OKLAHOMA GEOLOGICAL SURVEY

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IRON ORES

by

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Mineral Reports:

- No. 1, Volcanic Ash and Tripoli
- No. 2, Phosphate
- No. 3, Glass Sand
- No. 4, Iron Ores

In Preparation:

- Asphalt
- Limestone
- Dolomite

FOREWORD

The purpose of this report is to make available a summary of known data on occurrences of the iron ores of Oklahoma. Part I deals with the deposits of the Wichita Mountains area, Part II with iron ores in the Arbuckle Mountains, and Part III with scattered, miscellaneous deposits in other parts of the state.

The iron ores of Oklahoma are of several types, and much study remains to determine their exact characteristics and economic possibilities. However, it is believed a summary report giving brief descriptions of known materials, locations of deposits, and suggestions as to economic possibilities should be made available.

The iron ores of the Wichitas are magnetite and hematite, whereas those in the Arbuckles are principally limonite. Attempts have been made to utilize the hematite of the Wichitas for paint pigment. During the recent State Mineral Survey*, these deposits and many old prospect holes were investigated and sampled. The results of this work, and available literature supplemented by additional field and laboratory work, form the basis of this report.

Additional details on many iron ore deposits are available at the offices of the Oklahoma Geological Survey at Norman. Persons interested in particular deposits or particular types of ore may secure additional information, so far as it is available, by writing or visiting the Survey offices.

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*W.P.A. Project 65-65-538, sponsored and directed by the Oklahoma Geological Survey, 1936-1937.

CONTENTS

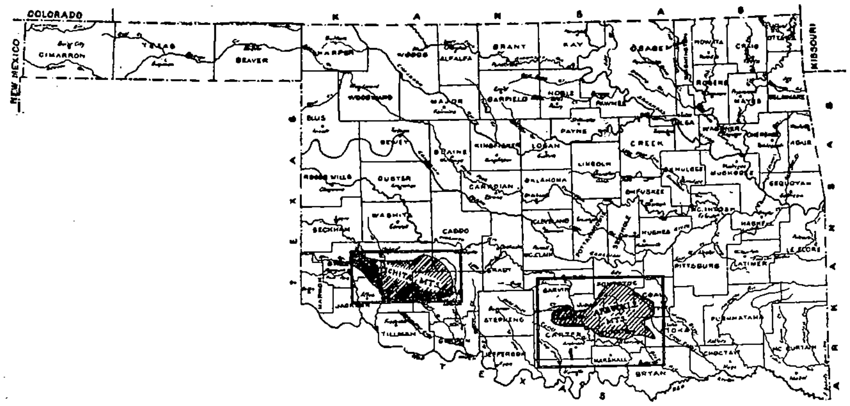

Fig. 1. Index Map of Oklahoma, showing location of Arbuckle and Wichita Mountains.

I. WICHITA MOUNTAIN AREA[1]

GENERAL GEOLOGY OF THE AREA

The geology of the Wichita Mountain region has been described (2,3,4)* and no attempt is made here to review it completely. However,a knowledge of some of the broader features is essential to an understanding of the iron ores and a brief summary is given.

The iron ores are located in the Wichitas, Kiowa and Comanche Counties, southwestern Oklahoma. These mountains form a physiographic unit consisting of hills and knobs rising above a flat plain, and extending from Fort Sill northwest to beyond Granite, a distance of 65 miles. In width, the Wichitas vary from a fraction of a mile to 28 miles.

The hills of the region are mainly Pre-Cambrian igneous rocks (granites, gabbros, and anorthosites). The flats are underlain by basic igneous rocks and Permian "red bed" sediments. Some hills on the outskirts of the region are formed of lower Paleozoic sedimentary rocks.[5]

The igneous rocks are probably continuous below the surface, underlying the sedimentary rocks,and are exposed only where they are sufficiently high to protrude above the sedimentary mantle.

A. MAGNETITE DEPOSITS

Small fragments of magnetite, common in all the anorthosite-gabbro areas, often have been weathered free from the igneous rock and are scattered over the ground. The magnetite also occurs in more or less concentrated masses intimately associated with the basic igneous rocks (anorthosites). Some of these latter deposits

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*See Bibliography at the end of this report.

have been tested by pits, trenches, and shafts but none of these workings are extensive. Magnetite is found throughout the anorthosite exposures but no large mass of this mineral has been uncovered. Whether or not large deposits occur is a question that can be answered only by a dip needle or magnetometer survey, or by core drilling. The surface exposures of the magnetite are irregular and in all probability the shape of the mass below the surface also is erratic. Estimates as to the size of the deposits cannot be made with the data at present available.

Only detailed surface mapping of the entire area would make possible the enumeration of all the deposits. Even if this were done, it would be difficult to draw the line between the anorthosites containing a considerable amount of magnetite, yet of no economic importance, and those that might have some commercial possibilities. Therefore, only a few type occurrences of the magnetite will be described.

SE¼ sec. 14, T. 4 N., R. 17 W., Kiowa County.

Magnetite fragments are abundant in a zone of altered anorthosite. This zone is approximately 40 feet wide and is exposed along the west bank of a creek. The other dimensions are unknown, but the deposit seems to be larger than most of those in the region. Granite intrudes the anorthosite close to the iron ore and the alteration of the basic igneous rock undoubtedly has been caused by solutions from this intrusion.

SE SE SE sec. 18, T. 4 N., R. 16 W., Kiowa County.

Magnetite fragments are found in an old prospect pit 6 feet deep in anorthosite. There has been considerable hydrothermal alteration and the rock has become loose and friable. Quartz stringers, and also some malachite (copper carbonate), are present.

NW SW sec. 24, T. 4 N., R. 16 W., Kiowa County.

Loose magnetite fragments are abundant over an area of 5 acres. The mineral is associated with loose anorthosite fragments and probably is a residual product from the weathering of the igneous rock.

NW$\frac{1}{4}$ sec. 29, T. 4 N., R. 16 W., Kiowa County.

Pieces of magnetite are scattered over an area 50 yards square on the side of a hill. The mineral is associated with anorthosite fragments.

