hill slopes and on the crest of the hill. They are partly in solid rock, but mainly in surficial clay and chert debris derived from the Boone chert, Cason shale, Fernvale limestone, and Kimmswick limestone, of which there are many exposures, both on the surface and in the workings. Explorations for carbonates consist of a network of tunnels and rooms in the Cason shale and topmost few feet of the Fernvale limestone, but much oxide ore free from carbonate was obtained in some portions of the ore deposit. (See pl. 9.)

A section of the rocks at this locality follows:

Section at Club House mine

	Feet
Boone chert: Massive and thin-bedded hard gray chert; the chert capping the crest of the hill has a thickness of	50
Cason shale: Sandy platy shale, shaly sandstone, and phosphate rock; when unweathered is mottled brown, yellow, and green and contains manganese carbonate and a little pyrite; when weathered is yellow to brown and contains horizontal seams of porous oxides of manganese and red and brown oxides of iron	4½
Fernvale limestone: Pinkish-gray granular cross-bedded limestone. The upper surface of the limestone is irregular. The uppermost part, 9 feet or less thick, contains minable quantities of manganese carbonates and oxides	95
Kimmswick limestone: Fine-grained, compact light-gray massive limestone to base of hill	Several

For many years the upper layer of the Fernvale limestone was the source of the manganese carbonate and oxide output of the mine. A red, coarsely granular manganiferous ferruginous carbonate, 3 to 30 inches thick, forms the basal portion of the Cason shale. This carbonate contains only 18 to 20 percent of manganese and is high in iron, so that it has not been the source of good ore. The ores in the Fernvale limestone form horizontal lenticular bodies lying under the Cason shale and have replaced the uppermost layer of the Fernvale limestone. (See fig. 6.)

The circulation of oxidizing ground water has produced several changes in both the ore bodies and the nearby rocks: (1) The manganese carbonates have been changed to oxides; (2) the color of the Cason shale has been changed from green to brown; (3) disseminated pyrite has been converted to iron oxides; (4) through the solution of the limestone residual clays have been formed through which masses of oxide ore are distributed; (5) channels and even caves of large and small size in the limestone have been formed, and into these the ore-bearing residual clays and the superjacent Cason shale and Boone chert have settled. (See fig. 6.)

The carbonates remain only in areas where the Cason shale and overlying Boone chert are horizontal and undisturbed. On the other hand, oxides, either with or without a small amount of carbonate, are found where the shale and chert have slumped as a result of the solution of the Fernvale limestone. The transition from carbonate areas to oxide areas is well illustrated at many places in the network of tunnels and rooms that explore the deposit.

In this mine the lenses of carbonate ore follow troughs between "horses" of "gray rock," which usually rise as much as 6 feet above the position of the rock nearby. The base of the carbonate lenses is therefore not a smooth plane but an undulating surface. In the por-

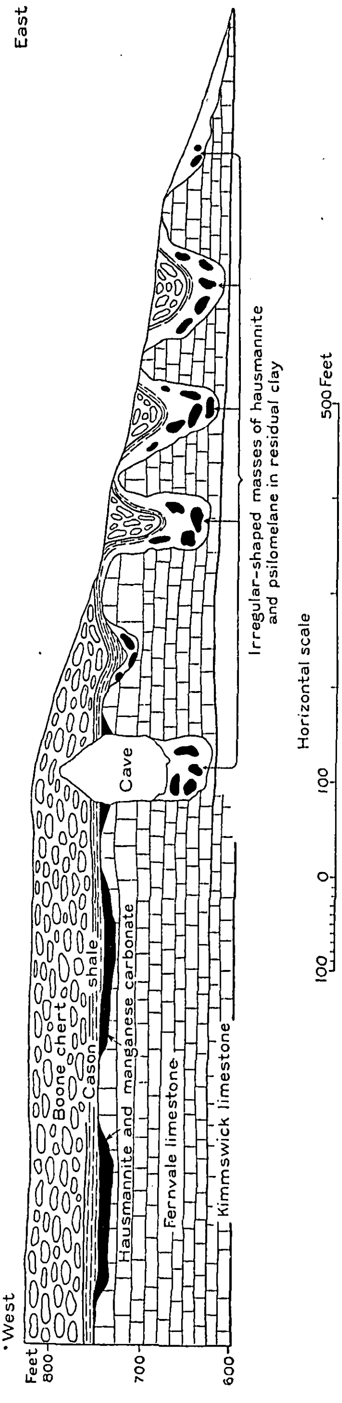


FIGURE 6.—Sketch section at Club House mine showing occurrence of lenticular ore bodies of hausmannite and manganese carbonate in Fernvale limestone and hausmannite-psilomelane masses in residual clay.

tions of the mine where the "horses" exceed this height, ground water has also deepened the troughs between them and changed much or all of the carbonate to the oxide form.

The carbonate lenses are separable into two horizontal layers, each of which, though distinct, lacks sharp boundaries. The upper layer contains the high-grade carbonate and attains a maximum thickness of 18 to 20 inches but averages 12 to 14 inches in a good workable face. It is composed largely of intimately mixed red and gray carbonates and much hausmannite, and the proportions differ from place to place. With these are associated crystal aggregates of barite, a little manganese silicate (bementite?), and veinlets of white carbonate and rhodochrosite. (See pl. 3, *A*.)

The lower layer of the carbonate lenses averages about 10 inches in thickness in much of the mine. It consists of manganese carbonates, a little hausmannite, and minute quantities of barite. The carbonates are more abundant here than in the upper layer, but the rhodochrosite is lighter in color than it is in the upper layer.

The rhodochrosite at the Club House mine was brought to the writer's attention in 1924, when R. S. Handford, the operator at that time, forwarded to him a specimen weighing several pounds. It forms minute veins and pockets as much as a foot across and a few inches thick and occurs in the top of the "gray rock" and in the overlying high-grade portion of the carbonate-oxide deposit but does not extend upward into the red carbonate layer 3 to 30 inches thick at the base of the Cason shale. Rhodochrosite forms only a small fraction of 1 percent of the output of carbonate ore. The manganese content of this mineral from the Club House mine was found on analysis (No. 4, p. 13) to be 33.8 percent.

The network of tunnels shows that the thickest parts of the lenses of carbonate follow irregular courses. Thicknesses as low as 6 inches of ore containing 45 percent of manganese are mined. Working faces commonly attain a height of 6 feet and rarely as much as 9 feet; average thicknesses in different parts of the mine are said to range from 2 to 4 feet. As shown in the network of tunnels the oxide ore varies greatly in thickness, ranging from a knife edge to 9 feet, and it forms a blanketlike deposit that lies in the troughs and spreads over the "horses" of the "gray rock," but it is thinnest over the "horses," where it measures only 1 to 8 inches in thickness. If a thin lens of oxide on a "horse" is followed, it may lead to a thick lens in a trough. The oxide is porous to compact; the softer, more porous portions contain much iron oxide, some in the form of earthy hematite. Calcite is found at a few places as veinlets in the oxides and as irregular masses enclosing the oxides.

The thickest lenses of carbonates and oxides have a general northeasterly trend. In 1936, all the minable ore from the known lenticular ore bodies at the top of the Fernvale limestone had been removed and some exploration was being conducted in an attempt to find additional bodies. From the network of tunnels in such bodies a total output of about 7,000 tons of oxide and carbonate ores was obtained through 1935.

The Fernvale limestone immediately underneath the carbonate bed is either gray or red. Apparently the red color is due to the presence of manganese carbonate and some hematite. It also contains veinlets of white and pinkish carbonates and some disseminated pyrite.

The color of much of the "gray rock" immediately underlying the areas of oxide ore is dark gray, owing to the presence of fine particles of manganese oxide disseminated through the rock. This manganese-bearing rock attains a thickness of 9 feet and, as shown by analyses, contains from 10 to 22 percent of manganese. This gray limestone was 8 feet thick in the face of a quarry from which Denison & Adler shipped 167 tons of material that contained 12 percent of manganese. In recent years much black manganese-bearing limestone was obtained during the mining of the carbonate and oxide ores in the drifts of the mine, and it is stated that 2,000 to 3,000 tons of such rock containing about 18 percent of manganese has been stored underground.

The manganese carbonates and oxides in the horizontal sheetlike ore body in the topmost part of the Fernvale limestone are the source of the irregular masses of oxides that are distributed through the residual clays and through the chert debris along the north and west hill slopes at the mine. The residual clays lie in large and small channels in the Fernvale and Kimmswick limestones; they overlie limestone pinnacles between the hollows; and they partly or entirely fill caves in these limestones. (See pl. 8*A* and fig. 6.) They are overlain on the hill slopes by different thicknesses of the Boone chert, either as loose fragments or as shattered, steeply dipping ledges that have settled down the slopes from their original position. One or more shafts on the top of the hill passed through 30 feet or more of the Boone chert and entered channels in the Fernvale limestone that were filled with ore-bearing clay. Shafts as much as 75 feet deep and tunnels and open cuts have been made in the ore-bearing clay on the slopes of the hill, and a cave partly filled with ore-bearing clay was followed by a tunnel for 200 feet. From the tunnel entering the cave about 4,000 tons of oxide ore is said to have been shipped. Ore-bearing clay has been mined in drifts under ledges of the Fernvale limestone near the mouth of the cave. Limestone pinnacles from around which the clay has been removed are excellently exposed in the open cuts. The channels between these pinnacles attain a width of 50 feet.

