OKLAHOMA GEOLOGICAL SURVEY

Robert H. Dott, Director

Mineral Report No. 10

MANGANESE DEPOSITS OF OKLAHOMA

by

C. A. Merritt

NORMAN

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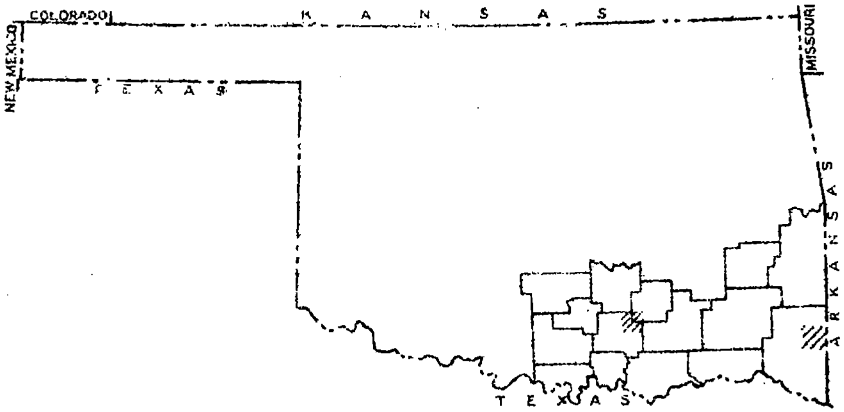

Figure 1. Index Map of Oklahoma showing areas of Manganese deposits discussed in this report (cross-hatched); located in Johnston, Coal, and McCurtain Counties. See figures 2 and 4 for details.

MANGANESE DEPOSITS OF OKLAHOMA

Introduction

Many inquires have been received by the Oklahoma Geological Survey in recent months concerning the occurrence of manganese in Oklahoma and the possibilities of its development.

In part these inquires could be answered by the excellent articles by Honess and Hewett. The latter, however, is not generally available to the public. Furthermore, some information concerning the deposits has been accumulated since these were published. Hence, it was thought advisable to write a general report on the manganese occurrence in Oklahoma and make the present information available to the public.

The material presented in this article is based on the previous literature, information accumulated by the recent State Mineral Survey*, and field and laboratory work by the writer during parts of the summers of 1940 and 1941.

The writer wishes to express his appreciation of the valuable field assistance rendered by Mr. W. E. Ham of the Oklahoma Geological Survey.

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

MANGANESE MINERALS

Numerous manganese minerals have been described, but few of these have any economic importance. With the exception of small amounts of rhodochrosite and manganocalcite, the world's manganese is obtained from the oxide minerals, especially psilomelane, pyrolusite, manganite, and wad. Hausmannite and franklenite are of local importance.

For the convenience of the reader the manganese minerals discussed in this article will be briefly described.

Oxide Minerals

Hausmannite, Mn_3O_4. (Mn, 72.1%). A steel-gray mineral with a chestnut-brown or reddish-brown streak; sub metallic luster; specific gravity 4.73 to 4.86; and hardness 5 to 5.5. It is tetragonal, commonly in minute octahedral-like crystals. These are brittle and show good basal cleavage. Hausmannite is found at Batesville, Arkansas, Olympic Peninsula, Washington, and Bromido, Oklahoma. In Oklahoma it occurs as minute grains intimately associated with manganocalcite and also with psilomelane. Hausmannite is generally interpreted as having been deposited from warm waters and it is not a weathering product of other manganese minerals.

Manganite, $Mn_2O_3.H_2O$. (Mn, 62.4%). A steel-gray to iron-black mineral with a dark-brown to black streak; sub-metallic luster; specific gravity 4.2 to 4.4; and hardness 4. It usually occurs as aggregates of thin radiating crystals. It is common in small amounts in manganese deposits.

Psilomelane. Chemical composition may be described by the formulae $MnO\ (Mn;K,Ba)O \cdot n\ H_2O$ and H_4Mn_5, but the composition is indefinite and the manganese content ranges from 50 to 57 percent. It is a black or steel-blue mineral, with specific gravity 3.7 to 4.7; hardness 5 to 6.5; sub-metallic luster; and conchoidal fracture. It usually is in rounded masses which are oxidation products of other manganese minerals.

Pyrolusite, MnO_2, generally with a little water (Mn, 60-63%). It is a grayish-black to black mineral, with a black or bluish-black streak; specific gravity 4.73 to 4.85; and hardness 2.0 to 2.5. It usually is granular and massive, but radiating columnar masses are common. It is a common weathering product of manganese minerals.

Wad, hydrous mixture of oxides of indefinite composition. The manganese content is therefore variable. Specific gravity is 3 to 4.3, very soft, color and streak black or brown. It is earthy and usually contains impurities of iron, silica, and alumnia.

Manganese Carbonates

Rhodochrosite, $MnCO_3$. (Mn, 47.8%). It is light rose in color, translucent, with vitreous luster. Rhombohedral cleavage; specific gravity 3.45 to 3.6; hardness 3.5 to 4.0. It often occurs in coarsely crystalline masses with good cleavage. It is not a common ore except at Butte, Montana.

Manganocalcites. There is a series of isomorphous calcium and manganese carbonates with compositions ranging from calcite ($CaCO_3$) to rhodochrosite ($MnCO_3$). These carbonates vary widely in appearance, some are white, others, gray, reddish-brown, or mottled. Some are coarsely crystalline, others less coarse. Deposits are found in several localities as at Chamberlain, South Dakota, and at Batesville, Arkansas. The high-grade deposits of the latter district are mined and are classified as follows:

1. White carbonate, manganese content low.
2. Gray carbonate, 32.6 to 38.5 percent manganese.
3. Red or reddish-brown carbonate; 20 to 30 percent manganese.

4. Mottled carbonate; a mixture of red and black carbonates, generally with some pink and white carbonates.
5. Chocolate brown carbonate, 16 to 22 percent manganese.
6. Yellow carbonate, 22 to 32 percent manganese

Hausmannite is associated with these manganocalcites in the Batesville district. The Bromide, Oklahoma, deposits contain various manganocalcites which can be classified in a similar manner.

USES OF MANGANESE

Approximately 5 percent of the manganese used in the United States is utilized for chemical and the remainder for metallurgical purposes.

The chemical uses include depolarizers in dry cells, dryers in paints and varnish, coloring matter in glass, pottery, and bricks, disinfectants, and others. Ores for these uses must contain over 80 percent MnO_2 and less than 1 percent iron. Copper, nickel and cobalt content is less than 0.05 percent. For many purposes this material is refined further.

The metallurgical uses include the manufacture of ordinary steels, high manganese steels, and non-ferrous alloys.

The non-ferrous alloys include alloys with copper, zinc, tin, aluminum, lead, magnesium, and other metals. High manganese steels have a high manganese content (12 to 40%) and because of their great toughness, strength, and hardness are used in armor plate, structural steel, rolls, railroad car wheels, ore crushers, cog-wheels, and for similar purposes.