NW$\frac{1}{4}$ sec. 33, T. 4 N., R. 16 W., Kiowa County.

Magnetite fragments are scattered over an area of 10 square feet. A shaft nearby shows the magnetite associated with anorthosite.

SE$\frac{1}{4}$ sec. 4, T. 3 N., R. 13 W., Comanche County.

Magnetite is found in a fissured zone at the contact of anorthosite and granite. Some of the iron mineral also is disseminated throughout the anorthosite. There has been some oxidation with the production of iron oxides and leucoxene (hydrous titanium oxide).

NW$\frac{1}{4}$ sec. 21, T. 3 N., R. 14 W., Comanche County.

A shaft, 100 feet deep, has been sunk at the contact of anorthosite and granophyre and an inspection of the material from this opening shows magnetite, sphalerite (ZnS), and galena (PbS). Considerable hydrothermal alteration is evident and the sulphide minerals probably were introduced by solutions from the granite magma.

Summary.—In all deposits there is clear evidence that the magnetite is associated with anorthosite. Even where the surface rocks are Permian, the presence of igneous minerals indicates the close connection between the magnetite and the anorthosite, and it is evident that the basic igneous rock underlies the sediments. In two deposits the magnetite is located at the contact of anorthosite and granite. In all cases there has been some hydrothermal alteration by igneous solutions, and also the introduction of quartz and other minerals.

All samples of the ore show some degree of surface weathering. The magnetite is partially altered to limonite and hematite and the ilmenite is partially altered to leucoxene and limonite. The outside of the magnetite specimens usually has a brown or yellow coating, whereas the inside is black and unaltered. The magnetite occurs as fine to coarse fragments in the deposits. Poorly defined octahedral crystals eight inches wide have been found, but usually the crystals are small and indistinct. Some specimens show a small amount of chalcopyrite ($CuFeS_2$), which may be partially altered to malachite (copper carbonate). In others, galena (PbS) and sphalerite (ZnS) are present and in most samples some quartz can be detected.

In general, the deposits have unknown boundaries that probably are irregular.

Chemical Character of the Ore

Three complete analyses of massive magnetite are given below. The specimens analyzed were selected hand specimens of magnetite containing very few impurities.

	No. 1	No. 2	No. 3
SiO_2	2.52%	2.20%	13.56%
FeO	5.34	10.43	31.64
Fe_2O_3	71.68	61.95	27.35
Al_2O_3	8.61	7.53	2.76
MnO_2	trace	trace	0.30
TiO_2	10.93	16.05	14.30
CaO	-----	-----	0.90
MgO	1.47	2.83	9.02
P_2O_5	1.07	trace	----
K_2O	-----	-----	0.40
Na_2O	-----	-----	0.60
S	-----	-----	----
CoO	-----	-----	----
NiO	-----	-----	----
Cr_2O_3	-----	-----	----
Total	101.62	100.99	100.85
Total Fe.	54.28	51.44	43.70

Three partial analyses also were made on hand samples from various deposits, though in these the samples were selected as typical of the average ore.

	No. 4	No. 5	No. 6
TiO_2.	-----	5.20%	4.40%
Fe.	19.80%	13.70	11.50
Insoluble residue*. .	56.60	75.34	73.00

No. 1. NW$\frac{1}{4}$ sec. 24, T. 4 N., R. 16 W.; No. 2. SW$\frac{1}{4}$ sec. 7, T. 4 N., R. 16 W.; No. 3. SE$\frac{1}{4}$ sec. 14, T. 4 N., R. 17 W.; No. 4. sec. 21, T. 3 N., R. 14 W.; No. 5. S$\frac{1}{2}$ SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 33, T. 4 N., R. 16 W.; No. 6. NW$\frac{1}{4}$ SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 4, T. 3 N., R. 13 W.

Analyses made by S. G. English and H. Sudduth, chemists for the Oklahoma Geological Survey.

*Insoluble residue after treating with concentrated HCl, HNO_3, and H_2SO_4. The residue is mainly undecomposed silicates.

Microscopic Character of the Ore

On microscopic examination ilmenite ($FeTiO_3$), can be seen to be present in the ore as small crystals with rectangular outlines and also as irregular elongated fragments. Also, in part, it is intimately intergrown as minute stringers up to 1 mm. in length, along the octahedral planes of magnetite crystals.

Minor amounts of diallage, biotite, and hornblende were noticed in thin sections. These minerals are partially altered to chlorite. A few grains and stringers of quartz were detected and also a little malachite and azurite.

A study of the chemical analyses, polished specimens, and thin sections show the following points:

1. The magnetite is titaniferous.

2. Analyses Nos. 1 and 2 show insufficient ferrous iron for all the titanium to be present as ilmenite, therefore, the ilmenite has in part been altered to hematite, limonite, and leucoxene. These minerals can be observed in the polished and hand specimens.

3. In the same specimens the low ferrous content shows that the magnetite has been partially altered to hematite and limonite.

4. In analysis No. 3 the ferrous content is high, indicating that there has been very little oxidation of the material.

5. The magnesium and aluminum are present as silicates, chiefly pyroxenes and their alteration products.

6. The titanium oxide content varies from 0 to 16.05 per cent. In sample No. 4, no titanium is present, but this specimen probably represents only a local phase of the ore. Furthermore, this sample and Nos. 5 and 6 are high in silicates and little titanium would be expected.

The variable chemical character of the deposits is indicated by these analyses. The amount of iron varies inversely with the quantity of titanium.

Origin of the Magnetite Deposits

Similarities of these occurrences with those of the titaniferous magnetites in other parts of the United States, which generally are considered to have been formed by crystallization from magmas (magmatic segregation deposits), strongly suggest that these iron ores had a similar origin.

The presence of magnetite in all the igneous rocks of the area and the intimate association of the iron mineral with the anorthosite support this hypothesis. The irregular shape of the deposits and their erratic distribution further corroborate this interpretation. Undoubtedly some hydrothermal action has taken place, for chalcopyrite, galena, sphalerite, and quartz were formed by deposition from magmatic solutions emanating from the granite magmas. The intense hydrothermal alteration of the anorthosite in some localities also supports this idea.