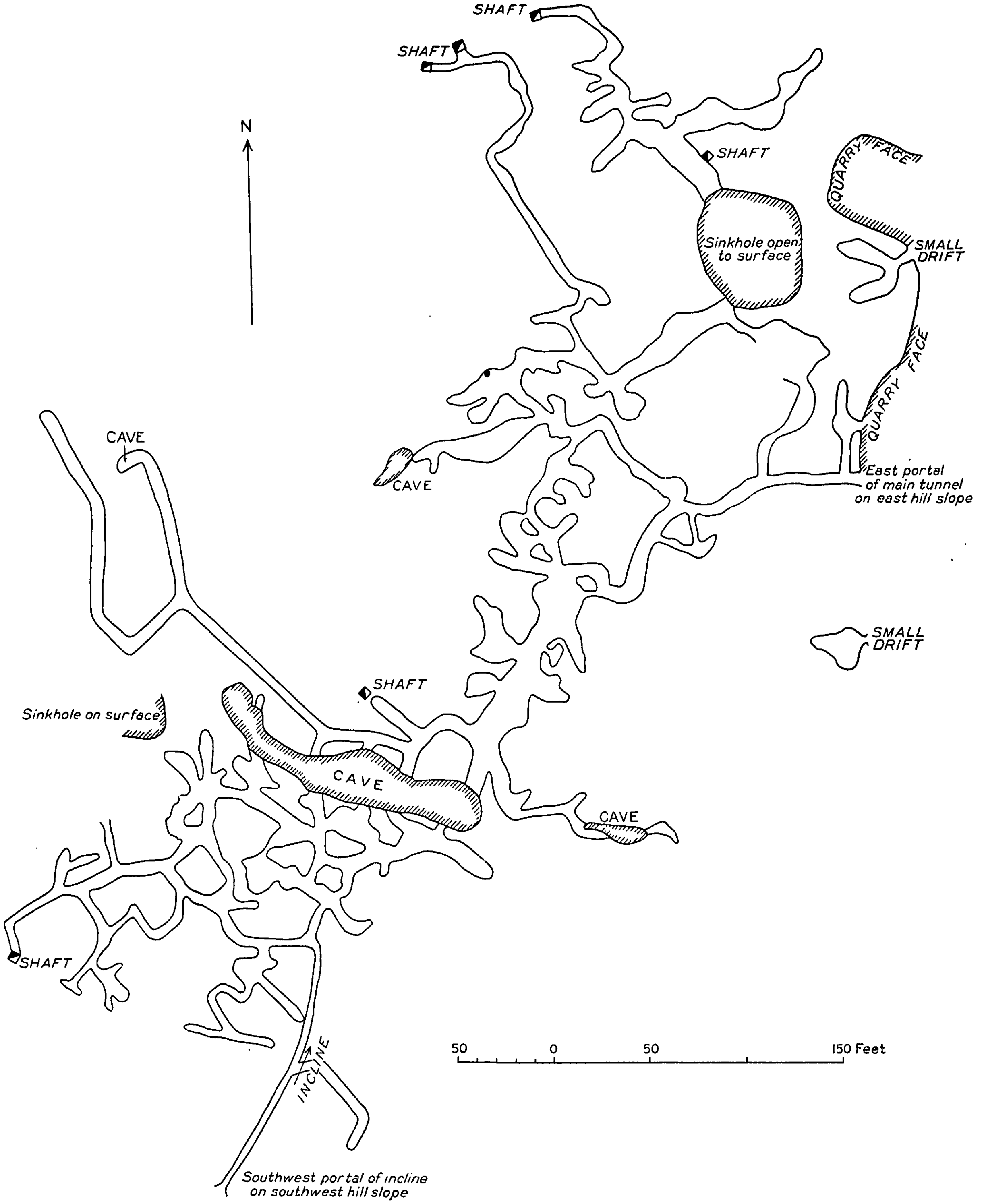
The manganese oxide ore that is free from the manganese carbonates is mainly psilomelane with minor quantities of hausmannite. It occurs in the above-described clays as irregular masses ranging in size from fine particles to large boulders. The largest boulder thus far found yielded 27 tons of ore.

The marketed oxide ores free from carbonate contain 45 to 58 percent of manganese; hausmannite and much gray carbonate contain about 45 percent of manganese; the shipments of intermixed oxides—chiefly psilomelane—and carbonates have an average manganese content of 37 to 38 percent.

CLUB HOUSE EXTENSION MINE

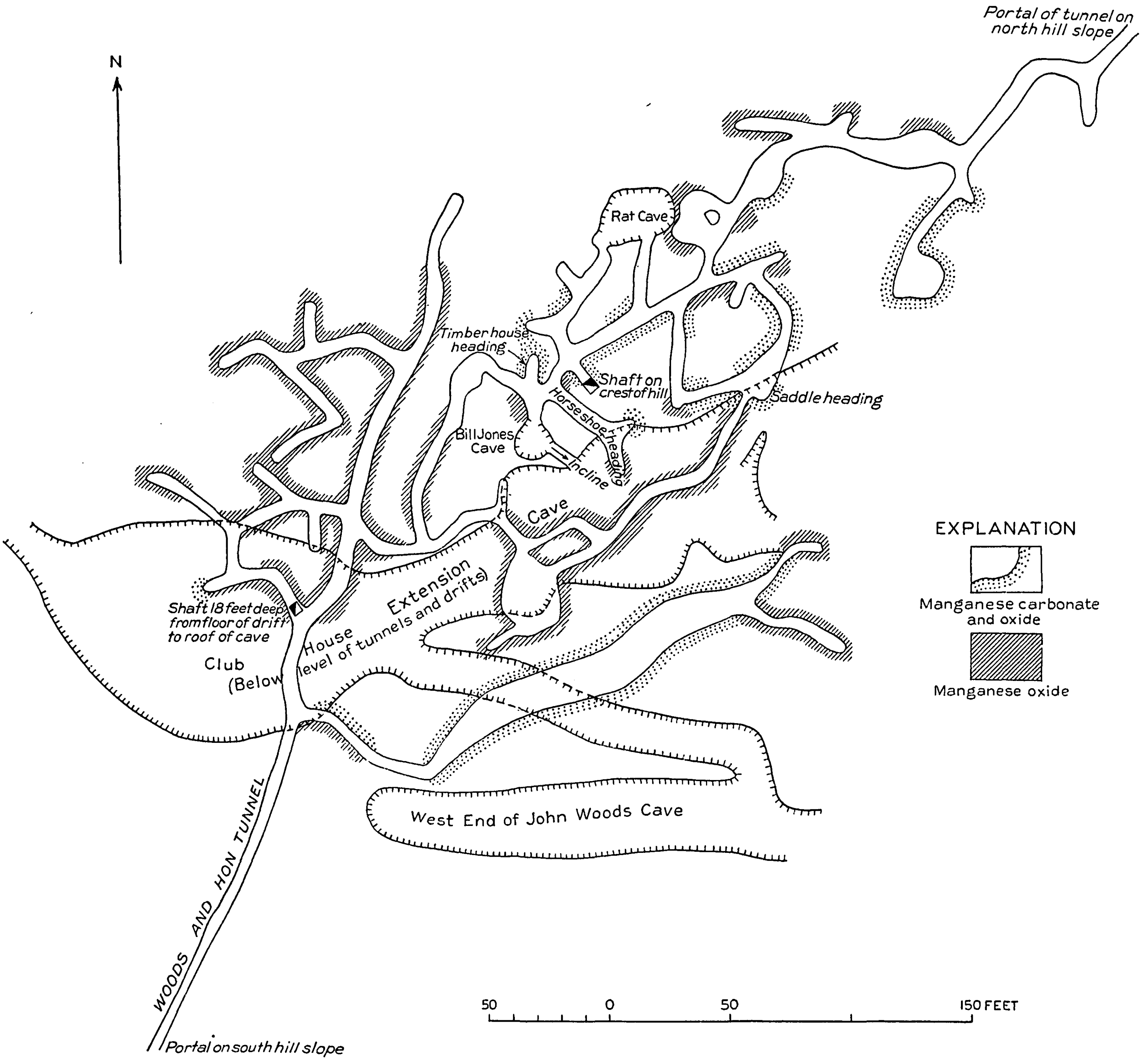
The Club House extension mine, also known as the New Club House mine, is on property owned and operated by W. H. Denison in sec. 8, T. 14 N., R. 7 W., half a mile north-northwest of Cushman. This property was first prospected by Mr. Denison in 1934, when some oxide ore containing 42 to 45 percent of manganese ore was obtained from the residual clays overlying the Fernvale limestone in half a dozen shallow shafts within a quarter of an acre on the north hill slope. Higher on the slope a small cut and an 80-foot tunnel 70 feet west of it were driven in the Cason shale and the topmost part of the Fernvale limestone. This tunnel and the other workings just mentioned lie across a hollow from and about 600 feet southwest of the Club House mine. In September 1935 an 80-foot shaft that revealed workable carbonate and oxide ores was sunk on the top of the hill 265 feet southwest of the portal of the tunnel. To facilitate bringing the ore to the surface, the tunnel on the north hill slope was then extended to connect with the drifts that had been run from the bottom of the shaft; and at a later time the Woods & Hon tunnel was driven in from the south side of the hill. The mine workings consist of crooked branching drifts whose courses were largely determined by the miners' policy of following the ore. The mine workings are shown on the accompanying map (pl. 10). The drifts entered two small caves, known as the Rat cave and the Bill Jones cave; and an incline descending about 20 feet from the Bill Jones cave entered a large cave (Club House Extension cave) in the Fernvale limestone. Much of the roof of this cave lies lower than the level of the drifts, and the Horseshoe and Saddle headings and parts of several drifts are above such portions of the cave, but other parts of the roof rise above the level of the workings.

The total production of the mine before the time of visit in November 1936 was a little more than 500 tons. The shipments consisted of intermixed oxides and carbonates of manganese and contained from 25 to 45 percent of manganese, but most of the marketed ore contained 30 to 35 percent of manganese. The shipments between November 1, 1936, and October 14, 1939, amounted to 397 tons of intermixed oxides and carbonates whose manganese content averaged



MAP OF CLUB HOUSE MINE SHOWING NETWORK OF TUNNELS AND ROOMS THAT HAVE EXPLORED CARBONATE-OXIDE BODIES AT TOP OF FERNVALE LIMESTONE.

Surveyed April 1, 1935, by Alvis Denison.



MAP OF CLUB HOUSE EXTENSION MINE SHOWING OCCURRENCE OF MANGANESE-OXIDE AND CARBONATE-OXIDE BODIES ALONG THE TUNNELS AND DRIFTS.

Plan of mine and associated caves as surveyed in November 1936 by Alvis Denison.

34 percent and 1,000 tons of oxide ore whose manganese content averaged 41 percent.

All the ore marketed from the mine except a small amount from the shafts on the north hill slope was obtained from the drifts shown on plate 10.

The rocks here include 80 feet of Boone chert, capping the hill; the Cason shale, lying below the Boone; and the Fernvale limestone, whose uppermost part contains the lenticular ore bodies. The rocks as well as the ore bodies lie nearly horizontal.

The Cason shale and the immediately underlying lenses of ore are followed by the drifts. The Cason shale, about 5 feet thick, consists mostly of brown shale and phosphate rock, which form the roof of the drifts; but underneath them there are a few inches to 3 feet of platy, earthy oxides of manganese and iron which constitute the lower part of the Cason shale. This part does not yield appreciable amounts of salable ore under present conditions, and most of it is therefore removed as waste in the course of mining.