Ordinary steels, which on the average require 14 pounds of manganese per ton of steel, is the great manganese consumer.

Manganese serves two purposes in the steel industry: (1) It increases the workability of the steel, enabling it to be forged, rolled, etc., without breaking; that is, manganese removes "red shortness" or breaking when hot, which defect is due to sulfur in the form of ferrous sulfide. In the refining of pig iron, iron sulfide separates out at a certain stage of cooling and forms thin envelopes around the grains of steel. These envelopes are low melting, and consequently such a steel will fall apart during forging, due to lack of cohesion between the grains. This defect is called "red shortness". If manganese is added to a cooling steel having these iron sulfide envelopes, the manganese will react with them, forming manganese sulfide globules which are minute and become dispersed throughout the metal. This eliminates the "red shortness". Manganese may also eliminate some oxygen though opinions differ as to the importance of this factor.

(2) Manganese produces beneficial effects on the resulting steel by entering into the steel and increasing its workability, hardness, and strength.

In a few special cases such as manganese-calcium carbonate ores, the ores are used to manufacture a high manganese pig iron. With these exceptions, however, the ores are smelted to special alloys of iron and manganese which are used in the refining of pig iron to steel. An alloy of manganese and iron is used rather than metallic manganese, as the latter is expensive to make and also oxidizes rapidly. These manganese alloys are described below.

(a) Manganese metal and electrolytic manganese contains 95-98% manganese and is used for special steels and in non-ferrous alloys. Its production is minor.

(b) Ferromanganese is used in the manufacture of ordinary and special manganese steels from pig iron and accounts for about 90 percent of the manganese required in the steel industry. The standard ferromanganese in normal times contains 78 to 82 percent manganese, about 16 percent iron, 0.05 to 1.0 percent silicon, and 6 to 7 percent carbon. During the last World War, however, a shortage of high-manganese ores caused a lowering of these standards and the manganese content dropped to 70 percent and even lower in some instances. The usual ferromanganese is manufactured from ores which contain over 45 percent manganese and have a manganese content at least seven times as great as the iron, with silicon not over 8 percent and phosphorous less than 0.25 percent.

(c) Silicomanganese. This alloy may be considered a special variety of ferromanganese used in the manufacture of certain killed steels. The silicomanganese has 65-70 percent manganese, 12 to 25 percent silicon, and 1.2 - 2.5 percent carbon. The annual production of this alloy is small.

(d) Spiegeleisen. This alloy contains 18-22 percent manganese, 70-80 percent iron, about 5 percent carbon, and 0.5 percent silicon. It is widely used in the production of Bessemer steel. As spiegeleisen contains only one-fourth as much manganese as ferromanganese, four times the tonnage of spiegeleisen compared to ferromanganese must be added to obtain the same manganese content and similar manganese action on sulfur. The percentage of silicon, phosphorous, and carbon, however, are essentially the same in the two alloys and hence the use of spiegeleisen means an introduction of approximately four times as much of these impurities as the use of ferromanganese causes. The alloys are added in the last operations of steel making, and the impurities added remain in the steel. Hence, spiegeleisen can be used only where high carbon is desirable as in the Bessemer steels, and conversely its use in low-carbon steels (open hearth steels) is prohibited. Spiegeleisen is made from ores which contain 10-35% manganese, usually over 15 percent. The iron should not exceed 2.7 times the manganese.

(e) Silicospiegel. This is a variety of spiegeleisen containing approximately 25-30% manganese and 7-8 percent silicon. It has a limited use in high-silicon steels.

(f) Manganiferous pig iron. This alloy contains approximately 5 percent manganese and is used for low-manganese steels. Its production is minor. It is made from manganiferous iron ores containing 5-10 percent manganese. These ores are abundant and the manganese content usually is paid for as though it were iron.

(g) High-manganese pig iron. Manganese carbonate ores from Batesville, Arkansas, are used to make a high-manganese pig iron. The high-lime content and the low content of moisture, silica, and alumnia makes this ore excellent for this purpose. The ore serves as a flux in place of limestone and also introduces manganese. Such manganese carbonate ores are rare. The ores of Bromide, Oklahoma, however, belong to this type.

The smelting of manganese ores to form these manganese alloys is similar in its broad outlines to the smelting of iron ore to form pig iron. The manganese ore is mixed with limestone and coke, and heated in a blast furnace with air introduced under low pressure. In this smelting, a large amount of slag is formed which contains from 9 to 15 percent manganese. The more silica in the ore the greater the slag with consequent increase in the loss of manganese. For this reason, silicon over 8 percent in the ore is penalized. It has been established that the amount of manganese in the resulting ferromanganese depends upon the amount of manganese and iron in the original ore. To make ferromanganese, with 78-82 percent manganese, most economically, the ore should exceed 45 percent manganese, and the manganese should be at least seven times as great as the iron content. The metallurgical practice dictates the standards of manganese ores that are desirable.

In times of emergency economy may have to be sacrificed and during the last World War ores as low as 35 percent manganese were used.

The physical structure of the ore also is important. Fine dust causes loss of manganese and also a deposition of dust in stoves and boilers. The hard, coarse ores are preferable and bring a premium.

U. S. Requirements, Production, and Imports

The United States has ample supplies of the lower grade manganese ores. The Cuyuna district, Minnesota, alone has a potential production of 8,646,000 tons of spiegeleisen and could provide manganese ores of this grade (14.9 percent manganese and 80.10 percent iron) for a considerable period of time.

The deposits of high grade ore in this country are small, scattered, and do not supply more than a few percent of our needs. As most of the ore required is of this type, we are dependent on foreign sources, as is shown by the fact that in 1939 this country produced 29,307 long tons of ore with 42 percent Mn and imported 627,131 long tons with 50 percent Mn. In 1937 the imports were from Russia 40 percent, Gold Coast 27 percent, Cuba 11 percent, India 11 percent, and Brazil 11 percent.

The production of manganese in the United States may be seen by the following figures. Prior to 1914, the country produced 3,000 to 7,000 tons or one percent of its requirements. In 1918 the curtailment of imports and consequent rise of prices stimulated domestic production and the country produced 311,000 tons of ore, or 35 percent of its requirements. After the war the competition of foreign manganese caused a rapid decline of the domestic industry and since 1918 until the last year or two the production has been less than 100,000 tons or 8 percent of requirements. The present emergency (1941) has again stimulated production considerably, and an active attempt is being made to make the country more self-sufficient. Also, research is being done on the utilization of lower grade manganese ores through beneficiation processes and on methods of using manganese more economically in the steel industry. Some authorities feel that this last offers the most practical solution of the problem.

The methods of beneficiation of low-manganese ores are several. The rhodochrosite ($MnCO_3$) ores of Butte, Montana, are calcined and the manganese content is raised from 35 to 50-66 percent. In Virginia and Georgia the ores are concentrated by jigs and tables. In Cuyuna range, Minnesota, a combination of tabling and flotation has turned out several thousand tons of concentrates (17 percent manganese). In the same region a pilot plant has been erected to test the Bradley leaching process which involves leaching with ammonium sulfate.