Surface weathering has partially altered chalcopyrite to malachite, azurite, and limonite; magnetite to hematite and limonite; and ilmenite to leucoxene and limonite.

Economic Possibilities of the Magnetite Deposits

It is possible that detailed studies of the area might uncover ore bodies of magnetite sufficiently large for mining purposes, providing that other conditions were favorable. Unfortunately, at the present time, the iron industry is prejudiced against titaniferous iron ores, and they are generally not acceptable if the titanium content is more than one per cent. The ores of the Wichitas have a variable titanium content, but the average of six analyses is 8.40 per cent TiO_2 (5.04 Ti).

The prejudice against titaniferous iron ores is due to the belief that such material requires an excessive amount of fuel to reduce it, and also that an infusible titanium compound develops, which accumulates and chokes the furnace. This makes the operation expensive, and it also requires more skilled labor to manipulate the furnaces. Since large quantities of hematite ore, free from titanium, are available, the titaniferous ones are utilized only in special cases.

Singewald (6) has experimented on the separation of ilmenite from magnetite by electromagnetic methods in ores from various localities, and in all tests he reduced the titanium content considerably,but not sufficiently to warrant mining. The intimate intermixture of the two minerals, and especially the presence of ilmenite along the crystal lines (octahedral) of magnetite, prevents a complete separation.

Experiments by Stansfield (7) and others with the electric furnace have given promising results, and it is possible that future years may bring a change in the status of these ores. The absence of sulphur is a point in their favor, and the presence of a certain amount of titanium is required in the manufacture of special alloys, such as tool steels.

There are several titaniferous-magnetite deposits known in the United States, some of which contain large bodies of ore and are located advantageously with respect to coke and industrial centers. It is likely that these will be developed before such less favorably situated ones, as those of the Wichita region.

Magnetite Sands of the Wichita Mountains

The sands of the Wichita Mountain area contain considerable titaniferous magnetite, derived from the anorthosites by weathering. Magnetite is found in the Permian sediments on the flanks of the mountains and in the Tertiary and Quaternary sediments in the central part of the region. These deposits have no commercial possibilities.

B. HEMATITE DEPOSITS

The hematite deposits of the Wichitas are found in the Reagan sandstone of Cambrian age, and are not related to the magnetite ores of the area, though it is possible that the latter deposits may have been one source of the iron in the hematite. The hematite ores occur as a bedded deposit in a sandstone member about forty feet above the base of the formation. Some of the beds are stained black by manganese oxides, and many contain considerable glauconite.

The only hematite occurrence of any size in the area is located in T. 4 N., Rs. 12 and 13 W. Williams (8) has described this deposit as follows:

> "A considerable body of iron ore (Fe_2O_3) occurs in the Reagan about forty feet above its base. The rocks at this point dip at an average angle of 30° to the northeast with a

> width of ore body of twenty-one feet. The ore is exposed for a distance of at least a mile in a general northwest-southeast direction. The ore body is nine feet thick three-fourths of a mile southeast of the principal mine shaft."

Chemical analyses of samples from different parts of the deposit show considerable variation in the iron content. Shead (9) reports analyses of the ore as follows: "Hematite, secs. 1 and 2, T. 4 N., R. 13 W., and secs. 7, 17, 20, 21, T. 4 N., R. 12 W., Comanche County. Ore body is 200 feet wide, runs 35 per cent Fe at the east end of the outcrop and 7 per cent Fe at the fault in section 7."

A representative sample was taken from a trench in sec. 17, T. 4 N., R. 12 W., from which a few tons of ore were shipped some years ago. This material, analyzed in the Oklahoma Geological Survey laboratory, showed the following content:

	%		%		%
SiO_2	63.22	TiO_2	trace	P_2O_5	0.41
Al_2O_3	4.42	CaO	0.19	CO_2	----
FeO	1.18	MgO	0.36		
Fe_2O_3	30.80	K_2O	0.53	Total	101.55
MnO_2	trace	Na_2O	0.44	Total Fe	22.46

A study of thin sections and polished specimens of the ore shows it to be essentially a sandstone with considerable hematite in the cement. The sand is rounded to sub-angular in shape and varies in size from 0.1 to 0.75 mm. in diameter. Rounded (oölitic) hematite grains are numerous. These are more or less rounded and have circular to elliptical cross sections, varying in size from 0.3 to 1.5 mm. in diameter. Many of the oölites have a sand grain in the center, but others have no observable nucleus. The oölites commonly show fine concentric bands. A green mineral is present as irregular masses both in the oölites and in the cement between the sand grains. This green mineral is chamosite ($Al_2O_3.3FeO.2SiO_2.x\ H_2O$).

Hayes (10) describes the Wichita hematites as follows:

> "The spherules, about half a millimeter in diameter, have an onion-like structure consisting of alternate concentric layers of hematite and a green iron silicate resembling chamosite. They are similar to those of the Wabana iron ores of Newfoundland of Ordovician age. Recrystallized hematite with some magnetic iron mineral occurs interstially between the sand grains and spherules and sparingly within the spherules."

The author believes that the chamosite and most of the hematite were formed at the same time as the Reagan sandstone, that is, the iron minerals were precipitated from the sea waters in which the sandstone was accumulating. However, there may have been some oxidation of the chamosite since Reagan time, and thus part of the hematite may belong to a later generation.

Economic Possibilities

A few attempts have been made to mine these hematite ores. The mining, however, has been on a small scale and has not involved any detailed surveys of the deposits nor systematic experiments on the best methods of utilizing the material. At one time, paint was manufactured at the workings by crushing the ores and treating them with oils. Some tons of ore also were shipped to Oklahoma City and treated in a similar manner. The large content of sand in the hematite gave the paint excellent adhering properties and it was hoped that it would be used for shingle paint and other similar purposes. For some reason these activities were abandoned after a short time, and there has been no mining at these deposits during the last few years. It is possible that paint pigment might be obtained profitably, especially if the hematite ores were first concentrated.