The ore body, as thus far explored, trends in a southwesterly direction and attains a width of about 200 feet. The distribution of the minable ore is very irregular, because of its variability in character and in thickness, which ranges from a knife edge to 5 feet. The ore body has replaced the topmost beds of the Fernvale limestone, and its base is somewhat uneven, owing in part to the unevenness of the replacement and in part to the effects of ground water, which has dissolved channels in the top of the limestone. (See fig. 7.) The top of the limestone is thus uneven, and the relief is as much as 4 feet. The unreplaced limestone beneath the ore body is gray or reddish brown, but where the carbonate ore has been partially oxidized by the action of ground water, the limestone has become black from the presence of disseminated particles of manganese oxide. This black limestone is said to have an average thickness of 2 feet underneath the oxidized portions of the ore body and to have an average manganese content of 15 percent.

Where not affected by ground water the ore body consists mostly of the gray carbonate but partly of the red variety. Hausmannite is not present in all parts of the ore body; only at the Timber House heading is it the chief ore mineral. In fact, hausmannite forms a much smaller proportion of the ore in the Club House extension mine than it does in the nearby Club House mine.

Where most altered by ground water the ore lies in shallow channels in the top of the "gray rock." Here the carbonates and the hausmannite are partly or entirely changed to porous but hard psilomelane, which occurs in the form of irregular masses and layers. Many cores of unaltered carbonate are found in the psilomelane in the course of the mining. (See fig. 7.) More ore has been mined from the oxidized than from the unoxidized portions of the ore body, and its manganese content is higher. In the troughs the ore averages about 2 feet in thickness.

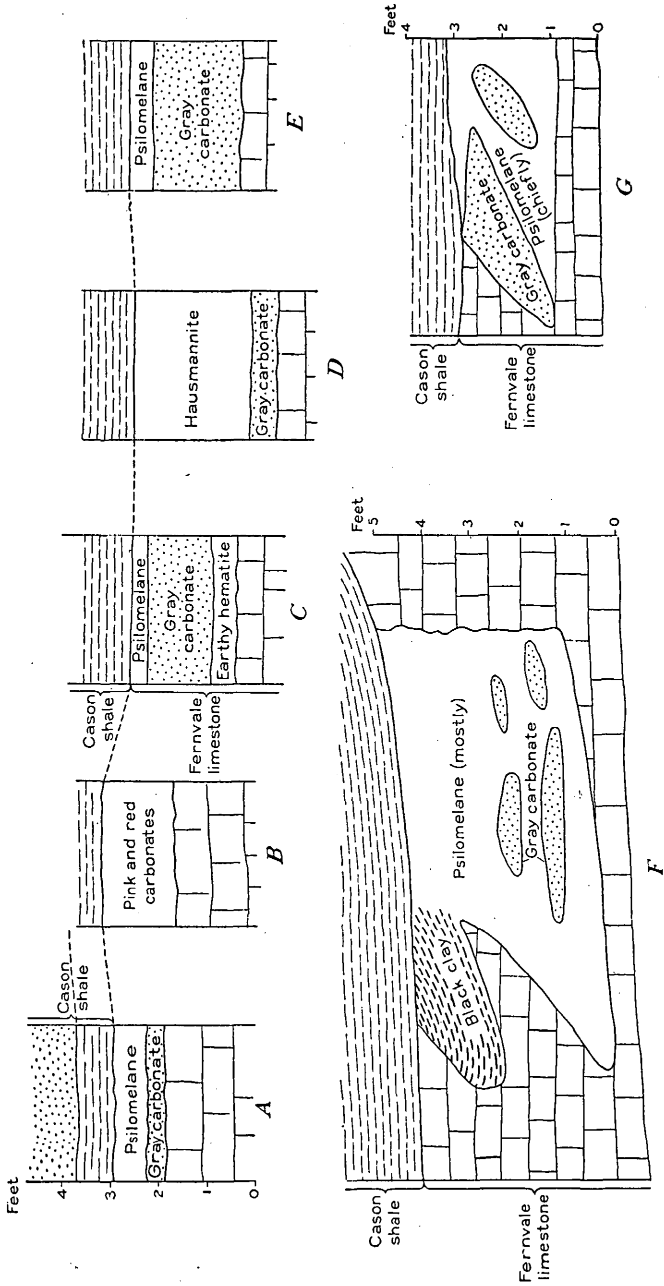


FIGURE 7.—Sketches at different places in Club House extension mine showing relations of manganese oxides and carbonates in top of Fernvale limestone. *A*, *C*, and *E*, Upper part of gray manganese carbonate has been changed to psilomelane; *B*, Manganese carbonates have not undergone oxidation; *D*, Hausmannite and gray manganese carbonate have not been changed by weathering; *F* and *G*, Psilomelane contains cores of unaltered gray manganese carbonate.

Near caves the oxide ore may be soft and granular, and the bodies are thinner. As these differences have been noted as far as 15 feet from a cave, miners are forewarned of its proximity. The soft ore adjacent to caves contains 25 percent of manganese, whereas nearby hard oxide ore contains as much as 45 percent. It thus appears that much manganese has been removed from the ore bodies by circulating ground water.

Although the ore lenses lie in a horizontal position they are not continuous for great distances and they are difficult to follow. This is due to the variability of the thickness of the ore within short distances, and the change from minable oxide ore to soft unminable ore at some places near the caves. In most places the lenses of the minable ore are so narrow that all the ore in a single lens is removed from a heading, and none is left on either side of the drift. Consequently, most of the minable ore encountered in the driving of the tunnels and drifts shown on plate 10 has been recovered. The discovery of additional bodies of commercial ore will require the extension of the drifts in the most promising places in the mine.

JOHN WOODS SHAFT

The John Woods shaft, on property owned by W. H. Denison, is on the crest of a ridge in the SE¼NE¼ sec. 8, T. 14 N., R. 7 W., half a mile northwest of Cushman. It lies 360 feet southeast of the shaft of the Club House extension mine, is 76 feet deep, and was sunk in the spring of 1936. From the bottom a drift was run west for a distance of 102 feet, where it ran into a large cave, the John Woods cave. A side drift 25 feet long was run north from the west end of the main drift.

The shaft was sunk through the Boone chert, then through the Cason shale, several feet thick, and into the Fernvale limestone. The drifts were horizontal in the uppermost beds of the limestone, and their roof is the phosphate rock of the Cason shale. Lying between the phosphate rock and the limestone is a bed of shaly and earthy oxides of iron and manganese as much as a few inches thick, which constitutes the basal bed of the Cason.

Little manganese ore was found in the workings, and no ore had been marketed before the time of visit (November 1936). Bodies of carbonate and oxide from 1 to 3 feet thick were found at four different places. Near the west end of the drift, and thus near the cave, ground water has affected the rocks by forming shallow solution channels in the top of the Fernvale limestone and by oxidizing the carbonates and other minerals. The Cason shale that forms the roof of the drift has thus settled to conform to the irregularities of the top surface of the limestone. Where the roof has been lowered as much as 2 feet, the "gray rock" has been darkened by disseminated manganese oxide to a depth of 20 inches; and in the topmost part of the "black rock" there are thin horizontal bodies of oxide ore (psilomelane and hausmannite).

The John Woods Cave has been formed in the Fernvale limestone, and manganese ore has been sought in it. The only manganese ore noted by the writer was about 600 feet west of the shaft, where by the solution and removal of the Fernvale limestone the Boone chert has settled down across the edges of the limestone. In passing through the chert and along its contact with the limestone ground water has deposited small quantities of wad and psilomelane.

MEEKER MINE

The Meeker mine is in sec. 8, T. 14 N., R. 7 W., half a mile west of Cushman on the south side of the head of the hollow in which Blowing Cave is situated. It has been worked intermittently since about 1890 and has yielded a small quantity of low-grade ferruginous manganese ore. In 1930 and 1934 W. H. Denison and Louis Peterson, the owners, shipped about 70 tons, a portion of which contained manganese carbonate.

The Meeker ore body forms a bed in the Cason shale and includes both oxide and carbonate of manganese. On the other hand, the tabular oxide-carbonate bodies of the Club House, Manganese Cave, Woodpecker Hollow, Pittman, and other mines of the district occur in the topmost beds of the Fernvale limestone.

The carbonate ore at the Meeker mine consists of red carbonate containing veinlets of white carbonate, rhodochrosite, and pyrite and disseminated phosphatic grains. The oxide ore is a soft, porous, platy material made up of ferruginous manganese oxides, among which is hematite.

The workings consist of short tunnels and small open cuts that have been made in the nearly flat-lying Cason shale. Because the ore bed is in the lower part of the shale, the openings are usually floored by the somewhat uneven upper surface of the Fernvale limestone. The Boone chert, which caps the hills in the vicinity, forms the hill slopes above the openings, and its basal beds are exposed at a few places.

Most of the mine openings were made in 1929, 1930, and 1934 by W. H. Denison and Louis Peterson. They are all briefly described below.

The westernmost tunnel, which was driven in 1929 and 1930, is known as the Carbonate tunnel. It runs west 75 feet into a hill slope on the west side of a short northward-drained hollow. It has two branches, one 25 feet long and the other 35 feet long, both of which run in a northerly direction. The ore bed as penetrated and followed by the tunnel averaged about 2 feet in thickness; at one place it reaches a thickness of 32 inches, of which 14 inches is brown manganese carbonate and the rest oxide with some brown carbonate and some shale. The carbonate contains minute bodies and veinlets of white carbonate and pyrite. The smallest observed thickness (1 foot) of the ore bed was immediately above a small limestone pinnacle that reached a height of 1 foot or more above the surrounding surface of the limestone. The following section, measured on the south side of the portal of the tunnel, shows the position of the ore bed in the Cason shale.

Section at portal of the Carbonate tunnel of Meeker mine

Cason shale:	*Ft.*	*in.*
Phosphate rock, top not fully exposed	4	
Red carbonate and some ferruginous maganese oxide		15–20
Fernvale limestone: The topmost 2 feet contains irregular pockets of brown manganese carbonate; only upper portion is exposed	5	

A sample of intermixed oxide and carbonate ore from the Carbonate tunnel is said to contain 36.90 percent of manganese and 0.48 percent of phosphorus. A sample of the red carbonate from this tunnel is reported to have yielded 25.90 percent of manganese.