Price

Chemical ore is quoted in dollars per long ton of ore, while the other ores are sold by the unit of manganese. A unit is one percent of a long ton; that is, 22.4 pounds of manganese.

The price naturally has fluctuated widely, especially in war time and a few quotations illustrate its changes, 1913 -- 25 cents per unit; 1918 -- $1.27; 1929 -- 31 cents; 1933 -- 17 cents; 1937 -- 44 cents; 1941 (August 1) 50-55 percent Mn, 70 cents and 48-50 percent Mn, 65 cents, c.i.f. -- U. S. ports.

Impurities of silicon over 8 percent, and of phosphorous over 0.25 percent are penalized. Hard, coarse ores bring a premium. During the war 1914-1918, bonuses were paid for ores east of the Mississippi River in order to stimulate production in the region where almost all the ferromanganese plants are located.

MANGANESE OCCURRENCES IN OKLAHOMA

Manganese deposits occur in the Ouachita and Arbuckle Mountains, from which some ore has been shipped. Manganese in small amounts is found also in several places in the "Red Beds" of Oklahoma, but these have no commercial significance. These occurrences will be discussed separately.

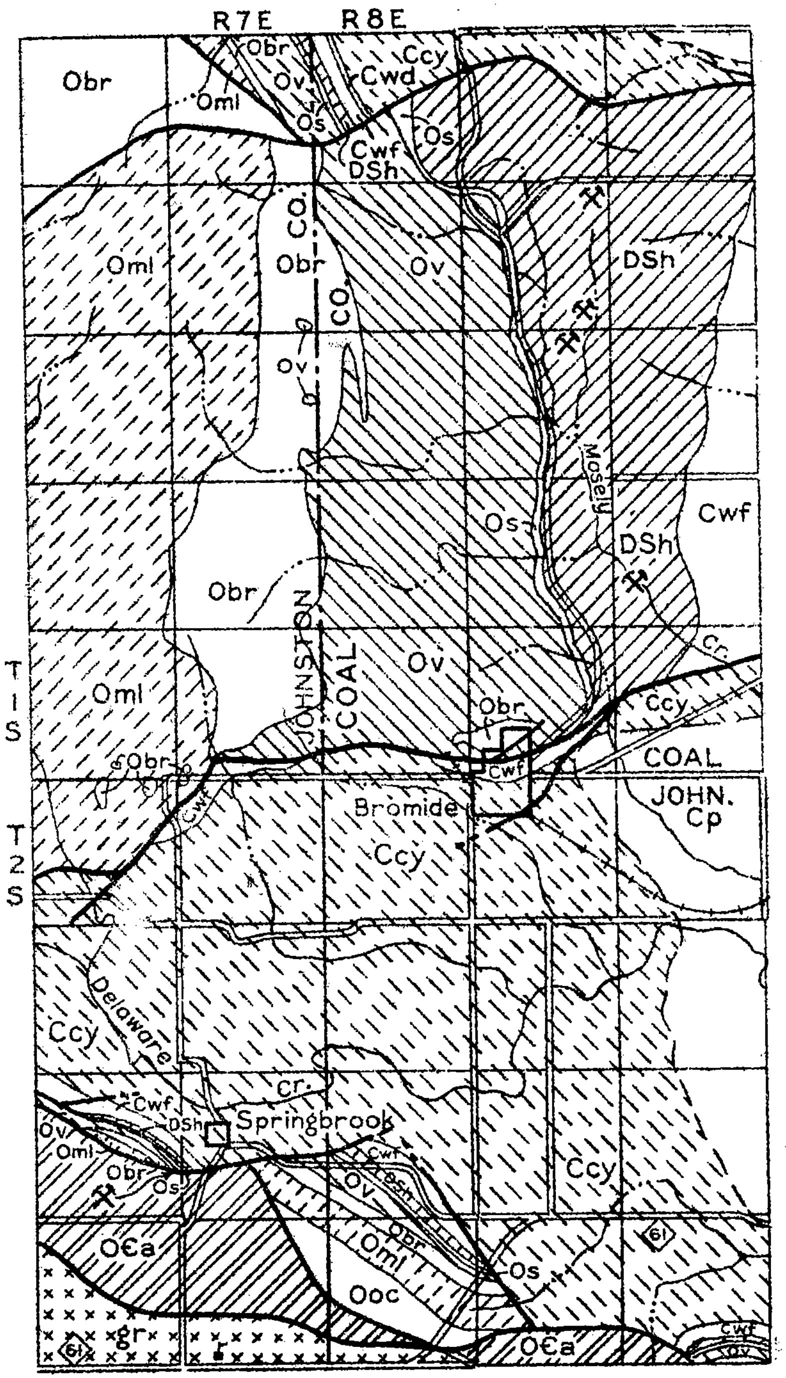
The production of manganese in Oklahoma has been almost negligible. The figures available are summarized below:

1891	206 tons of ore shipped from Bromide area, Arbuckle Mountains, value $1,174. The ore was shipped to Chicago and used to make spiegeleisen. (1)

Figure 2. Geologic Map of Bromide District, Johnston and Coal Counties, (After Decker, Okla. Geol. Survey Bull. 55) showing Manganese workings.

Scale: 1 mile = 0.75 inch

Ccy	Caney shale	
Cwd	Welden limestone	
Cwf	Woodford formation	
DSh	Hunton limestone	
Os	Sylvan shale	
Ov	Viola limestone	
Obr	Bromide formation	Simpson group
Oml	McLish formation	
Ooc	Oil Creek formation	
OЄa	Arbuckle limestone	
gr	Pre-Cambrian granite	
⚒	Manganese prospect hole	
—	Faults	



Oklahoma Production (Continued)

1916 One car load of ore collected in the spring of 1916, near Pine Mountain Springs, McCurtain Co. The ore was shipped from Hatton, Ark. (2)

1923 Production of manganese ore (greater than 35 percent manganese) is credited to Oklahoma. Production figures are not available. (3)