II. ARBUCKLE MOUNTAIN AREA

GENERAL GEOLOGY OF THE AREA

The Arbuckle Mountains form a rudely triangular plateau area approximately 50 miles along each side, located in Murray, Johnston, Carter, Pontotoc, Atoka, and Coal Counties. Geologically, the area consists of great thicknesses of early Paleozoic sedimentary rocks, chiefly limestones and dolomites, which are flanked by late Paleozoic and Cretaceous rocks. In the central portion of the mountains there are exposures of Pre-Cambrian igneous rocks.

The area has been highly folded and faulted and the structure is complex. In several places the sedimentary beds dip at high angles or are almost vertical, with the result that many beds of different formations and character are exposed within a few square miles. This complex structure is of considerable importance in studying the iron ores of the region.

BROWN-IRON ORES

Brown iron ores have been known in the Arbuckle Mountains for many years, but the literature on these ores is extremely meager. A brief general description has been given by Reeds (11), and a map of the surface exposures of a few of these deposits, by G. E. Burton in 1917, is in the files of the Oklahoma Geological Survey.

The brown iron ores are found associated with the Arbuckle dolomites and limestones, Simpson sands, and Viola and Hunton limestones, but especially with the rocks of the Arbuckle group. The ores occur as small masses in many places, but known deposits of appreciable size are few in number. Some of the larger deposits occur at the crests of small hills, due to the greater resistance of the iron ore to erosion, and others are related to faults or folds. At the surface, the ore occurs in intimate contact with the country rock or as loose surface fragments varying from the size of shot to masses several feet in diameter, and weighing several tons. The surface exposures of the ore are variable, some covering only a few square feet, while others have large fragments scattered over several acres. On some of the larger outcrops, several tons of iron ore are in sight, but the soil covering prevents any estimate of the continuity of the ore or the amount of country rock present.

The ore is the so-called brown iron ore, which is a term applied to the hydrous oxides of iron. The Arbuckle Mountain ores are mainly a mixture of limonite ($Fe_2O_3.nH_2O$) and goethite ($Fe_2O_3.H_2O$). Some varieties are brown to black and cellular, while others are yellow and earthy, and still others black, dense, and botryoidal. The black type often is composed of radiating fine needles of goethite; while the porous type commonly has a thin layer of needle goethite lining the cavities. Such goethite must have been formed after the limonite. Small amounts of hematite sometimes are present, also minute crystals of wavellite $[Al_3(OH)_3(PO_4)_2.5H_2O]$, and some fragments of gray, botryoidal opal. Chert is rather abundant in most of the localities.

In some deposits, crystal faces varying from 1/8 inch to 1 inch are noticeable. These are cubes, cubo-octahedrons, octahedrons, pyritohedrons, and cubes modified by pyritohedrons. These crystals furnish clear evidence that the original mineral was pyrite, and that the limonite is pseudomorphic. Other fragments are stalatitic or pipe-like, which character suggests pseudomorphs after marcasite. Goethite is rare or absent in the pseudomorphic ore. Thin coatings of residual clay and sand cover the tops and flanks of the hills.

Chemical analyses made on selected surface specimens, which were washed to remove any adhering sand or clay, gave the following results:

	1.*	2.**
SiO_2	3.68%	7.41%
Al_2O_3	0.86	1.88
Fe_2O_3	83.61	79.44
TiO_2	trace	trace
MnO_2	trace	0.07
P_2O_5	none#	0.03#
CaO	0.02	0.25
MgO	0.38	0.07
K_2O	0.10	0.19
Na_2O	0.52	0.49
CO_2	0.11	0.06
H_2O	10.81	11.61
S	0.14	0.11
Total	100.23	101.61
Fe	58.48	55.56
P	-----	0.014

*Analysis by R. G. Mihram, Chemist, Oklahoma Geological Survey. Surface sample from deposit No. 3, NE¼ sec. 31, T. 1 N., R. 5 E., Pontotoc County, lab. no. 8196.

**Analysis by S. G. English, Chemist, Oklahoma Geological Survey. Surface sample from deposit no. 2, NE¼ sec. 1, T. 1 S., R. 4 E., Johnston County, lab. no. 8195.

#The specimens analysed were taken from the surface, and all or part of the phosphorous may have been leached from the ore.

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The average iron content of the above samples is 57.02%. This figure probably is somewhat higher than the average ore, as the samples were selected hand specimens, from which the sand and clay had been washed. The low content or absence of phosphorous probably is due to the leaching of the surface ore by meteoric waters.

Analysis No. 1 was made from a specimen of brown-ore pseudomorphic after pyrite and marcasite, and the low sulfur content indicates an almost complete oxidation of the sulfide minerals at the surface. Analysis No. 2 is from altered siderite and a low sulfur would be expected. Possibly this latter ore also originally contained a little pyrite or marcasite.

The silica is present chiefly as chert, but to a less extent as clay silicates. The carbon dioxide, calcium, and magnesium represent a small amount of associated dolomite.

Unfortunately, only surface or near surface samples are available for analysis, and this point must be kept in mind in interpreting the analyses. With depth, oxidation and leaching may be less complete and this may mean a change in chemical character, especially in the sulfur and phosphorous content.

The ores are somewhat similar to those of Missouri, and the following quotation from Crane (12) gives an interesting comparison.

> "Chemical Composition: The ore is a uniformly low grade limonite. The iron content of car load shipments ranges from 41% to 50% and averages about 45.50%. The range for silica is from 13.50% to excessive, while phosphorous varies from traces in the leached ore to 0.10%, but averages about 0.06%. Sulphur is uniformly low, rarely exceeding .10% and is never present in visible quantities as in the secondary limonite. Manganese is present in quantities ranging from 0.35% to 3.00%, being uniformly higher than in the secondary ore. Moisture varies from 1% to 5% and the loss by ignition is from 7% to 11.25%."

Chemically, the Arbuckle iron ores appear to compare favorably with brown ores of other parts of the United States, as for instance, those of Tennessee, Georgia, Alabama, and Missouri.

Origin of the Ores

The importance of the origin of these deposits lies in its implications concerning the size, shape, depth, and character of the deposits, which features are of the utmost importance in determining the economic possibilities of the ore, and also the manner of prospecting and mining. The origin of the ores involve several points, namely (1) the source of the iron, (2) the manner of transportation and precipitation of the iron, (3) localization of the deposits, and (4) later alterations of the deposits.