On the east side of the short northward draining hollow about 200 feet east of the Carbonate tunnel the ore bed has been followed southeastward into the hill for a distance of 35 feet by a tunnel, here designated the Oxide tunnel. The ore bed in the Oxide tunnel occupies the same position in the Cason shale as that in the Carbonate tunnel, but here all the ore is oxide; the carbonate has undergone oxidation and might be penetrated if the tunnel were extended farther into the hill. The oxide ore ledge contains some clay, and the thickness ranges from 12 to 27 inches, but averages 24 inches. The following section was measured at the portal of the tunnel:

Section at portal of Oxide tunnel of Meeker mine

Boone chert:	*Ft.*	*in.*
Chert; only basal beds are exposed	5	
Clay	1	
Cason shale:		
Brown low-grade phosphate rock	3	5
Ferruginous manganese oxide	1–2	
Fernvale limestone.		

An old tunnel, partly caved, is on the hill slope 80 feet northeast of the Oxide tunnel. The ore bed, which here consists of oxides, lies 15 feet higher than that in the Oxide tunnel. This indicates either a fault between the two tunnels or a southwesterly dip of the rocks.

A tunnel 115 feet long on the north hill slope about 200 yards east of the above-described old tunnel reveals the following section:

Section at East tunnel of Meeker mine

	Inches
Cason shale:	
Greenish-gray phosphate rock	24
Shaly brown rock, containing much low-grade manganese ore which is stated to contain 18 to 20 percent of manganese. Some of the ore occurs in saucer-size concretions as much as 5 inches in diameter	30
Low-grade soft manganese oxide	9–10
Fernvale limestone.	

This tunnel was driven in 1934, and a few tons of ore from it was marketed.

Immediately east of this tunnel are some pits that were made during the World War, and east of them is an opening made in 1934 from which several tons of low-grade manganese ore consisting of carbonate and oxide was marketed.

According to W. H. Denison the oxide ore bed in the openings made during the World War contains 20 percent of manganese and 25 percent of iron.

COLE ORCHARD PROSPECT

The Cole Orchard prospect, which is on land owned by Walter H. Denison, is in the SE¼ sec. 7, T. 14 N., R. 7 W. The prospect consists of many small pits on the north and northeast slopes of a hill, and from them manganese oxides have been recovered and marketed for many years. The oxides occur as a bed in the phosphate rock of the Cason shale and as loose masses in the soil lower on the hill slopes.

Here the Cason formation is composed chiefly of phosphate rock, as much as 10 feet thick, which crops out as horizontal ledges along the hill slopes. The principal opening is a tunnel 75 feet long extending in a westerly direction on the west side of a hollow that drains to the north. The tunnel has been made in the lower part of the Cason formation and the top of the Fernvale limestone. At the portal a bed of manganese oxide, 9 to 10 inches thick, occurs in the Cason formation and is separated from the Fernvale limestone by a bed of green phosphate rock 12 inches thick and a subjacent bed of green and brown shale 6 inches thick. At a distance of 20 feet from the portal the bed of manganese oxide grades into a red manganese carbonate, which continues to the face of the tunnel. The field relations indicate clearly that the carbonate bed has been changed at and near the surface to manganese oxide through the oxidizing influence of ground water. The several small pits on the hill slopes northwest of the tunnel reveal a bed of manganese oxide in the Cason for a distance of about half a mile. In most of the pits the bed is 10 inches thick, but in two it is thinner, reaching a minimum of 3 inches. At this locality there may be a single continuous bed of manganese oxide or one or more discontinuous beds. The exposures are insufficient to determine which alternative is correct, but the character and other features of the different exposures suggest the presence of a single bed. Undoubtedly the oxide form of manganese at all the pits represents a surficial oxidation of manganese carbonate, just as it does at the tunnel locality.

The manganese oxide, as shown in the several openings, is somewhat porous, and 3 tons of it that was marketed is said to have contained 38 percent of manganese and a high percentage of iron. The manganese carbonate found in the tunnel is reported to contain about 22 percent of manganese and about the same percentage of iron.

F. M. BARNES MINE

The F. M. Barnes mine, now owned by W. H. Denison, lies in the S½NE¼ sec. 14, T. 14 N., R. 8 W., on the southeast side of Little Lafferty Creek 3 miles west-southwest of Cushman. Mining of manganese ore on this property has extended over many years. Only oxide ores were recovered before 1934, but some carbonate ore was obtained in 1935.

The openings occur in two groups—one in Big Pine Hollow, which is followed by the road between Cushman and Penters Bluff, and the other in Little Pine Hollow, which lies to the north across a high ridge from Big Pine Hollow. The openings of both groups include shallow pits and cuts in the outcrop of the Cason shale and in the thin mantle of chocolate-colored clay of the Fernvale limestone, of which many ledges are exposed. Ore has been mined from this clay and from a carbonate-oxide bed in the Cason shale. In addition, carbonate-oxide bodies in the top of the Fernvale limestone have been explored by a tunnel and the other openings in Big Pine Hollow.

In Little Pine Hollow an open cut, visited in 1918, shows a 19-inch bed of iron oxide, ferruginous manganese oxide, and manganese oxides. An analysis, then available, of a sample of this oxide ore is reported to have shown 16 percent of manganese, and a second available analysis is reported to have shown 19 percent of manganese. The following section in the cut was measured in 1918:[21]

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[21] Miser, H. D., op. cit. (Bull. 734), p. 220.

Section in cut at F. M. Barnes mine in Little Pine Hollow

	Ft.	in.
St. Clair limestone: Gray fossiliferous limestone	4+	
Cason shale:		
Massive and thin-bedded ferruginous sandstone	7–8	
Sandy and shaly ferruginous manganese oxide	1	7
Green phosphatic sandstone		8
Platy gray shale containing a few thin lenses of iron oxide	3	
Fernvale limestone: Rusty limestone separated from the Cason shale by a foot or more of chocolate-colored clay, which is a residue from the decomposition of this limestone. The top of the limestone is irregular.		

A section measured in 1931 in the same or a nearby cut revealed a bed of oxide and carbonate ranging in thickness from 14 to 22 inches. The section follows:

Section in cut at F. M. Barnes mine in Little Pine Hollow

	Ft.	in.
St. Clair limestone:		
Cason shale:		
Concealed on slope	2+	
Phosphatic sandstone	10	
Reddish-brown manganese carbonate and oxide		14–22
Phosphate rock		9
Shale to base of exposure		6

The manganese-bearing bed in the second section seems to be the same as that in the first. The face where the second section was measured reveals the portion of the bed where the manganese carbonate has been affected relatively little by surficial oxidation. The exposures indicate that some mining had been done on the bed between 1918 and 1931.

Openings have been made on both slopes of Big Pine Hollow, and some are adjacent to the road. At the times of visit in 1931, 1935, and 1939 all of them except the tunnel were badly caved.

The tunnel, which was driven in 1936–37 by W. H. Denison, extends 225 feet in an easterly direction into the hill on the north side of Big Pine Hollow in the SW¼NE¼ sec. 14, T. 14 N., R. 8 W. Its face is about 10 feet higher than the portal. The tunnel was driven in the topmost beds of the Fernvale limestone, and its roof is the phosphate rock of the Cason shale. Small quantities of manganese oxides and carbonates were found in the limestone, and only about 10 tons of high-grade manganese ore had been shipped before the time of visit in October 1939. Bodies of manganese oxides, chiefly psilomelane, lie between the Fernvale and the Cason in the half of the tunnel near the portal. These reach a thickness of 14 inches at some places, but they thin out and are absent elsewhere. Farther back in the tunnel irregular pockets of manganese oxides and carbonates as much as 12 inches thick occur in the topmost bed of the Fernvale, but at some places they occur in the limestone as far as 2 feet below the top. The manganese carbonates include both the gray and brown varieties.

Some irregular masses of oxides more than a foot across were noted in the Fernvale limestone in the stream bed in the bottom of Big Pine Hollow. They doubtless represent surficial portions of carbonate masses that are present below the top of the limestone.

An analysis of rhodochrosite from Big Pine Hollow is reported to show 36.20 percent of manganese; a red carbonate is said to show 28.80 percent, and another sample of carbonate whose color is not known shows 24.15 percent. Of the 25 to 30 tons of manganese ore mined and marketed by Mr. Denison in 1934 and 1935 from Big Pine Hollow half was manganese carbonate and the other half oxide.

W. C. COLLIE MINE

The W. C. Collie mine, owned by Mrs. W. C. Collie, is in the NE¼NE¼ sec. 14, T. 14 N., R. 8 W., 3½ miles west-southwest of Cushman. It is on a tract that adjoins the north side of the property on which lie the Little Pine Hollow workings of the F. M. Barnes mine. Most of the openings are shallow cuts and pits on a steep north slope, and from them large and small masses of oxide have been obtained from the chocolate-colored clays residual from the Fernvale limestone.

One small cut exposed a northward continuation of the ore bed in the Cason shale at the F. M. Barnes mine. On the Collie property the bed ranges from 13 to 18 inches in thickness and is composed of a reddish-brown manganese carbonate with which there is some oxide. The ore bed, like that at the Barnes mine, is overlain by a thick bed of phosphate rock and underlain by a thin bed of phosphate rock.

There is no record of any production of carbonate ore from this locality, and the extent of the workings indicates that little or none has been marketed.

MARTIN NO. 1 MINE

The Martin No. 1 mine is in the SW¼ sec. 14, T. 14 N., R. 8 W., on the southeast side of East Lafferty Creek 4 miles west-southwest of Cushman and 1½ miles southeast of Penters Bluff station. It has been operated intermittently since 1917. In 1917 and 1918 J. R. Martin, the owner, produced more than 200 tons of manganese oxide ore that he obtained from the residual clay of the Fernvale limestone. This ore in carload lots contained about 38 percent of manganese. In 1934 the mine was operated by A. B. Reither and T. F. Shell, owners at that time, who produced 400 tons of manganese carbonate ore intermixed with a little oxide ore. The manganese content of carload lots of this carbonate ore ranged from 34.07 to 41.58 percent and averaged 36 percent. Further work on the property was done in 1936, 1938, and 1939, but it yielded little salable ore during these years. The first carbonate ore mined at this locality was obtained during or soon after the World War from a shaft from which oxide ore in the boulder form was being mined. The carbonate was, however, not distinguished at that time from the associated limestone and was accordingly discarded. Fragments of the carbonate found lying on the old shaft dump in October 1931 had become coated with a film of oxide, but when broken a gray variety of carbonate was revealed.

The mine workings, which are mostly short tunnels but also include small pits and cuts, are distributed through a distance of a quarter of a mile along the base of a northwest hill slope, on the southeast side of East Lafferty Creek.

Here the St. Clair and Fernvale limestones and the intervening Cason shale are exposed in the workings and on the hill slope. They have a low southerly dip, and in consequence, they crop out lower and lower on the hill slope in a downstream direction. The manganese-bearing beds, the Cason shale and the top of the Fernvale limestone, pass below East Lafferty Creek near the southernmost opening.