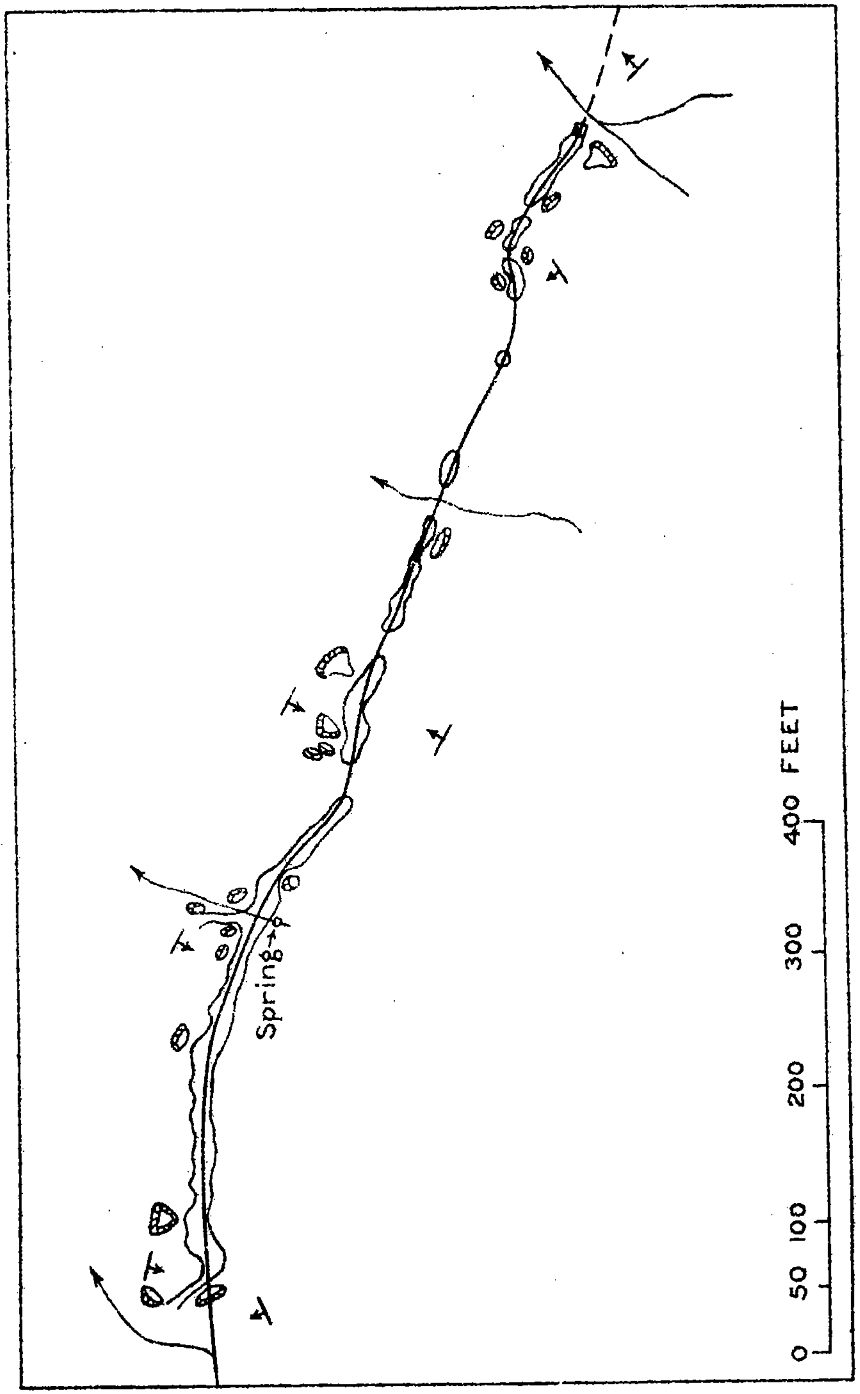
(a) Manganese Deposits of the Arbuckle Mountains

Some interesting deposits of manganese are located in the vicinity of Bromide, near the eastern end of the Arbuckle Mountains. These deposits have been briefly described by Weeks, (1,4,5); Reeds, (6) and Snider, (7) and later in considerably more detail by Hewett. (8) In this discussion the previous descriptions have been freely used.

The largest deposit in this region is near Springbrook, formerly known as Viola, about four miles southwest of Bromide. The other deposits are located one to five miles north of Bromide in the valley of Moseley Creek. These two manganese regions will be discussed in turn.

Figure 3. Sketch Map of Springbrook manganese deposit, located in secs. 13 & 14, T. 2 S., R. 7 E. Johnston County. (After D.F. Hewett U.S. Geol. Survey Bull. 725-E, Fig. 49.)

———	Fault line between Arbuckle and Viola limestone formations.
⊢	Direction of dip (arrow) and strike
⬭	Ore piles, indicating approximate portion of fault zone that is mineralized
⊂═	Test trench
⟶	Drainage lines



Springbrook deposit.

This deposit is in SE$\frac{1}{4}$ sec. 14, T. 2 S., R. 7 E., Johnston County; and is the largest deposit of manganese now known in the Bromide region. The deposit is a mineralized fault zone along which the Arbuckle limestone has been brought up in contact with the Viola limestone, (see figures 2 and 3). The fault strike varies from N 70° W to almost west and dips 65° to 85° south with a vertical displacement of about 2000 feet. The Arbuckle limestone on the south side of the fault and the Viola limestone on the north side both dip towards the fault plane. The Viola has a dip of 65°--80° south close to the fault and the Arbuckle 55° north. About a mile south granite and Arbuckle limestone are in contact along another fault.

The ore body has been partially explored by eight disconnected trenches placed over a distance of 1000 feet along the fault zone. The trenches now are partly filled with slumped-in material. The largest trench is 450 feet long, 20 feet wide, and 18 feet deep, and the others are from 20 to 80 feet long, 5 to 15 feet wide, and 5 to 10 feet deep. Most of the trenches have ore piles along their rims, but a few lack these and apparently encountered no ore.

The ore occurred in irregular lens-like masses of variable sizes surrounded by clay in the fault zone. The ore piles are of two types; those at the east end show only masses of earthy brown wad, whereas those along the western trenches show an irregular mixture of hausmannite and manganocalcite.

In the latter ore hausmannite occurs as black, minute pyramids (up to 1 mm. wide) lining druses or present in minute veinlets cutting the carbonate. The greater the percentage of hausmannite, the darker the color of the ore. The manganocalcite is a finely crystalline mass varying in color from pale-gray through light-reddish and light-reddish-brown to dark-reddish brown. It apparently is an isomorphous mixture of calcium and manganese carbonates and is called manganocalcite. Much of this mixed ore has a mottled appearance.

Small amounts of pyrite, siderite, calcite, dolomite, quartz, and chalcedony are present. The siderite is pale, Yellowish-green. The calcite occurs as white to colorless, clear crystalline masses and veinlets. Dolomite is found in pale-red veinlets. Quartz is present as clear to white masses filling druses. The chalcedony is a reddish brown or yellowish-green variety with the coloring due to arborescent growths of iron oxide.

Minerals were deposited in the following order:

1. Manganocalcite -- oldest
2. Hausmannite
3. Quartz and chalcedony
   fracturing
4. Calcite and dolomite

The chemical composition of the manganocalcite-hausmannite ore is shown by the following analyses made on samples collected by G. E. Burton of the Oklahoma Geological Survey.