The source of the iron seems to have been the country rocks of the general region in which the deposit occurs, probably to a large extent the rocks which have been eroded away from higher levels in the adjacent few square miles. As previously stated, the sedimentary rocks in some localities, are highly folded and dip at steep angles, a structural condition which exposes many sedimentary beds in a small horizontal area. The weathering of such a region would affect many different beds, all of which contain iron. Most of the beds have minor amounts of iron, but some, such as the glauconitic Reagan sandstone, have considerable quantities. The weathering of such rocks would produce iron-bearing solutions, and these would migrate to lower levels along the openings, especially through porous rocks, joints, sink holes, or along faults. Most of the unweathered rocks associated with ores are rather compact and porosity seems to have been a minor factor compared with structural openings, especially faults. In some instances the structure of the area may have produced artesian circulation, and the ground waters later would rise to the surface along faults as artesian springs or flows. Warm artesian waters of meteoric origin probably produced the manganese deposits southwest of Bromide and also the iron ore associated with them. In special cases, of favorable structure, solutions may have come from considerable distance along the dip of a sedimentary bed. In an area as structurally complex as the Arbuckles, involving as it does many types of sediments and numerous faults and folds, the question of the source of iron is difficult to answer for all deposits. The original source of the sulfur, likewise is unknown.

The transportation of iron probably took place as the iron bicarbonate in meteoric waters, which were generally cold, but perhaps warm or hot in artesian circulation. The iron solutions encountering limestone or dolomite beds would precipitate siderite ($FeCO_3$) and dissolve calcite or dolomite. This reaction (replacement) is due to the lower solubility of the siderite than that of the limestone or dolomite. Some limonite pseudomorphs after small siderite rhombohedrons were noted in thin sections, a feature which corroborates this interpretation. In other cases sulfur was present in the solutions and the iron was precipitated as pyrite, or marcasite, as is clearly shown by the limonite pseudomorphic cubes, and other crystal forms. The siderite deposits later weathered near the surface to limonite and goethite, while the pyrite and marcasite deposits weathered to limonite.

The weathering of the deposits and associated rocks has produced some residual ores at the surface and also some sand and clay. Usually this residual mantle is quite thin, less than a few feet deep, though it may have a considerable areal extent if the eroded rocks were flat. The ores probably are Tertiary or recent in age, since old deposits, if any, would have been removed by erosion. Very few brown ores older than Tertiary have been recognized in any part of the world.

Economic Possibilities

If other factors were favorable, the content of iron is sufficiently high, as indicated in the analyses, to furnish iron ore, though probably the ore, as mined, will not be as rich in iron as the selected hand samples analyzed. The associated dolomite or limestone may assist in the fluxing of the ore, though an excess of carbonate might necessitate the addition of silica.

The sizes of the iron deposits are unknown. At the surface, limonite is exposed in some deposits over an area of a few square yards, while in others the surface exposure covers several acres. The soil covering, however, prevents the determination of the continuity of the ore throughout these areas, though in a few deposits, trenches, some 50 feet long, show solid ore at the sides and bottom. The quantity of ore can be determined only by detailed prospecting involving trenches, pits, shafts, coring, or geophysical methods. Brown-iron ores are notoriously erratic in size and shape, and without more data than are now available, any prediction concerning volume is of little value.

In all probability the ores will not extend to great depths and their outlines will be irregular. The lower limit of replacement by descending meteoric waters would be the ground water table and some of the deposits probably extend to that depth, which is 50 feet or more below the top of the iron hills. No direct evidence of this is available, but a few shafts have been sunk from 6 to 20 feet and have remained in solid ore to the bottoms of the workings. In special cases, where artesian circulation formed the ores, the depth may extend somewhat below the ground water table. On the other hand, some of the deposits may play out within a few feet of the surface as in the residual ores or those associated with shallow joints or crevices.

The ores are considered to have developed by the replacement of dolomite or limestone by siderite, or pyrite and marcasite, the iron solutions entering along openings such as faults, joints, or crevices, and replacing the carbonate rock from those inlets. Later surface weathering has caused some residual concentration of the ore. If this interpretation of the origin is correct, the ores will have an irregular shape, the latter depending primarily on the ease of replacement of the country rock, and the iron ores at depth may have a different horizontal extent from the surface exposures, if different sedimentary beds are encountered at depth. Furthermore, the replacement may or may not be complete and it is possible unreplaced masses of the country rock might be found associated with the ore at depth. Also, the weathering of flat rocks containing scattered masses of ore would produce a residual soil containing scattered ore fragments, perhaps over a considerable area, but with a thickness of only a foot or a few feet.

The completeness of oxidation also is an important economic consideration. In those deposits which have considerable thickness there should be three mineralogical zones which grade into one another with depth. The upper zone will consist of thoroughly weathered ore, that is, limonite,or a mixture of limonite and goethite. The intermediate zone will be partially oxidized siderite or iron sulfides, and the lower zone will be unaltered siderite, or pyrite and marcasite. If oxidization has continued for a long period of time, the oxidized material may extend to the ground water table, if the original ore extended that deep. If the alteration has been limited in time, the oxidized material may be quite shallow.

In the case of the altered pyrite and marcasite deposits, the depth of complete oxidation is of the utmost importance, for partially altered pyrite will have a high sulfur content and be unusable. Fresh unaltered pyrite could be used to manufacture sulfuric acid, but if the zone of partially oxidized material is wide, it would be too costly to remove it. Furthermore, no vertical shafts exist in these altered sulfide deposits, and thus there is no direct evidence concerning their depth. The Missouri deposits are somewhat similar and the following discussion by Crane (13) may be of interest.

"Size of the Deposits: The deposits vary greatly in size, those directly associated with the limestone being usually small, often containing only a few tons of ore, while those embedded in residual clays are frequently large, some of them having produced more than 60,000 tons. Where the ore outcrops over several acres the tonnage will probably exceed this figure. It is hardly probable, however, that many deposits will exceed 100,000 tons.