The ore-bearing portions of the Cason shale and Fernvale limestone have been revealed in many openings that have been examined in 1939 and earlier years. The openings that had not caved in and that showed ore at the time of the different visits to the tunnels are described below.

A short tunnel near the north end of the line of openings on the hill slope passed through and then beneath debris of chert, limestone, and soil and entered the Cason shale and an underlying layer of manganese ore. The shale, 24 inches thick, is brownish black and contains seams of manganese and iron oxides and also "buttons" of the same oxides. The layer of ore at the portal consists of manganese oxides and measures 12 inches in thickness. It is said that in the driving of the tunnel, which is 20 feet long, the layer was found to contain a little manganese carbonate and to measure 24 to 36 inches in thickness. At a point 10 feet from the portal the oxide ore occurred as irregular masses in the topmost part of the Fernvale limestone. Beyond this point the ore layer overlies a ridge of this limestone and pitches steeply to the north and east on the sides of the ridge.

A cut in the bottom of a hollow 50 feet south of the above-described tunnel measures 50 by 15 feet; it showed in 1935 the following section of ore-bearing rocks:

Section in cut on Martin No. 1 property

	Feet
St. Clair limestone	10+
Cason shale: Brown shale containing "buttons" of iron and manganese oxides	2½
Fernvale limestone: Gray limestone containing pockets and veins as much as 9 inches wide of gray and red manganese carbonates and rhodochrosite along bedding planes and cracks. A little pyrite is associated with the carbonates. In the top part of the limestone exposed to weathering much of the limestone has become blackened from the presence of manganese oxide, and the manganese carbonates in the pockets and veins have changed to the oxide form	7

In 1936 the above-described cut had been enlarged and revealed a flat-lying body of rhodochrosite and brown carbonate 1 foot thick and 2 feet long, lying 3 feet below the top of the Fernvale.

A pit measuring 10 feet square and 8 feet deep on the south side of the hollow encountered masses of ore, some lying loose in clay and others attached to the Fernvale limestone. The masses consisted of a peripheral layer of psilomelane enclosing a core of rhodochrosite and gray manganese carbonate. These masses represent the partly oxidized portion of a veinlike body 9 to 11 inches thick of mottled manganese carbonate in the Fernvale limestone. This body, dipping to the west, was followed for 4 feet in that direction and ended against residual clay, but toward the south it ended in the limestone.

The Ed Thoma tunnel, whose portal is near the pit just described, was driven in 1938 and 1939. It averages 11 feet in width and 6 feet in height and was driven to the south a distance of 40 feet in the Cason shale and the underlying Fernvale limestone. The roof at most places is formed by this shale and by the overlying St. Clair limestone, but at some places the tunnel is roofed by a bed at the top of the Fernvale. The rock strata in the tunnel dip to the south and are 2 to 3 feet lower at the south end than at the portal. The tunnel reveals bodies of the gray, brown, and pink carbonates of manganese and some hausmannite, especially at its south end, where such a body lying next to the floor is 2 feet thick and is 4 feet below the top of the Fernvale limestone.

Southwest of the tunnel just described is another tunnel with two forks, one 30 feet long and the other 20 feet long, which was visited in 1939. It was driven in the upper 6 to 7 feet of the Fernvale limestone and found seams and irregular pockets of manganese carbonates as much as 27 inches long at different places, some near the roof and some near the floor. In the pile of ore removed from the tunnel were noted rhodochrosite, gray and brown manganese carbonates, and some associated pyrite and barite. An exposure at the portal of the tunnel shows the Cason shale between the St. Clair limestone above and the Fernvale limestone below. Here the shale is 3 feet 3 inches thick and is brown. In its lower 10 inches are irregular areas of reddish carbonate of manganese. A 17-foot shaft 35 feet northwest of the tunnel was sunk in beds of the Fernvale limestone that are black from the presence of finely disseminated particles of manganese oxide.

The opening farthest to the southwest that was visited in 1939 is a tunnel 4 to 6 feet in width and 5 feet in height, which was driven 12 feet to the southeast. It encountered the St. Clair limestone, the Cason shale, and the Fernvale limestone. A small quantity of rhodochrosite was noted in the Fernvale limestone near the portal. The Cason shale varies greatly not only in its thickness but in its character. At the portal it is composed of greenish phosphate rock ranging from 18 inches to 4 feet in thickness, and at the end of the tunnel it is 10 to 16 inches thick and is composed of dark shale and reddish manganese carbonate in equal or nearly equal proportions. The tunnel follows a fractured zone in the St. Clair limestone, and the southerly dip in this limestone is lower southwest of the tunnel than northeast of it. At the portal a lenticular, nearly horizontal mass of the limestone immediately above the Cason shale is 3 feet thick and is exposed for a distance of 12 feet along the face of the hill. It is a mottled rock from the presence of irregular areas of specular hematite, barite, quartz, finely crystalline light-pink rhodochrosite, and coarsely crystalline pinkish-red rhodochrosite.

MARTIN NO. 2 MINE

The Martin No. 2 mine is in the NW¼ sec. 14, T. 14 N., R. 8 W., on the southeast side of East Lafferty Creek, 4 miles west-southwest of Cushman. This property adjoins on the north side that on which the Martin No. 1 mine is located. The mineral right of the property is owned by the Arkansas Fertilizer Co., and the agricultural right by J. R. Martin.

The mine has been worked at times for many years, and the production consisted entirely of manganese oxide ore until 1934 and 1935, when 75 tons of ore, half of which was manganese carbonate, was mined and marketed.

The workings, which are shallow pits and short tunnels, extend along the west and northwest hill slopes for a quarter of a mile. The chocolate-colored manganese-bearing clay, 2 to 12 feet thick, which contains the irregular masses of oxide ore (psilomelane), overlies the uneven surface of the Fernvale limestone and is overlain by chert fragments and massive blocks of the St. Clair limestone. A pit visited in 1918 revealed 3 feet of the lower part of the Cason shale which is composed of red shale and a green platy earth in which there occur irregular masses of iron and manganese oxides, a few "buttons" of iron oxide, and a layer of manganese oxide a few inches thick.

The recent openings had caved in before the last visit to the property, April 9, 1935, and none of them revealed the manganese carbonate in place. As broken fragments of the Fernvale limestone lie on the waste dumps, the carbonate ore was probably obtained from that limestone. Some of the fragments are black from the presence of finely disseminated manganese oxide, and some contain portions of masses of manganese oxide.

McBRIDE MINE

The McBride mine, which is on land owned by John P. Forest and leased by W. H. Denison, is in the NW¼ sec. 27, T. 14 N., R. 8 W., about a quarter of a mile east of Walls Ferry station on the Missouri Pacific Railroad. It was operated during the World War, when manganese oxides, consisting chiefly of psilomelane, were mined and marketed. In 1938–39 Mr. Denison did some prospecting here by making a shallow cut on the north side of the hollow. The cut, which runs in an east-west direction with the hill slope, follows the contact between the Cason shale and the underlying Fernvale limestone for a distance of 30 feet. It exposes the topmost beds of the Fernvale and also the lower part of the Cason. As shown in the cut, red and gray carbonates of manganese have largely replaced the limestone to the bottom of the cut, which is 18 inches below the top of the limestone. Although the floor of the cut was concealed nearly everywhere by loose material at the time of visit (October 25, 1939), it did not show the base of the carbonate-bearing zone in the limestone. The carbonates where affected by weathering have been altered to psilomelane. The small amount of manganese ore, 5 tons, marketed by Mr. Denison, consisted chiefly of manganese carbonates but partly of psilomelane. Its manganese content ranged from 25 to 35 percent.

MANGANESE CAVE MINE

The Manganese Cave mine, also known as the Penters Bluff Cave mine and Harvey mine is on north and west hill slopes in the NW¼ sec. 15, T. 14 N., R. 8 W., just south of the Penters Bluff spur on the Missouri Pacific Railroad. It is owned by the Cave Mining Co. Mining was first started here in 1917 by R. S. Handford and has continued intermittently since then. The cave from which the mine was named was discovered in November 1918. It is about 200 feet long, 100 feet wide, and 60 feet high. At that time the mine was leased to Wagner, Johnson, & Capehart, but in January 1919 the lease was bought by J. B. Harvey, who formed the Manganese Cave Mine, Inc. The company did a little prospecting in the spring of 1919 and it leased the property to R. W. Earnheart and J. D. Magness in January

1920. Messrs. Earnheart & Magness worked the property by means of tunnels driven into the solid manganese ore-bearing rock. Other operators include W. L. Hogg and R. S. Handford in 1925, A. B. Reither in 1928, and W. H. Denison in 1929, 1930, and 1934. The marketed output of manganese oxide ore was several carloads in 1917 and 1918, and the production from 1920 to 1934, inclusive, according to information available to the writer, was about 500 tons of ore that consisted of intermixed oxides and carbonates.

The workings comprise small open cuts and tunnels on the north and west sides of the hill slopes about 110 feet above the Missouri Pacific Railroad, which runs along the west base of the hill. The tunnels have been driven into the hill as much as 65 feet until they reach the cave. The openings reveal the Cason shale and also the overlying St. Clair limestone and the underlying Fernvale limestone.

Two sections that describe the rocks measured in April 1920 and in October 1931 are given below.

Section in cut at Manganese Cave mine

	Ft.	*in.*
St. Clair limestone: Pinkish-gray granular fossiliferous limestone	10	
Cason shale: Greenish-yellow platy clay, known as phosphate rock	1	10
Fernvale limestone:		
Massive bed of limestone; medium- to coarse-grained; contains oolites and flattened dark greenish-gray pebbles that appear to be phosphatic. Some reddish-brown manganese carbonate and some manganese oxide occur in the lower part of the bed	3	8
Lens of oxide ore, composed of psilomelane, hausmannite, wad, and red and yellow oxides of iron. This lens, according to the miners, is underlain by low-grade manganese ore and limestone		1

Section in cut at Manganese Cave mine

	Ft.	*In.*
St. Clair limestone: Gray limestone	6	
Cason shale: Brown and yellow shale and phosphate rock; contains some manganese oxide	1	3
Fernvale limestone:		
Reddish-brown massive and shaly limestone	3	
Manganese ore bed, composed of oxides and carbonates	1–5	
Gray limestone.		