	12	13	20	21a
MnO	43.73	27.66	46.05	59.65
(Mn)	(33.84)	(21.42)	(35.64)	(46.26)
FeO	6.28	7.06	5.50	25.90
(Fe)	(4.88)	(5.49)	(4.27)	(20.13)
P_2O_5	.11	.12	.0	.57
(P)	(.05)	(.054)	(.0)	(.25)
SiO_2	18.44	22.71	15.02	2.03
Undetermined (CaO, MgO, CO_2, etc)	31.44	42.45	33.43	11.85

(Analyses made by Oklahoma Geological Survey)

The origin of the deposit seems clear. It was developed by meteoric waters containing manganese and other constituents circulating through the fault zone and replacing the Viola limestone. The clay associated with the lenses of ore is the unreplaced clay of the limestone. The structural conditions in this deposit are such that under-ground waters would flow both from the south and from the north to the fault zone where they would rise to the surface. A spring situated along the fault a few hundred feet from the ore bodies lends strength to this interpretation. It is not definitely known whether the rising meteoric waters were warm or cold, but hausmannite has been interpreted as deposited from warm waters in most localities where it is found. Structurally any of the rocks of the region may have been the source of the manganese.

As far as is known, no material has been shipped from this deposit. The ore in sight, however, is considerable and Hewett estimated that 5000 tons of ore containing 35 percent manganese could be obtained within 100 feet of the surface.

Manganese Deposits north of Bromide

These deposits are located in the valley of Moseley Creek in the Hunton limestone (Silurian) (see figure 2). The deposits are of three types: (1) replacements along fractures and faults, (2) replacements along bedding planes, and (3) residual. The first two contain minerals similar to those found in the Springbrook deposit, namely a mixture of hausmannite and manganocalcite, with minor amounts of wad. The third type is dominantly psilomelane. These types will be described in turn.

Replacement deposits along fractures and faults

In SW$\frac{1}{4}$ sec. 28, T. 1 S., R. 8 E., Coal County, 1$\frac{1}{2}$ miles northeast of Bromide, is an old trench which probably was worked in the early nineties, as it is shown on Taff's map made in 1897, (Atoka Folio.) The only evidence of workings is a trench,

40 feet long, 15 feet wide, with a maximum depth of 8 feet, now partially filled with slumped material. The country rock is Hunton limestone striking slightly west of north and dipping 10° E. The formation is made up of pale-yellowish, earthy limestone in beds varying in thickness from 6 inches to 2 feet. The deposit occurs as irregular masses of ore in a fracture zone in the limestone, which zone trends N 60° W and is limited by two nearly vertical fractures 15 feet apart. The fractures about an inch wide are filled with pyrite and carbonate. The dumps show manganocalcite and hausmannite, with a little pyrite, calcite, and quartz.

In its essential features this deposit is similar to the one at Springbrook; that is, it was formed by replacement of limestone by rising meteoric waters containing manganese. These waters probably were warm. The replacement is clearly shown by the decrease in the amount of iron, magnesium, and manganese in the limestone from the fractured zone outwards. The surface waters entered the beds from the west, flowed down the east-dipping rocks, and rose up along the fractures. Chemical analysis shows nearby Hunton limestone contains 0.3 percent manganese and this formation may have been the original source of the manganese.

There is approximately 100 tons of ore containing about 40 percent manganese in the dumps.

It is probable that other fractured zones exist in the Moseley Creek valley and are similarly mineralized.

Replacement deposits along bedding planes

Two deposits of this character are known. One is located in sec. 17, T. 1 S., R. 8 E., where several small open cuts are found in an area of 100 sq. feet. The largest cut is about 40 feet in diameter and 10 feet deep. A bed of pale reddish Hunton limestone forms the floor of the pit and no evidence of fractures or faults can be seen. No man-

ANALYSES OF MANGANESE ORE SHIPPED FROM MOSLEY CREEK AREA

Cars	Weight (pounds)	Iron (per cent)	Silicon (percent)	Phosphorus (percent)	Manganese (percent)	Moisture (percent)	Price* per ton Delivered at Chicago
2	44,003	6.00	1.40	0.055	39.66	4.05	$10.32
2	53,226	6.15	1.45	.066	39.67	4.75	10.31
2	49,807	5.72	1.70	.060	43.18	3.25	12.09
2	45,816	6.76	1.20	.053	38.54	4.05	10.02
5	156,738	8.50	1.50	.050	40.50	3.70	10.93
4	93,910	8.09	....	....	35.78	5.00	8.95

* Price; f.o.b. cars at Lehigh was $5.70 per ton. (Weeks, U.S. Geol. Survey, Mineral Resources, 1892, p. 196, published 1893)

ganese minerals are now present in the cuts, but the location corresponds with that from which 17 carloads (197 tons) were mined and shipped to Chicago in 1891 to make spiegeleisen. The preceding table gives the analyses of manganese ore shipped from this deposit.

The analyses indicate that the ore was partly carbonate as the totals of the analyses are considerably less than 100 percent, and carbon dioxide is not reported.

Another deposit of this general type is found in NE$\frac{1}{4}$ sec.17, T. 1 S.,R. 8 E., about 4 miles north of Bromide. The ore is a lenticular mass lying parallel to the bedding of the enclosing limestone which strikes north and dips 5°-10° E. No faults or fractures are noticeable. The workings consist of an open cut 100 feet long, 40 feet wide, and maximum depth of 8 feet. The lens of ore is 1$\frac{1}{2}$ feet wide at the north end and widens to 8 feet at the south end. At the north end the lens is composed of two layers of calcite containing dendritic hausmannite but no manganese carbonates. As the lens thickens toward the south, the middle part is made up largely of black calcite, gray manganocalcite, and black grains of hausmannite. In the center of the lens is an irregular mass of mottled pale-reddish and white manganocalcite and yellowish-green siderite. At the south end of the open cut, where the lens is 8 feet thick, it is made up largely of white calcite containing plumose hausmannite. Some minute grains of chalcopyrite are present in the dark manganocalcite.

<u>Analysis of material from this deposit</u>

MnO	22.88
FeO	13.86
CaO	24.20
MgO	Trace
Al_2O_3	.40
SiO_2	1.60
Loss on ignition (CO_2, etc.)	32.80
H_2O	1.08
P_2O_5	.30
	97.12

Several hundred tons of ore containing 15-20 percent manganese are in the dumps, but sorting would be necessary to obtain 35 percent manganese ore.

These replacement deposits probably were formed by warm ground waters circulating at depth along bedding planes of the rock or rising upwards through openings. The original source probably was manganese disseminated in the Hunton formation.

Residual Deposits

Small deposits of residual psilomelane are common along the valley of Moseley Creek. In NE$\frac{1}{4}$ sec. 20, T. 1 S., R. 8 E. there are two trenches. One trench is 120 feet long, 45 feet wide, and 5 feet deep; the other is 40 feet long, 6-10 feet wide, and 6 feet deep. The larger trench was made by plowing the surface clay and the smaller trench follows a solution channel in the limestone. Nodules of botryoidal psilomelane containing some hausmannite and also some rounded limestone masses are present in the clay. Apparently most of the psilomelane has gathered up and the amount originally present cannot be estimated. This deposit is residual and probably has been formed by the weathering of manganocalcite-hausmannite replacements in nearby limestones.