"Depth of the Deposits: The thickness of the deposits appears to be as variable as their lateral dimensions. In case the ore occurs upon or is closely associated with limestone it frequently extends only a few feet beneath the surface. Where the ore is embedded in a thick mantle of residual material, it often has a considerable thickness, several such deposits having been worked to a depth of 50 feet without reaching the lower limits of the ore body. The pit at the Kingsbury mine, in Howell County, is 70 feet deep and is still in ore. In the immediate vicinity of this mine a 200 foot hole, drilled for water, while not showing ore, was entirely in residual material and indicates the possible depth to which the ore might extend.

"Outcrop: Outcrops of this class of deposits vary greatly in size and form and often indicate the nature of the deposits. However, in most cases the character and size of the outcrop are insufficient criteria upon which to base a reliable estimate of the size of an ore body.

"A very promising form of outcrop consists of large and small fragments of ore, forming a small knoll on the crest of a hill or ridge. Outcrops of this type are particularly characteristic of those localities where the residuum is thickest, and are generally indicative of important deposits of ore."

Brown ores at one time furnished much of the country's iron, but the development of the Lake Superior iron ores caused a decline in their production. However, they still are actively mined, and in 1930 they furnished 1.2 percent of the country's ore, that is 720,500 tons of ore with a 38 to 52 percent iron content. Also they are considered one of the great iron reserves of the country, it being estimated that at least 3,750,000,000 tons are available in the southern states.

The present knowledge of the Arbuckle brown iron ores is far too sketchy to make any predictions concerning the feasibility of mining them. Only detailed studies can answer this question. The writer believes, however, that the general features are sufficiently encouraging to justify the expense of such studies.

The study should include detailed geologic mapping of the areas where iron ores are known to occur, and especially, careful prospecting of all faults and folds. Geophysical prospecting might be a valuable supplement to surface geology. Single deposits are too small to keep a furnace operating over a long period of time, and smelting operations would have to depend on many deposits. Brown ores are so erratic that any development should be on a small scale, and in general, hand labor rather than expensive machinery should be used, at least in the prospecting stages.

The problem also is intimately linked with the availability of coke, and the coking possibilities of Oklahoma coals should be thoroughly investigated. At one time considerable coke was manufactured in old Indian Territory.

Description of Some of the Brown Iron Ore Deposits

Sec. 6, T. 1 N., R. 5 E., Pontotoc County.

This deposit is exposed on two low adjacent hills in the north-central part of the section. The ore occurs as numerous masses, of variable sizes, many being several feet across, scattered over the tops and flanks of the two hills. The total amount of ore exposed at the surface is several tons. The soil covering between the ore fragments prevents a determination of the continuity of the ore, and there are no workings to assist one in this problem.

The ore is dark-brown to black limonite and goethite; much of it is porous (cellular) though a little is compact and dense. Some yellow, powdery limonite is noticeable and also a little hematite. Some fragments of the ore have an iridescent coating. Much of the goethite is in small needle-like crystals lining cavities in limonite, or as rounded masses with a fibrous structure. Chert fragments are common, intimately associated with the iron oxides.

The country rock is Arbuckle dolomite which is exposed as small outcrops on the side of the larger hill and also in outcrops a short distance to the north and to the south. The strikes and dips change considerably at the different outcrops, and the rocks obviously have been folded and possibly faulted. It seems probable that the localization of the ore is related to this structure.

NE$\frac{1}{4}$ sec. 1, T. 1 S., R. 4 E., Johnston County.

This deposit is located on a small hill, 25 feet high, on the north side of the quarter section. The hill, 200 x 300 feet, is covered with small to large masses of iron ore, many fragments being several feet wide. Several tons of ore are in sight. A trench 10 feet deep and 50 feet long, shows massive ore along the sides and bottom.

The ore is a mixture of limonite and goethite and in all respects similar to deposit No. 1. The ore is mainly dark-brown to black, cellular oxides, with a small amount of yellow limonite. Some of the ore is black, shiny, and botryoidal, with fine needles of goethite. The latter mineral also lines many cavities of the limonite as fine needle-like crystals. A few pseudomorphs of iron oxide after pyrite crystals were noticed, but these are rare, and in this respect the deposit is in marked contrast to the one a mile northeast (No. 3). Considerable chert is present and the lower flanks of the hills are covered with a thin layer of soil. The crest of the hill is covered with 5 feet of sand impregnated with iron. The sand probably is detrital.

A second small deposit was observed, about 700 feet southeast of the first hill, with Arbuckle dolomite and soil separating the two deposits.

Analysis No. 2 was made from a hand specimen taken from this deposit.

NE$\frac{1}{4}$ sec. 31, T. 1 N., R. 5 E., Pontotoc County.

This deposit is a mile northeast of deposit No. 2. Fragments of iron ore are found scattered over an area of many acres, though only in a few small areas is the ore concentrated. The ore now is dark-brown to black limonite and obviously is pseudomorphic after pyrite crystals. Cubes, cubo-octahedrons, octahedrons, pyritohedrons, and cubo-pyritohedron crystals are abundant. These vary in size from 1/8 inch or less up to 1 inch along a side. Most of the ore shows these crystal faces and thus originally enormous masses of pyrite crystals must have been present. Stalactitic and pipe-like forms suggest some original marcasite. It is not clear whether this deposit is related to the one a mile southwest (No. 2), as the intervening zone is soil-covered, and outcrops are few. It is possible that a wide structural or stratigraphic zone, including both these deposits, has been subjected to the action of iron-bearing solutions, though the two deposits are mineralogically distinct. This feature is not definite evidence that they could not be related, for it is possible for the same solutions to deposit different minerals at different places, since deposition depends upon the solubilities of the dissolved constituents and the amount of those constituents present. If the solutions contained ions of iron and sulfur and the bicarbonate radical, it is possible that FeS_2 and $FeCO_3$ might be precipitated from the same solution but at different points. In some spring deposits, manganese and iron minerals are precipitated from the same waters but at different places.

In most of this deposit, the iron ore is too scattered to have economic significance. It probably represents residual iron ore that was disseminated in Arbuckle dolomite, which has since been eroded away. No information concerning the depth of the deposit is available, but it seems probable that the ore has no great thickness over most of the area, though it is possible that one or more local areas where the ore is concentrated, may have a considerable depth.