The ore mined in 1917 and 1918 consisted of manganese oxides—psilomelane, hausmannite, and possibly braunite and a nearly equal quantity of ferruginous manganese oxide—occurring in the form of boulders weighing as much as 1,000 pounds in the top of the Fernvale limestone. The oxide has replaced some of the limestone along cracks and bedding planes and locally makes up a large part of the rock mass. The parts of the limestone in which the oxide ore is present contain a fine to coarse-grained yellowish-brown manganese-bearing carbonate, of which an analysis follows:[22]

Analysis of manganese-bearing carbonate from Fernvale limestone at the Manganese Cave mine

[R. C. Wells, analyst]

Manganese (Mn)	35.50
Iron (Fe)	6.54
Silica (SiO_2)	1.51
Alumina (Al_2O_3)	2.06
Lime (CaO)	10.60
Magnesia (MgO)	.96

The sample analyzed was partly oxidized. The chief constituents appear to be chemically combined to form a manganese-iron-calcium carbonate. This mixed carbonate has entirely replaced parts of the limestone, and surficial portions of it have changed to psilomelane. A few boulders of ore that were mined near the surface in 1918 appeared to consist entirely of manganese and ferruginous manganese oxides, but when they were broken open, the cores showed unaltered carbonate.

The ore mined in 1920 and later years has been obtained from a bed at or near the top of the Fernvale limestone. This bed, like the associated rock lies nearly horizontal. It ranges in thickness from a knife edge to 10 feet; many measurements show 7 feet, but the average thickness is said to be between 3 and 4 feet. The bed is composed of rhodochrosite, the white, gray, and red carbonates of manganese, and some oxides, including hausmannite and hematite. Pyrite is present in small quantity. Psilomelane and gypsum have formed as the result of the oxidation of the pyrite and the carbonates. In driving a tunnel in 1920, a pocket of limestone 18 inches in diameter was encountered in the ore bed. Fragments of the limestone resembled the Fernvale limestone.

The ore shipped was simply hand-sorted during mining. Carload lots of oxide ore shipped during the World War contained as much as 45 percent of manganese, but lots of the intermixed oxides and carbonates have had a smaller manganese content. One car shipped in 1920 contained 34 percent of manganese; another shipped the same year contained 36 percent; five cars shipped in 1925 contained 40.75, 37.46, 38.60, 42.52, and 35.10 percent; four cars of low-grade ore shipped in 1925 averaged 32 percent; and the 191.3 tons shipped in 1934 averaged 27 percent. Analyses of car-lot shipments in 1929 and 1930 containing manganese carbonate from this mine intermixed with

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[22] Miser, H. D., op. cit. (Bull. 734), p. 228.

manganese carbonate from other mines near Penters Bluff are given on page 24.

SMITH MINE

The Smith mine, which is owned by R. L. Smith, is at the north base of an eastward-trending hill slope three-eighths of a mile east of Penters Bluff spur. The openings at the time of the last visit, October 6, 1931, included two small open cuts, 100 yards apart, from which 4 or 5 carloads of ore was mined and shipped in 1929 and 1930 by W. H. Denison.

The openings expose the brown Cason shale, 4 feet thick, between the overlying St. Clair limestone and the underlying Fernvale limestone. The uppermost portion of the Fernvale has been largely replaced by manganese carbonate, of both the gray and reddish-brown varieties, with which is associated much pyrite. The part of the limestone containing manganese carbonate is reported to have ranged in thickness from 1 to 4 feet.

The marketed ore was almost entirely carbonate; only a little manganese oxide was present. By means of hand picking during mining operations most of the leaner material was discarded. The 4 or 5 cars of ore contained from 28 to 33 percent of manganese. The iron content in the ore reached 20 percent. Analyses of three of the carloads of manganese shipped in 1929 and 1930 are given on page 24, but two carloads contained also carbonate ore from nearby mines.

WOODPECKER HOLLOW MINE

The Woodpecker Hollow mine is on land owned by W. H. Denison in the SW¼ sec. 2, T. 14 N., R. 8 W., and consists of numerous openings in Shop Hollow, which drains west into the head of Hankins Hollow. The distance from the mine to the mouth of Hankins Hollow is about three-quarters of a mile, and that from the mouth of Hankins Hollow to Penters Bluff station, to the southwest, is 1 mile.

The mine has been operated intermittently for a period of perhaps 50 years, and many hundred tons of manganese oxide ore has been marketed. The first carbonate ore was mined and marketed in 1929 by Mr. Denison, but beginning in 1929 the marketed ore consisted of both manganese carbonate and oxide. The carbonate-oxide production was continued by Mr. Denison through 1931, but the mining of oxide ore since that date has been accompanied by the recovery of a small amount of associated carbonate ore.

Several formations—the Boone chert, St. Clair limestone, Cason shale, and Fernvale limestone—which lie horizontal or nearly so, are exposed in this vicinity, and the irregular masses of manganese oxides that formed the entire output of the mine up to 1929 were obtained from the residual clays and from the wash that is associated with the clays. Exposures of Fernvale limestone are found at many places. The Cason shale, a few feet thick, is exposed only in a few openings, being elsewhere concealed by its residual clay, by massive blocks of the St. Clair limestone, and by chert debris from the Boone chert.

The openings from which the oxide ore was recovered include pits, short tunnels, and shafts, some of which are 35 feet deep. The openings from which the intermixed carbonate and oxide are obtained are of similar character, though they enter the solid rock, and nearly all of them explore the topmost part of the Fernvale limestone.

The easternmost opening, known as the Ingals cut, about 100 feet long, follows the outcrop of the Cason shale and the top of the Fernvale limestone on a south hill slope on the north side of Shop Hollow. In the eastern part of the cut a tunnel was driven 50 feet into the hill. The cut near the portal of the tunnel reveals 5 feet of Cason shale—here red shale and brown phosphate rock—overlain by 10 feet of St. Clair limestone and underlain by 6 feet of limestone at the top of the Fernvale. The carbonate ore bed, as revealed on the west side of the tunnel, lies at the top of the Fernvale and ranges from 12 to 27 inches in thickness. In the face of the tunnel 12 inches of limestone separates the Cason shale from the ore bed, which is there more than 3 feet thick. The carbonate ore bed has been sufficiently exposed to show that it is present for the full length of the cut; the average thickness in this distance appears to be about 15 inches. It is composed of rhodochrosite, the red, gray, and white manganese carbonates, and a considerable amount of the oxide, hausmannite. There occur also some hematite, barite, neotocite, bementite, and quartz. (See pls. 3, *B*, and 4, *A*.) In addition psilomelane and wad are found in the surficial weathered portions of the ore bed. The adjoining portions of the limestone are reddish gray to black and contain fine disseminated particles of hausmannite and psilomelane. (See fig. 8.)

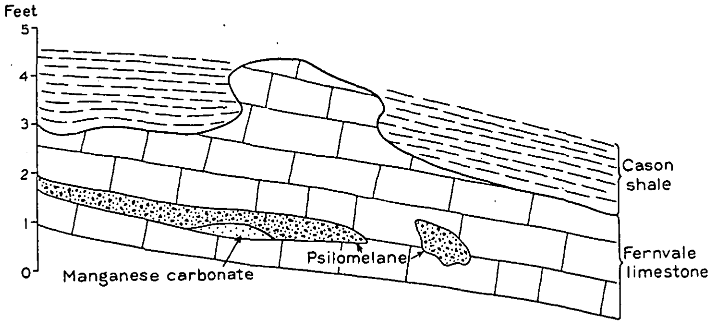

FIGURE 8.—Sketch of part of face of Ingals cut, Woodpecker Hollow mine, showing relations of manganese carbonate and psilomelane in Fernvale limestone. The Fernvale contains disseminated particles of manganese oxide, and its manganese content averages about 15 percent.

About 1,000 feet west of the Ingals cut both oxide and carbonate ore form irregular masses distributed through the Fernvale limestone below the carbonate bed at the top of the limestone. The masses, having been freed by solution from the enclosing limestone, now form small and large boulders in the residual clay. Their peripheral layers are psilomelane and hausmannite; the cores of many are gray carbonate, coarse rhodochrosite, and hausmannite. Some cores contain bementite. Here the surficial portions of the limestone—the exposed portions and also the portions adjacent to the residual clays—are dark owing to the presence of finely disseminated manganese oxide.

Across Shop Hollow from the Ingals cut, on a north slope, oxide ore has been mined from a small pit and an adjacent tunnel, 10 feet long. The following section is revealed:

Section on south side of Shop Hollow

	Ft.	*In.*
St. Clair limestone	6	
Cason shale; contains as much as 15 inches of brown phosphate rock	2	6
Fernvale limestone: Brown, yellow, gray, and white carbonates of manganese, whose weathered portions are coated with a zone of psilomelane; exposed thickness above water in pit is 30 inches; some pyrite and earthy hematite are present; carbonate ore is said to extend 5 feet or more below surface of water.		

A small pit 100 feet west of the short tunnel above described shows the topmost part of the Fernvale limestone, from which masses of manganese oxide ore, chiefly hausmannite, have been blasted. The limestone is red and contains in places an intimate mixture of pink and red carbonates of manganese and some hausmannite.

The ore mined in 1929 and 1930 from the Ingals cut and tunnel was sorted into three grades, one containing 50 percent of manganese, another 40 percent, and another 20 percent, each of which was shipped separately. It was hauled to Penters Bluff spur for shipment. The production of carbonate-bearing ore from the property in 1929–31 is reported to have been four or five carloads.

Analyses of two samples of red carbonate from the Woodpecker Hollow mine showed 33.45 and 33.75 percent of manganese. An analysis of a sample of intermixed hausmannite and carbonate from an opening on the south side of Shop Hollow is said to show 42.50 percent of manganese. A sample of the coarse rhodochrosite obtained by the writer was found on analysis (No. 5, p. 13) to have a manganese content of 36.3 percent.

Analyses of carload lots of manganese ore shipped in 1929 to 1931 from this mine are given on page 24, but some of the lots contained ore from nearby mines.

PARKER MINE

The Parker mine, near the head of Hankins Hollow, has been operated in recent years by W. H. Denison, who has mined and marketed ore consisting of both manganese oxides and carbonates.

The oxide ores of the earlier production were found in the form of irregular masses scattered through the residual clays of the Fernvale, Kimmswick, and Plattin limestones or in chert wash derived from the Boone chert, which caps the nearby hills.