A sample of this float ore was sent by M. C. Hess to the E. J. Lavino Company of Philadelphia for analysis. It showed: Mn 60,95 percent, Fe 1.18 percent, SiO_2 0.77 percent, and phosphorous 0.043 percent. Also Weeks reports nodular ore averages 66 percent manganese, 0.35 silica, 1.23 iron, and 0.023 phosphorous. This material would be excellent ore. The deposits, however, are small and scattered; and the cost of collecting the nodules would be considerable. It is possible that a small tonnage could be obtained this way.

Economic Possibilities of the Bromide Ores

It is estimated that 5000 tons of 35 to 40 percent manganese ore are present within 100 feet of the surface at Springbrook, and one deposit in the valley of Moseley Creek probably has 100 tons of 40 percent ore in the dumps. Another deposit has several thousand tons of 15 to 20 percent ore in the dumps. In addition there are many tons of residual psilomelane scattered over the floor of Moseley Valley. The total tonnage of deposits now known in the region would total at least 10,000 tons though some of this would be lean ore (15 to 20 percent Mn). It is probable that detailed systematic prospecting of the region would uncover other deposits.

The quality of the ore is variable. The residual psilomelane nodules contain approximately 60 percent manganese but are scattered and would be expensive to collect. Some of the replacement deposits would yield 35 to 40 percent ore while others would require sorting to yield a similar grade of ore.

Somewhat similar manganese carbonate-hausmannite ores in the Batesville district, Arkansas, containing 35 or more percent manganese have been mined since 1928. Their low content of moisture, silica, and alumina, and the high content of lime has made them desirable for high-manganese pig iron. The Bromide ores could be used for the same purpose.

The Bromide ores are far removed from the nearest smelters and would be costly to handle. Their utilization depends upon the cost of mining, sorting and transportation. They are small when compared to deposits in other states and any developmental work should be done in a most conservative manner. The whole area should be carefully prospected. The prospecting would require trenches, pits, or core-drilling, as the masses are irregular lenses and there is no way of estimating their depth or continuity from surface outcrops. The manganese belt has been traced for twelve miles in

Moseley Creek valley and in addition the Springbrook area is manganiferous. The prospecting area thus is considerable.

(b) Manganese Prospects in the Ouachita Mountains, Oklahoma

Manganese minerals are found in many places in the Ouachita Mountains, southeastern Oklahoma and southwestern Arkansas. Throughout the region the manner of their occurrence is essentially the same. In several localities the manganese is sufficiently concentrated to attract attention and many of them have been explored by shallow pits, shafts, and tunnels, and a few tons have been shipped. The deposits in the Ouachita Mountains of Arkansas have been described by Penrose and Miser (9,10) and the Oklahoma occurrences by Hewett and Honess. (11,12) These publications, especially the one by Honess, have been freely used in this article.

The Oklahoma manganese deposits of the Ouachita Mountains are in McCurtain County. They are of three types, namely: (1) cements and replacements in novaculite, (2) detrital nodules in river alluvium, and (3) residual masses in clay. Only the first class need be considered in any detail, for the other two are very small and have no economic significance.

Manganese minerals are widely distributed in a horizon in the lower division of the Arkansas novaculite, and probably can be found in all outcrops of these beds. The minerals occupy bedding planes, joints, and thin veins in the brecciated rock, or occur as pockets. The pockets vary in width from a few inches to four feet, but rarely exceed one foot. The veins are very thin, usually less than one inch. In Arkansas an eight foot vein is reported. Locally the manganese oxide is sufficiently concentrated to entice prospecting and considerable exploratory work has been done on these occurrences. Psilomelane is the chief mineral, but minor amounts of manganite and pyrolusite can be detected microscopically. Usually some limonite and considerable red clay are associated with the ore. In places iron oxide is more abundant than the manganese minerals.

The character of the ore is well shown by an analysis given by Miser. It was made from a composite sample of specimens collected from 39 localities in Arkansas. (10)

	Mn	43.52
	Fe	6.72
(a)	SiO_2	5.17
	P	0.35
	Al_2O_3	4.80
	CaO	1.42
	MgO	trace
	S	0.02

(a) Silica and insolube in HCL

The more important prospects (see map 4) of of the Oklahoma portion of the region will be described below.

Pine Mountain Prospect

Eight shallow pits, less than 6 feet deep, now partially slumped in, have been dug near the center of the SW$\frac{1}{4}$, sec.15, T. 3 S., R. 26 E., on the crest of Pine Mountain. These are reported to be the workings from which one car load of ore was collected in the spring of 1916 and shipped from Hatton, Arkansas. So far as is known, no later work has been done on these prospects.

The pits have been sunk in beds of the lower Arkansas novaculite. This rock is white, dense, and has a stony luster; the weathered surfaces have a pink or yellow color due to iron oxide. The rock occurs in massive beds, 2 to 6 feet thick, which strike N. 75° W. and dip 58° N. The rock is jointed into irregular fragments and locally it is highly fractured. The novaculite is more resistant to erosion than the adjacent beds and forms the crest of the mountain.

Pockets and veinlets of psilomelane with minor manganite and pyrolusite can be found in a zone 6 to 15 feet wide and 700 to 800 feet long following the strike of the rock. The mineralized zone is restricted to a few beds in the lower Arkansas novaculite. The central part of this zone has more manganese than the outer parts. The mineralization along the strike of this zone is very spotty, with pockets of manganese oxide being separated from one another by large masses of barren novaculite. The prospect pits have been located on the richer pockets and these would not average 20 percent ore though one or two might reach 40 percent ore.

The ore is botryoidal and stalactitic and occurs as small veins and pockets in the brecciated novaculite. The manganese minerals have been precipitated from ground waters circulating through fractures and thus forms a cement around novaculite fragments.

Figure 4. Geologic Map of Hochatown District, McCurtain County (modified after Honess, Okla. Geol Survey Bull. 32.)

Cross-hatching denotes outcrop of Arkansas novaculite which contains the manganese deposits.