Analysis No. 1 was made from a hand specimen taken from this deposit.

SW$\frac{1}{4}$ sec. 16, T. 1 S., R. 6 E., Johnston County.

Iron oxide fragments are scattered over an area 400 by 400 feet on the top and flanks of a hill 25 feet high. The ore occurs in the typical small to large fragments, many being several feet wide. A trench, 30 feet long and 12 feet deep, shows solid ore along the sides and the bottom. The total of the iron ore exposed at the surface, including that from the trench, represents many tons.

The ore is a mixture of limonite and goethite and is dark-brown to black in color, and porous (cellular). Some of the goethite occurs as fine needles lining the cavities in the limonite. A small amount of hematite and considerable chert were noted. Some specimens of the latter mineral show cracks filled with limonite. Under the microscope a few radiating-needle crystals of wavellite were noted; also thin sections show many rhombohedrons of siderite altered to limonite.

Most of the area is soil covered but there are a few outcrops of Arbuckle dolomite. The strike and dip of this rock changes from place to place, indicating a fold and possibly a fault. Another large deposit (No. 5) occurs a mile south, and a few iron ore fragments were found in the zone between. The connection, if any, between the two deposits is not clear, but it is possible there is some structural or stratigraphic connection and that a large area has been subjected to minor mineralization by iron solutions, with greater concentration in local areas.

SE$\frac{1}{4}$ sec. 21, T. 1 S., R. 6 E., Johnston County.

In almost all respects this deposit resembles the one a mile north (No. 4). In areal extent the iron ore fragments cover an area of 350 x 250 feet on the top and flanks of the hill. This deposit has two shafts, one about 6 feet deep and the other approximately 20 feet deep. The two shafts are only a few feet apart, and both show solid ore at the sides.

Partial analyses of hand samples from this deposit gave the following results:

	(1)	(2)
Insoluble residue*	4.32%	4.00%
Fe	57.1	56.7
MnO_2	0.03	trace

*Insoluble residue after treatment with conc. HCl, H_2SO_4, and HNO_3.

(1) Lab. No. 4859 (2) Lab. No. 4860.

NW SE sec. 11, T. 1 S., R. 6 E., Johnston County.

Brown iron ore fragments are scattered over an area of 2 or 3 acres. The ore occurs in large to small pieces. Some of the fragments are pseudomorphs after pyrite crystals, while others show no evidence of pseudomorphs. In a few small areas, considerable masses of ore are bunched together, but over most of the area the iron ore is scattered. Most of the ore appears to have been formed by the weathering of Arbuckle rocks which contained scattered masses of ore. The deposit probably is quite thin over most of the area, though it is possible that local masses may extend to depth.

Partial analyses of samples from this deposit gave the following results:

	(1)	(2)
Insoluble residue*	6.30%	3.42%
Fe	57.60	58.85
MnO_2	none	trace

*Insoluble residue, after treatment with conc. HCl, H_2SO_4, and HnO_3.

(1) Lab. No. 4880 (2) Lab. No. 4858.

NW$\frac{1}{4}$ sec. 15, T. 2 N., R. 5 E., Pontotoc County.

This deposit is located in sandstone of the Bromide formation, Simpson group. The ore is found over a small area, mainly as a sandstone impregnated with limonite. There is considerably more sand than limonite and the deposit has no commercial possibilities.

The rocks in this area have been folded into an anticline with a fault on the south side which has brought the Sylvan shale and Bromide sand in contact. This structure seems to have controlled the deposition of the iron minerals. Meteoric solutions containing iron migrated down the south-dipping porous sandstone (Bromide), until they reached the impervious Sylvan shale at the fault. The solutions here were dammed and precipitation of iron minerals took place. The limonite thus occurs north of the fault in the Simpson beds.

Iron-manganese deposits near Bromide.

In the vicinity of Bromide, several deposits of manganese occur and some of these have associated hydrous iron oxides. These deposits are essentially manganese and the iron content is rather small. They have been described by Hewett (14) and the reader is referred to his article for further details.

Other deposits of brown iron ore in the Arbuckle Mountains are known but the ones here described are considered typical.

III. OTHER IRON ORES OF OKLAHOMA

SIDERITE DEPOSITS

Small amounts of siderite have been reported from several of the vein deposits in the Ouachita Mountains, and also from the manganese deposits near Bromide. Such siderite is of scientific interest only.

Siderite appears to be rather widespread in the sediments of Pennsylvanian age. In these rocks it occurs as black dense layers (black band ore) usually thin and local in extent, and also as a nodular siderite in a conglomerate appearing rock (clay ironstone).

In sec. 5, T. 28 N., R. 22 E., Ottawa County (Survey of 1874), four or five beds of black dense siderite, each a few inches thick, are found interstratified with black shale, along the east bank of Neosho River, ½ mile upstream from a bridge. The siderite beds are exposed for 200 yards or more.

The occurrences of siderite known at present are too small to have any economic significance.

PYRITE AND MARCASITE

In 1911, 124 long tons of iron sulfides were mined from the zinc deposits of Oklahoma. The ore was used to manufacture sulfuric acid. No figures are available of the production of iron sulfides in later years, but such production, if any, is very small.

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SUPPLEMENTARY NOTE ON THE IRON ORES OF THE ARBUCKLE MOUNTAINS

(August, 1940)

Since the publication of Mineral Report No. 4, in January 1940, there has been some prospecting and production of iron ore from the Arbuckle Mountains and it seems advisable to make these additional data available at this time.

In recent years, special cements, containing higher quantities of iron and silica have been developed for use in massive concrete construction, to reduce the heats of hydration, and thereby minimize the alternate expansion and contraction, and the setting up of stresses in the concrete mass.

Iron ores are utilized by some plants to obtain the additional iron, and the Okla. Portland Cement Company, at Ada, has obtained 4,100 tons from Arbuckle Mountains brown-ore deposits of the Galbreath Iron and Manganese Company and the Concho Sand and Gravel Company. An additional tonnage is being utilized by founderies in Oklahoma. If the demand for both uses continues, the Arbuckle iron ores will be developed more extensively.