Most of the openings that have revealed intermixed oxide and carbonates of manganese are on the west and south slopes of a hill on the east side of the hollow, in the NW¼ sec. 11, T. 14 N., R. 8 W. The southernmost openings of the Woodpecker Hollow mine are on the north slope of this hill. The Parker openings are small, widely scattered pits that have been dug on the hill slopes along the outcrop of the Cason shale and the top of the Fernvale limestone. A pit on the south slope showed 3 feet of Cason shale lying underneath the St. Clair limestone and above a 10-inch horizontal seam of hard manganese oxide consisting chiefly of psilomelane. A gray variety of manganese carbonate is said to have formed a 2-inch seam underneath the 10-inch seam. The oxide and carbonate seams have replaced the top of the Fernvale limestone. The Cason shale itself, which is composed of yellow phosphate rock and yellow shale in nearly equal proportions, contains thin seams of manganese oxide. Other openings reveal rhodochrosite, a red carbonate, and the oxides psilomelane and hausmannite in the topmost part of the Fernvale limestone. The carbonates and oxides occur in pockets, seams, and veinlets in the limestone.

On the west side of Hankins Hollow at a locality near the base of the east hill slope and near a cabin small pits have yielded several tons of manganese carbonate from the upper part of the Fernvale limestone. The carbonate forms boulders which are coated by manganese oxide, and it also occurs as horizontal lenses as much as 4 inches in thickness. The exposures at the time of visit indicated that all the ore occurred originally as masses in the limestone a few feet below its top. Some manganese oxide forms horizontal slabs and seams as much as 3 inches thick, and some adheres to the exposed portions of the limestone. Much of the limestone in the vicinity is colored dark by finely disseminated particles of oxide, some or all of which doubtless represents the surficial oxidation of particles of carbonate distributed through the rock.

An analysis of a carload lot shipped in 1930 and containing carbonate ore from the Parker mine and the Woodpecker Hollow mine shows 26.50 percent of manganese. This analysis is given on page 24.

EDMUNDSON PROSPECT

The Edmundson prospect, on land owned by W. H. Denison, is near the cave in the head of Hankins Hollow, in sec. 2, T. 14 N., R. 8 W., 1¾ miles northeast of Penters Bluff spur.

A few small pits that have been made at this locality have yielded manganese oxides and carbonates. Loose boulders of oxide ore were obtained from the residual clays of the Fernvale limestone, and also some was blasted from the limestone. Several tons of the portions of the limestone partly replaced by manganese carbonates (pink and reddish brown) and oxides (braunite and psilomelane) had been mined and shipped prior to the time of visit, in October 1931. At that time a pit on the west side of the hollow showed a 5-foot face of limestone, which was blackened in places from disseminated particles of manganese oxide and which contained small seams and veins of manganese oxides and carbonates. Across the hollow east of the pit there was observed a face, measuring 2½ feet vertically, of reddish-brown carbonate ore at the top of the Fernvale. Also in this locality some boulders of manganese oxide lying loose in the soil contained cores of pink and brown carbonates.

ELLA CLARK PROSPECT

The Ella Clark prospect is on land owned by W. H. Denison, in the N½SE¼ sec. 2, T. 14 N., R. 8 W., on a hill between West Lafferty and East Lafferty Creeks, 3½ miles west by north of Cushman and 2½ miles northeast of Penters Bluff station. Small quantities of manganese ore have been mined here from time to time for many years, beginning in 1916. The output has consisted for the most part of oxide ore containing more than 50 percent of manganese, but in 1931, 4 tons of carbonate-bearing ore was blasted from ledges of the Fernvale limestone on the gentle northwest slope and near the crest of a hill. The hill is capped by this limestone, and the broken ledges, as well as the exposed portions of the limestone, show the presence of small irregular masses and fine particles of manganese oxide disseminated through the limestone. The limestone is black from the presence of the oxide particles, some of which are hausmannite. The ore at this locality does not occur at the top of the limestone, which has been eroded in the vicinity, but is many feet below the top.

PITTMAN MINES

The Pittman mines are on land owned by Mrs. Julia Coleman in sec. 3, T. 14 N., R. 8 W., 1½ to 2 miles northeast of Penters Bluff station. They have been worked at times during the last 50 years and have produced many hundred tons of manganese ore. The first shipments of ore containing some manganese carbonate were made during the World War; this ore came from an opening known locally as the Hinkle mine. This mine next produced carbonate ore for several years, beginning in 1928, and an opening on the northwest side of Hankins Hollow produced some carbonate ore in 1930 and 1931. The two openings yielding the carbonate ore are on slopes on both sides of a north-northeastward-trending ridge on the east side of West Lafferty Creek.

The Hinkle cut is on a west hill slope. It consists of a north-south cut 80 feet long that was dug back into the hill a distance of 40 feet and a tunnel 10 feet wide and 5 feet high that was extended 30 feet farther. The face of the cut revealed in 1931 the following section:

Section at Hinkle cut

	Ft.	*in.*
St. Clair limestone	5+	
Cason shale, green; contains thin layers of reddish-brown manganese carbonate	3	6
Fernvale limestone:		
Bed of manganese carbonates and oxides		8–30
Gray and brown limestone.		

The tunnel is not level but extends down the dip of the bed—namely, 20° E. At the south end of the cut there is a cave in the top of the Fernvale. The roof of the cave, like the tunnel, pitches toward the east about 20°, parallel with the dip of the rocks, but at the east end of the cave it pitches 30° to 40°. It is noteworthy that the ore bed in the cave consists of manganese oxides, which have been formed by the oxidation of the carbonates.

At most places in this mine the carbonate-bearing bed is 30 inches thick but in places it thins to 8 inches. The thin portions overlie low "ridges" in the underlying limestone.

The carbonate-oxide ore produced from the Hinkle cut and tunnel for the several years beginning in 1928 amounted to 400 tons, which contained an average manganese content of 35 percent. Analyses of three different samples of the red carbonate free from oxide at this locality show 28.50, 27.55, and 27.81 percent of manganese.

Carbonate ore was obtained from a series of small openings on the southeast slope of the ridge that forms the northwest side of Hankins Hollow. Here the carbonate-bearing rock at the top of the Fernvale limestone has been uncovered and opened at different places for a distance of 200 feet along the hill slope, and a tunnel extends 50 feet north into the hill. The Fernvale is overlain by 4 feet of Cason shale, and this in turn by the St. Clair limestone. The base of the Cason contains lenses and pockets of oolitic limestone as much as 8 inches thick, which rest upon the irregular surface of the Fernvale and occupy narrow fissures in the limestone. The topmost 6 feet of the

Fernvale contains rhodochrosite, the white, gray, and red carbonates, and the oxides hausmannite and braunite. Much limestone with little or no manganese is, however, distributed through this thickness. In places hausmannite, bementite, and barite have replaced the limestone or shaly limestone in which braunite and brown carbonate occur. Other specimens reveal mottled carbonates (white, red, and black), hausmannite, and barite that have replaced limestone. In 1930 and 1931 this locality yielded one carload of high-grade carbonate-oxide ore, containing more than 35 percent of manganese, and one car of ore containing 25 percent of manganese. It is stated that the 6-foot face of ore rock contains about 25 percent of manganese and that after the separation of the oxides and the highest grade of carbonates during mining the rest of the face contains about 20 percent of manganese.

Some of the bouldery masses of oxide that are found in the residual clay of the Fernvale limestone northwest of the head of Hankins Hollow show a peripheral band of manganese oxide which envelops a core of brown and white carbonates. The largest boulder reported contained 3 tons of oxide and white carbonate.

The bottom of a sinkhole near the top of the hill on the divide between Hankins Hollow and Lafferty Creek is said to expose green, pyrite-bearing Cason shale and a 3-foot thickness of intermixed manganese carbonate and oxide.

Analyses of carload lots shipped in 1929–31 from the Pittman mine are given on page 24, but some of these lots contained also manganese ore from nearby mines.

CASEY PROSPECT

The Casey prospect, known also as the Skelton-Handford,[23] is in sec. 3, T. 14 N., R. 8 W., 1 mile northeast of Penters Bluff station. The openings that were visited in 1918 and again in 1931 are on the east slope of a hill adjoining the valley of West Lafferty Creek. Small pits at this locality penetrate the chocolate-colored manganese-bearing clays, which overlie the irregular surface of the Fernvale limestone. Large blocks of the St. Clair limestone that have settled down the slope a few feet partly conceal the clays. Some manganese oxide ore has been obtained from this locality for many years. The oxide ore was found on the slope in the chocolate-colored clays, but in 1929 pits were dug in the Cason shale and in a 15-inch bed of reddish-brown manganese carbonate, partly oxidized, that lies between the Cason shale above and the Fernvale limestone below. Some 4 or 5 tons of the carbonate-oxide ore from this bed was mined and shipped in 1929.

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[23] U. S. Geol. Survey Bull. 734, pp. 245–246.

PENTERS BLUFF MINE

The Penters Bluff mine is on the south point of a hill about a quarter of a mile northeast of Penters Bluff station, on land owned by the American Manganese Co. The mining at this locality was done in the fall of 1929, when 60 tons of ore containing about 28 percent of manganese was marketed.

An east-west opening extends 100 feet along the face of the hill. The cut was extended into the hill as much as 30 feet where the burden over the ore-bearing rock is 12 feet thick. The manganese ore forms a horizontal lenslike body, ranging in thickness from a few inches to 4 feet, which is overlain by 30 inches of yellow and brown shale and phosphate rock and this in turn by chert-bearing soil through which a few masses of St. Clair limestone protrude.

The ore lens appears to form the lower part of the Cason shale; the 30 inches of shale and phosphate rock mentioned above constitute the upper part of the Cason. The base of the lens is irregular and represents an unconformable contact between the Cason shale and the Fernvale limestone. "Horses" or ridges of the limestone on the upper surface of the Fernvale reach a height of 20 inches.

Most of the ore lens consists of green and red mottled rock in which there are flattened oolites and phosphatic shells. A large proportion of it is fine- to coarse-grained manganese carbonate. The base of the overlying shale contains similar oolites and "buttons" (Girvanellas), as well as veinlets of manganese oxide. The Fernvale limestone, especially the portion in the ridges, is red and green and contains numerous calcite and manganese carbonate veins as much as 1 inch thick. The brown color of portions of the limestone is apparently due to the presence of manganese carbonate. There is little manganese in the oxide form in the eastern part of the cut; the oxides that are present are psilomelane and wad and have been formed by the surface oxidation of the carbonate. In the western part of the cut, where ground water has deeply channeled the Fernvale and St. Clair limestones, much or all of the manganese carbonate has been changed to manganese oxide. The accompanying sketch (fig. 9) of the face of the ore lens shows its relations to the Fernvale limestone and the upper part of the Cason shale.

Analyses of two samples of the manganese carbonate from this mine show 27.90 and 28.50 percent of manganese. Analyses of two carload lots that contained carbonate from the Penters Bluff mine and also from the Manganese Cave mine showed 27.30 and 29.80 percent of manganese.