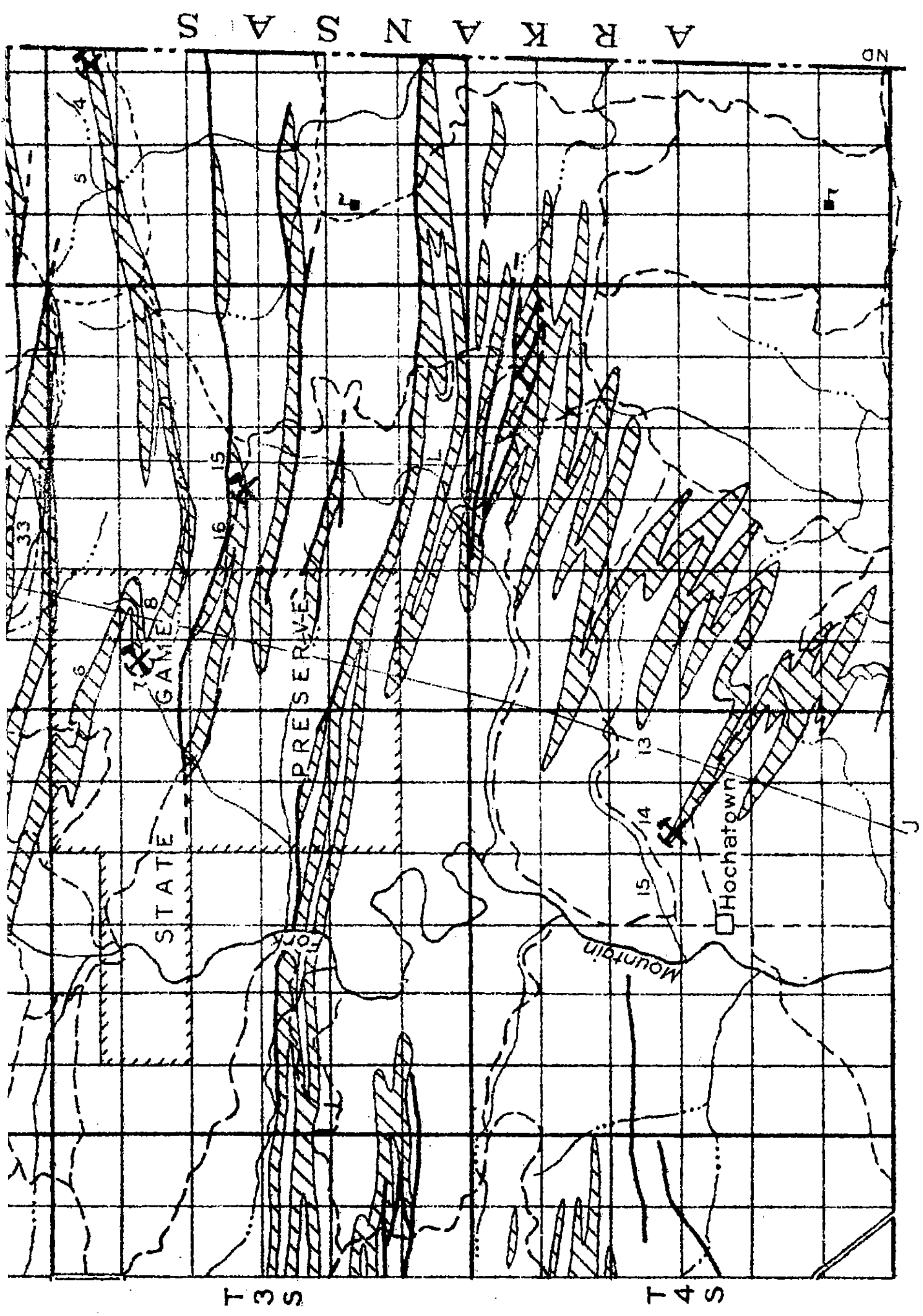
J-J and L-L indicate lines of structure profiles shown on Honess' Map (Bull. 32, Plate I.)

Scale: 1 mile = 0.375 inch

⚒ Manganese prospect hole

---- Better trails

...... Forest trails



Considerable red clay is associated with the ore and also is present in seams in the ore. This clay may have been washed in from the weathered Missouri Mountain slate which underlies the novaculite and is exposed to the south of the pits. Part of the clay, however, may be residual from the weathering of the novaculite which contained shale-slate layers.

The following are analyses of these ores made by the K. C. Testing Laboratory, Kansas City, Mo.

Analyses of Manganese from Pine Mountain

	I	II	III	IV
Gold	0.00	0.00	0.00	0.00
Silver	.06 Oz./Ton	.03 Oz./Ton	0.00	Oz./Ton .05
Silica	15.90	10.73	56.25	63.21
Manganese. . .	39.50	46.71	9.83	7.05
Iron	6.83	5.04	7.73	3.14
Phosphorus . .	.19	.14	.24	.08

I and II picked samples; III and IV grab samples.

A partial analysis made by A. C. Shead, chemist for the Oklahoma Geological Survey of ore from this locality is as follows:

H_2O at 120°C.	4.97
SiO_2	2.10
P	.057
Fe	4.63
Al_2O_3	2.24
Mn	49.20
$CaCO_3$	5.08

Hochatown Prospect

Three old pits are located about one and a half miles northeast of Hochatown in the SW$\frac{1}{4}$, sec. 14, T. 4 S., R. 25 E. These are on the mountain side north of the "Hollar."

The pits are located at the west end of an overturned synclinal fold which plunges eastward and dips north. The mountain ridge is made up of Arkansas novaculite with the Missouri Mountain slate exposed on the flanks. The ores are found in the lower Arkansas novaculite which is hard, dense, white and brecciated, with weathered surfaces showing a red or pink color.

The three pits now partially slumped in are about 15 feet deep and 6 feet square. The two higher ones were sunk in novaculite and the lower one began in novaculite float and penetrated into Missouri Mountain slate. The slate contained no ore. The dumps show several tons of high grade ore and many tons of the country rock. The ore is present as small veinlets and pockets in the novaculite. Considerable red clay is associated with the ore. Psilomelane is the chief manganese mineral but minor amounts of pyrolusite and psilomelane can be detected.

The zone of mineralization is about 6 feet wide and can be traced for 1000 feet along the strike of the rocks. The mineralization, however, is very spotty in this zone, and only a few percent of the whole zone would be manganese oxide.

Prospects Near Grady Smith Trail in Sec. 33, T. 2 S., R. 26 E.

Several prospect pits have been sunk in sec. 33, T. 2 S., R. 26 E. South of the Grady Smith trail in the SW$\frac{1}{4}$, a few shallow pits have been sunk in a five foot brecciated zone of Arkansas novaculite on the north slope of an east-west ridge. Small amounts of disseminated manganese oxides associated with some iron oxides are present in the dumps. An analysis of a hand specimen showed 49.80 percent manganese and 2.37 percent iron.

In the NW$\frac{1}{4}$, SE$\frac{1}{4}$ a twenty foot prospect hole has been sunk in the southeast summit of an east-west ridge. A few tons of botryoidal manganese have been piled up. The ore occurs as seams and pockets in the brecciated novaculite.

The main workings in this section, however, are in SE$\frac{1}{4}$, NW$\frac{1}{4}$, on the south slope of an east-west ridge of novaculite. A thirty foot tunnel has been made into the side of the hill and some 20 or 30 tons of high grade ore has been piled at the entrance. A few feet east and a little lower on the hillside is a shallow pit in the novaculite. A few tons of ore have been piled around the rim of this pit. It is reported that manganese minerals can be found in a narrow zone of novaculite for 3/4 of a mile east-northeast and several hundred yards west. The two workings are in this zone.