Description of Additional Deposits

Secs. 15 and 16, T. 1 S., R. 5 E., Johnston County.

This deposit is leased by the Concho Sand and Gravel Company of Oklahoma City and has produced 1,350 tons of iron ore to date (August, 1940) and many tons still are in sight. The ore is obtained from two places, one in NE$\frac{1}{4}$ sec. 16 and the other in NW$\frac{1}{4}$ sec. 15. The ore is the usual massive, pseudomorphic type after cubes and divergent crystal aggregates of pyrite, and the inner portions of some fragments still show unaltered pyrite. A few tons of barite were found in large white masses, composed of platy crystal aggregates; a little clear glassy opal also was observed. In sec. 16 the ore is scattered over the flanks of a low hill, as is also the case in sec. 15. In the latter locality, however, large masses of iron ore also were found at the top of a low hill. There is considerable sand, clay, and loose masses of Arbuckle dolomite present in the ore. The adjacent dolomite outcrops have variable strikes and dips, which indicates some type of structural anomaly. Some slickensides were noticed in the ore, showing there has been some post-mineralization faulting.

SE$\frac{1}{4}$ sec. 15, T. 1 S., R. 5 E., Johnston County.

The Galbreath Iron and Manganese Co. has produced several hundred tons of iron ore from this deposit, (August, 1940). It is located .75 mile southeast of the Concho Sand and Gravel Co. deposit, previously described. The ore occurs in two large hills. One hill shows Arbuckle dolomite outcrops with masses of iron ore scattered over the surface and also intimately associated with the dolomite, the ore being the usual pseudomorphic type after pyrite. Some slickensides were noted in the ore. The second hill has a few feet of soil covering which contains large and small masses of pseudomorphic ore. Below the soil is a layered sandy clay containing a high percentage of iron from which most of the production has come. This type is somewhat unusual in the Arbuckle area but it also is found in sec. 9, T. 1 N., R. 6 E., Pontotoc County, from which the Galbreath Iron and Manganese Co. also has produced some ore.

NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 15, T. 1 S., R. 7 E., Johnston County.

Masses of iron ore are found in limestone formation of the McLish (Simpson Group). The ore is on the surface and intimately associated with the limestone. Many tons of ore are in sight and a few trenches and pits have been dug, but there has been no production. The ore is the usual massive pseudomorphic type showing cube faces and also divergent aggregates of altered pyrite crystals. It is possible that the deposit is related to the fault between the McLish and Bromide formations. (15)

SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 27, T. 1 N., R. 4 E., Murray County.

Large and small masses of iron ore aggregating several tons, are scattered over two low hills of Arbuckle dolomite. Most of the ore is the common pseudomorphic type showing cube faces and divergent aggregates of altered pyrite crystals. Some of the ore, however, does not show these features. On the western hill there is a small outcrop of limonite,a few feet high, with an irregular contorted shape. There has been no production from this deposit.

Sec. 12, T. 2 S., R. 1 E., Murray County.

West of U. S. highway 77, several tons of limonite lie in piles around a shallow pit in Arbuckle dolomite.

Iron Ore in the Davis Zinc Field.

In secs. 17, 18, and 21, T. 1 S., R. 1 E., Murray County, deposits of sphalerite and smithsonite occur and at one time some zinc was produced. The mineralized region is confined to a zone of Arbuckle dolomites which strikes northwest and dips 40 to 50 degrees to the northeast. The structure, however, is complicated by minor folds and faults. Some of the rocks show brecciation.

Some iron ore is present in this mineralized zone and Snider has described it as follows (16). "Other metals occur in small quantities with the zinc. An interesting feature is a narrow belt of iron ore (hematite) seldom over one rod in width, which lies near the middle of the dolomite member throughout the length of the out-

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15. "Geologic Map of Arbuckle Mountains, Oklahoma," by Charles E. Decker, C. L. Cooper, and Rex McGehee, *Okla. Geol. Survey Bull*. 55, 1931.

16. Snider, L. C., "Preliminary Report on the Lead and Zinc of Oklahoma," *Okla. Geol. Survey Bull*.9, pp. 87-88, 1912.

crop. Boulders of hematite, in part altered to limonite, are strewn thickly along the surface of this belt. Some of them are as much as 10 feet in diameter. In only a few cases does the iron ore extend as much as 10 feet beneath the surface. The richest portion of the zinc ore so far seems to be in close proximity to this iron-bearing horizon.

"The cause of this segregation of the iron ore into so narrow a belt is problematic, but it is entirely possible that it is due to a small fault parallel to the strike of the rocks. Such a fault would be almost impossible to trace in the dolomite unless the ore itself be taken as evidence of its existence. The localization of the ore took place before the formation of the small faults perpendicular to the strike previously mentioned since the iron ore belt is offset by them."

The writer visited this area and found the occurrence as described by Snider, except that limonite is far more abundant than hematite, and goethite also is present. Some of the ore shows cube faces and divergent crystal aggregates indicating it is pseudomorphic after pyrite.

The iron ore may have been derived from the alteration of glauconite which is abundant in the Reagan sandstone of this area. It is possible that the weathering of the nearby Pre-Cambrian igneous rocks also furnished some of the iron.

The iron ore outcrops are small but numerous, and many tons of ore could easily be obtained from this region.

Secs. 8 and 9, T. 1 N., R. 6 E., Pontotoc County.

In the NW$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 9, large and small masses of iron ore are scattered over a low hill of Arbuckle dolomite. The ore is the usual pseudomorphic type showing cube faces after pyrite, but contains an unusually large amount of chert and also a few minute, glassy crystals of quartz. Below a few feet of soil at the top of the hill is a layer of clay, rich in iron. It is reported that four drill holes show iron ore to a depth of 28 feet. The Galbreath Iron and Manganese Co. has produced several hundred tons of ore from this deposit, to date (August, 1940).

In the NE$\frac{1}{4}$ sec. 8, a small amount of ore has been picked up from the flanks of a low hill of Arbuckle dolomite. The ore is the usual pseudomorphic type after pyrite crystals.