SPECK MINE

The Speck mine is about half a mile north of Penters Bluff station, on the west slope of the ridge on which the Penters Bluff mine is located, on property belonging to the Speck heirs. As the result of mining here in the spring and summer of 1931 by W. H. Denison and in 1934 by A. B. Reither there was shipped about 50 tons of manganese oxides and carbonates, chiefly carbonates.

The mine opening, a north-south cut 35 feet long which extends back into the hill about 35 feet, exposes a face of 12 feet of St. Clair limestone above the ore-bearing rock. In a portion of the cut the lowermost 10 inches of the St. Clair limestone is brown instead of the usual gray. The brown color is obviously due to the presence of manganese carbonate. Under the St. Clair the Cason shale is represented by a green massive phosphatic sandstone which ranges in thickness from a knife edge to more than 3 feet. The top of the Cason is nearly horizontal, but the base is uneven, because the surface of the Fernvale on which the material for the Cason was deposited is irregular.

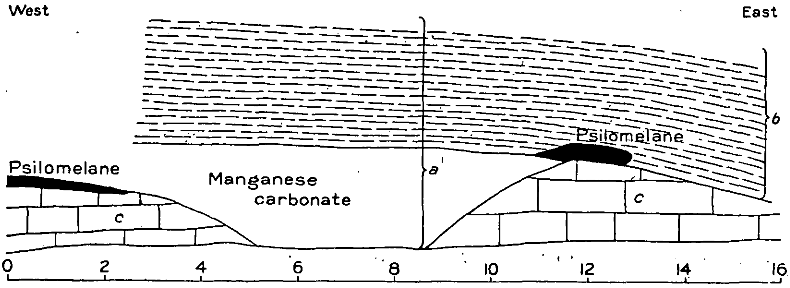

FIGURE 9.—Sketch of part of face of Penters Bluff mine showing lens of manganese carbonate lying below an oxidized zone in Cason shale. Black areas represent pockets of psilomelane. *a*, Cason shale; *b*, shale and phosphate rock containing seams and veinlets of manganese and iron oxides; *c*, ridges of Fernvale limestone containing veins of calcite and manganese carbonate.

The uppermost part of the Fernvale contains much manganese carbonate and some oxide, which have partly replaced the limestone through a thickness varying from 12 to 30 inches, but some portions of the gray to brown limestone have not been replaced. The manganese carbonates are red and gray, and the oxide is chiefly hausmannite, though the surficial portions of the manganese-bearing rock contain psilomelane. The ore-bearing limestone and the phosphatic sandstone are cut by many veins as much as 1 inch thick of dense, hard hematite and of calcite and manganese carbonate, which are usually arranged in bands parallel with the vein walls. The veins are widest and most numerous in the portion of the limestone adjacent to the ore-bearing rock. Some of the manganese-bearing carbonate in the veins is fine-grained and white to cream colored, and some is red. The carbonates and adjacent limestone display fracturing and offsetting along the fracture planes. Veinlets of red and cream carbonates and pyrite occur along some of the fractures.

ALEXANDER PROSPECT

The Alexander prospect lies about half a mile east-northeast of Penters Bluff station, east of the road that follows the ridge west of West Lafferty Creek. It was not visited by the writer. It is reported that most of the manganese ore here is low-grade oxide that contains a high percentage of iron, but a little manganese carbonate is reported to be associated with the oxide ore. The prospect has produced 15 tons of ore.

ENOS-LINDSEY CAVE PROSPECT

The Enos-Lindsey Cave, in which a little prospecting was done before 1928 by the White River Manganese Co. and in 1939 by Sims & Harkelroad, is west of the White River and 1 mile southwest of Penters Bluff station. The entrance to the cave is a large opening extending precipitously downward about 30 feet from the bottom of a sink hole in the NW¼NW¼ sec. 8, T. 14 N., R. 8 W. The cave is in an area of Boone chert, and the wall of rock around the entrance reveals the lower portion of the chert and also the underlying St. Clair limestone. The cave is a large one with many branches running in a somewhat horizontal position in the Fernvale limestone, though the floor in large parts of the cave is 25 feet or more below the top of the limestone. The main part of the cave is said to run in a northwesterly direction, and passages totaling many thousand feet in length have been entered. The Cason shale, about 1 foot thick, which lies between the St. Clair and Fernvale limestones, was noted near the entrance, where it is offset 6 feet on an east-west vertical fault with downthrow on the north side, but was not recognized elsewhere in the cave. The prospecting that had been done prior to 1928 consisted chiefly of the collection of 50 samples for analysis from different places in the manganese-bearing rock, which was said to range in thickness from a knife edge to 9 feet and to average about 4 feet. The analyses of the samples are reported to show an average manganese content of 19.44 percent.

In 1939 a steel rail track 1,200 feet long was laid in the cave for the conveyance of manganese ore in buckets on hand-operated trucks to the entrance, where they were hoisted by windlass to the surface. Altogether about 100 tons of ore said to contain 37 percent of manganese was removed in 1939 from the cave and hauled by truck by way of Marcella and Locust Grove to Batesville and Cushman for shipment. The ore was obtained at two places. One of these, where about 25 tons was removed, was in the roof of the cave at a place where the Fernvale limestone is broken by an eastward-trending fracture that has a possible downthrow of 6 to 8 inches on the north side. The ore here was obtained from an area 10 feet square and through a 3- to 4-foot thickness of limestone.

The other place where manganese ore was obtained is southwest of the entrance, at the end of the track. Here a solution-widened joint running S. 30° W. is displayed in both the roof and the floor. The manganese ore was obtained from an area 20 by 50 feet through a vertical distance of 8 feet on the roof and walls.

The manganese ore noted both in the cave and on the surface, where some of it had been placed, is porous and consists of psilomelane, wad, and some pyrolusite. Some of it contains much calcium carbonate because it was obtained from oxide-bearing limestone that had become porous in places through the complete and partial removal of the calcium carbonate. Although manganese carbonate has not been noted by the writer in the Enos-Lindsey Cave, the oxide-bearing limestone if followed away from the walls of the cave will doubtless be found to grade into carbonate-bearing limestone, just as the course of mining showed it to do in and near the cave at the Manganese Cave mine, 1 mile to the northeast, at Penters Bluff station.

ST. CLAIR MARBLE CO.'S PROSPECT

A prospect on the property of the St. Clair Marble Co. is on the southwest point of a hill above the company's quarry, which is alongside the Missouri Pacific Railroad, 2½ miles southeast of Guion. The quarry has been opened in the top of the Plattin limestone, in the Kimmswick limestone, and in the lower part of the Fernvale limestone. The higher beds of the Fernvale and also the St. Clair limestone are exposed on the steep slope above the quarry. The boundary between the St. Clair and Fernvale limestones is not clearly shown, and the Cason shale normally lying between them may be absent; if it is present, it does not exceed a foot in thickness.

The prospecting that had been done prior to the time of visit, April 11, 1935, consisted in stripping some of the topmost part of the Fernvale limestone. A horizontal lens of mottled white and brown carbonates of manganese, 8 inches in thickness and 5 feet or more in length, lies about 1 foot below the top of the limestone. The surficial portions of the carbonate lens have been changed to the oxide psilomelane.

WILLIAMSON PROSPECT

The Williamson prospect is on the J. W. Williamson property, 2½ miles southeast of Guion and a quarter of a mile north-northwest of the St. Clair Marble Co.'s quarry. The Fernvale and St. Clair limestones are exposed nearby.

A little blasting had been done in two small pits 100 yards apart on the south point of a hill. The manganese ore body here is a horizontal lens lying at the top of the Fernvale limestone. In neither pit is its full thickness shown, but the portion shown in one pit is 24 inches thick and in the other 27 inches. Between the pits it measures only 8 inches in thickness. The ore body was formed by a replacement of the top portion of the limestone. The manganese minerals include white, gray, and brown carbonates and the oxides hausmannite and psilomelane. A sample consisting of the carbonates and oxides is said to show on analysis 40 percent of manganese.

Loose masses of oxide ore, as well as some adhering to the limestone, are reported to have been found along the hill slope at the top of the Fernvale limestone for a quarter of a mile or more northwest of the openings.

ALEX. FULKS PROSPECT

A prospect on land owned by Alex. Fulks is in a small hollow on the southeast side of Dry Creek, in the NW¼ sec. 33, T. 15 N., R. 9 W., south of the White River and about 1¾ miles south of Guion. Considerable work has been done here recently by C. C. Sims, but little or no manganese ore has been shipped. The workings consist of several pits and cuts that extend along both sides of the hollow for a distance of about 750 feet. Limestone ledges are exposed both in the pits and on the surface. The lowest limestone exposed in the hollow is the Fernvale limestone, but above it there is 20 feet of pinkish-gray fossiliferous St. Clair limestone, and above the St. Clair is several feet of brown crinoidal limestone, which is the St. Joe limestone member of the Boone chert. The slopes above the St. Joe limestone are covered with chert debris.

The two largest openings are cuts each about 60 feet long on the northeast side of the hollow. They have been dug along the outcrop of the St. Joe limestone. The face of the cut to the northwest shows well the occurrence of the manganese in the limestone. The recognizable mineral is an oxide, probably psilomelane, that occurs in irregular masses in a 2-inch zone for 25 feet along the face of the cut and as fine particles in irregular areas especially along cracks in the 2 feet of limestone below the 2-inch zone. Below this 2-foot bed of limestone are 8 inches of red shaly limestone (above) and 5 inches of gray shale (below), which are presumably the basal beds of the St. Joe limestone. The face of the cut to the southeast shows 3 feet or more of reddish-brown limestone like that in the northwest cut, but the surfaces of the fragments of the limestone blasted from the cut have turned black from the formation of a surficial coating of manganese oxide.

Three pits on the southwest side of the hollow were badly caved at the time of visit, but they show St. Joe limestone that has been stained black by manganese oxide.

About 200 yards northwest of the cuts on the northeast side of the hollow a pit has been dug in residual soil overlying St. Joe limestone, and from this pit porous psilomelane and wad have been obtained and placed in a small pile nearby.

The manganese oxides at this locality appear to be derived partly if not wholly from disseminated manganese carbonate in the limestone. The red color of the unweathered limestone does not, however, appear to be due to the presence of manganese carbonate, but to red earthy material like that so widely present in the St. Joe farther west in Arkansas. No analyses of the limestone are available to the writer, but the inference, based on the small quantity of manganese oxides in the residual clay and the absence of a black film on the surfaces of much of the limestone, is that the manganese content is low.

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