The occurrence of the manganese oxide is well shown in these workings. The minerals occur as seams and pockets in the brecciated novaculite. Most of the seams and pockets are quite small but locally the ore is present in rather pure masses up to 1 foot in width. The novaculite between such masses, however, is far greater in amount and probably not twenty percent of the whole mass is manganese oxide. Considerable clay, red and gray, is associated with the ore in the dumps. In part it may have been derived from the weathering of the Missouri Mountain slate and possibly in part from the shale-slate in the novaculite.

Other Occurrences of Manganese

A small deposit in the SW$\frac{1}{4}$ sec. 3, T. 3 S., R. 27 E., close to the Arkansas state line is being prospected at the present time. The workings consist of a few hundred square feet of surface stripping in clay, a few shallow pits, and a small opening in the novaculite. A few tons of manganese ore has been piled near the workings.

The country rock is Arkansas novaculite which forms the crest of the hill. On the flank of the hill is a small pocket of clay which contained rounded masses of manganese oxides and admixed iron oxides. This clay probably is weathered Missouri Mountain slate which has been washed into a depression. The manganese oxides are residual from the weathering of novaculite which contained pockets of manganese oxides. The clay can be easily separated from the ore, but the manganese-bearing clay is quite local and will yield only a small amount of ore. The stripping of this clay has exposed novaculite in places, and some of this rock has been blasted. The novaculite shows the usual thin seams and small pockets of manganese ore.

Manganese oxides in Arkansas novaculite were noted in many other places. In the NW$\frac{1}{4}$ sec. 11, T. 4 S., R. 26 E., near Clebit Spring, small pockets and veins were found along the road cut for a distance of 100 feet.

In the NW$\frac{1}{4}$, NE$\frac{1}{4}$ sec. 7, T. 3 S., R. 26 E., a brecciated zone, five feet thick and quarter of a mile long has local concentrations of manganese oxides. Some of the pockets measure two and a half feet long, and an analysis of a hand specimen showed 33.49 percent manganese and 1.94 percent iron. This deposit is situated on the flanks of the high series of ridges known as Pine Mountains.

Other minor occurrences of manganese in brecciated novaculite are found in Cross Mountains at the center of north line, sec. 1, T. 3 S., R. 26 E. also near the center of west line of sec. 9, T. 4 S R. 26 E., and north of center of sec. 26, T. 3. S., R. 24 E.

Small amounts of wad in alluvium can be found along the West Fork of Rock Creek at the center of south line, sec. 20, T. 4 S., R. 26 E. Likewise it is present on a tributary of Bull Creek SW$\frac{1}{4}$ NE$\frac{1}{4}$ sec.

35, T.3 S.,R.26 E. The nodules in the latter locality can be followed south two hundred yards to the south slope of Williams Mountain where the manganese and iron oxides are present in a novaculite outcrop.

Origin of the Manganese Deposits

The manganese oxides were introduced after the brecciation of the novaculite as is clearly testified by the manganese oxide cement around the brecciated fragments of the rock. The manganese was precipitated from ground waters circulating through the openings in the rock and the greatest mineralization is found at the noses and chutes of plunging anticlines and synclines or near faults, that is, those areas where the deformation has been most intense. The original source of the manganese is not definitely known. Any of the rocks of the region which contain disseminated manganese minerals may have contributed a portion of the manganese. However, the restriction of the mineralized zones both in Oklahoma and Arkansas to a horizon in the lower Arkansas novaculite and another horizon in the upper novaculite strongly suggests that the major portion of the manganese was obtained from these stratigraphic units. The upper division often contains 25 to 50 percent of a manganiferous carbonate which Honess believes to be rhodochrosite.

In this connection, Miser and Purdue write:

"The mode of occurrence of the manganese ores in the Arkansas novaculite suggests that their origin and that of the novaculite are intimately associated. The novaculite is regarded by the writers and some others as having been deposited through chemical or organic processes, or both; and thus belonging to the class of cherts. The manganese was probably deposited as a manganese-bearing calcite at the two main ore horizons, but some of it was doubtless deposited as a carbonate in other parts of the novaculite and in the overlying and underlying shales.

"The concentration of the ores has been effected by ground water, which has carried down their constituents from the vast mass of rock that has been eroded from the region. The local concentration of the ores into deposits large enough to be of value appears to have been dependent upon the amount of open space in the Arkansas novaculite, which is hard and compact and usually has no visible openings between the layers or along the joints. The places where fissures are largest and most numerous would be most favorable for the circulation of underground water and consequently for the deposition of the ore, little of which replaces the novaculite. The fissures were formed during the folding, faulting, and fracturing of the novaculite late in the Carboniferous period." (13)

Economic Possibilities of the Manganese

Much of the ore has 40 or more percent manganese content which would be high enough for the manufacture of ferromanganese if the phosphorous content did not exceed the phosphorous limit (0.25 percent). The ore averages 0.35 percent phosphorous. The manganese oxides in the Arkansas novaculite fill bedding planes and cracks, and occurs as small veins and pockets scattered throughout the rock, and the total amount of manganese in the area is very great. Only locally does the ore form 20 or more percent of the rock and such occurrences are always small and separated from other similar pockets by large amounts of novaculite. In order to obtain ore of commercial grade it would be necessary to crush and concentrate the material by jigs or tables. No prospect was seen where there was sufficient ore to justify the expense of such machinery,and there is no reason to believe the grade of ore will increase with depth; in fact, in many places it will decrease. It is possible that a few deposits might yield a small profit, but this is problematical and the majority cannot be worked profitably under present conditions and prices.

Similar deposits in Arkansas have been known for many years and have been explored by many prospect workings. The ore shipped from that region, however, would not exceed a few hundred tons.

It is possible that non-metallurgical uses might find a market for some of the ore. For instance, the wad or low-grade ore might be used to produce chocolate colored bricks or to give color to the spots of speckled bricks.

(c) Manganese in the "Red Beds"

Manganese minerals are common in small amounts in various parts of the "red beds" of western Oklahoma. Locally the black oxides of manganese often give the sandstones a dark color. In these instances the manganese content usually is less than one percent, but in places it is somewhat more concentrated.

Manganese also is found in the shales of the "red beds" in the form of nodules. In NW$\frac{1}{4}$ sec. 2, T. 5 S., R. 11 W., Cotton County, on the north bank of the Red River, many nodules up to one foot in diameter are present. Analysis of a nodule gave 13.09 percent manganese, 38.34 percent acid-insoluble material, and considerable carbonate. In SW$\frac{1}{4}$ sec. 36, T. 4 S., R. 9 W., Jefferson County, carbonate nodules containing 6.58 percent manganese are abundant. Also in SE$\frac{1}{4}$ sec. 33, T. 4 S., R. 8 W., Jefferson County, calcareous nodules in red shale contain 6.23 percent manganese. Calcarious nodules associated with copper minerals from sec. 24, T. 4 N., R. 1 W., Garvin County, analyzed 1.83 percent manganese.

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