Exploration and Development of the Sedimentary Iron Ores of Missouri

by

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ABSTRACT

During 1956, sedimentary iron ore production in Missouri reached an all-time high of 113,298 tons.

Sedimentary iron deposits occur either as hematite ores in filled-sink deposits or as concentrations of limonite fragments in residuum. These are distributed in five general geographic districts in the south half of the state. The geologic characteristics of deposits in each district are discussed. Many of the known deposits have been explored by drilling since 1955.

Total cost for a single plant to mine a limonite deposit is about \$87,000.00. The ratio of raw ore in place to ore concentrate of the limonite deposits is about four cubic yards to one ton of ore.

INTRODUCTION

One of the primary functions of the Missouri Geological Survey and Water Resources is to compile and disseminate data concerning the mineral resources of the state. Geological information and technical data are thus made available to the prospectors and operators of potential economic mineral deposits.

The recently increased interest in and requests for data regarding the sedimentary iron ores of Missouri have prompted the publication of this report. It is hoped that the brief resume of the geologic characteristics of the deposits, the descriptions of actual mining operations, and the suggestions for exploration and development will help the investor, prospector, or operator avoid certain pitfalls commonly encountered in the mining of sedimentary iron ores.

The iron ores of Missouri may be divided into two general types: (1) magnetite-hematite ores that occur in igneous rocks such as the deposits at Iron Mountain in St. Francois County, and those currently being explored in the Bourbon-Sullivan area in Crawford County; and (2) hematite-limonite ores that occur either in residual surface material or in sink holes developed in sedimentary strata. The iron deposits that occur in residual soils and clays are commonly called *brown iron ores*. Such deposits are composed mainly of limonite. Red or blue hematite is the chief ore mineral of the filled-sink type deposit.

History, Production, and Distribution

The occurrence of brown iron ore or limonite in Missouri was first recorded in 1673 by a French Jesuit missionary by the name of Marquette (Houck, 1908, p. 161). The first iron ore furnace was erected in 1815 at the Stouts Creek shut-in near Arcadia in Iron County. Although this furnace was constructed mainly for the treatment of magnetite-hematite ores, a small quantity of limonite ore was also processed. In 1823, the Perry furnace was built 5 miles north of Caledonia in Washington County primarily for the treatment of limonite ores.

During 1819 and 1820 the Harrison-Reeves furnace was built on Thicketty Creek, 3 miles southeast of Bourbon in Crawford County, and in 1829 a furnace was erected at Meramec Spring, 5 miles southeast of St. James in Phelps County. These furnaces were constructed for the treatment of hematite ores obtained from filled-sink type deposits.

Production from filled-sink deposits progressed steadily during the late 1800's, and by the end of 1900 approximately 2,500,000 tons or ore had been produced. The low iron content of the brown iron ores retarded their economic development, and it was not until around 1900 that any production of consequence was noted from these deposits. By the end of 1910, approximately 300,000 tons of brown iron ore had been produced. By the end of 1946, approximately 3,800,000 tons of ore from the filled sinks and 800,000 tons of brown iron ore had been produced.

Tonnage figures for the production of limonite in Missouri during the past 10 years are shown in Table 1. There is no record of any production of hematite from filled sinks from 1947 to 1955, but in 1956 approximately 523 tons of this ore were produced.

Table 1

Brown Iron Ore Production in Missouri, 1947-1956

Year	*Tons produced*
1947	0
1948	0
1949	120
1950	19,169
1951	10,888
1952	34,638
1953	34,863
1954	28,555
1955	52,553
1956	112,775

Although occurrences of iron-bearing minerals are known in nearly every county of the Ozark region, mining activity and prospecting has established five general districts in which a number of deposits are concentrated. These districts are outlined on the index map, Figure 1. They have been determined for convenience of description and must be regarded as artificial. In places the district boundaries overlap, and several isolated deposits are situated outside the districts shown.

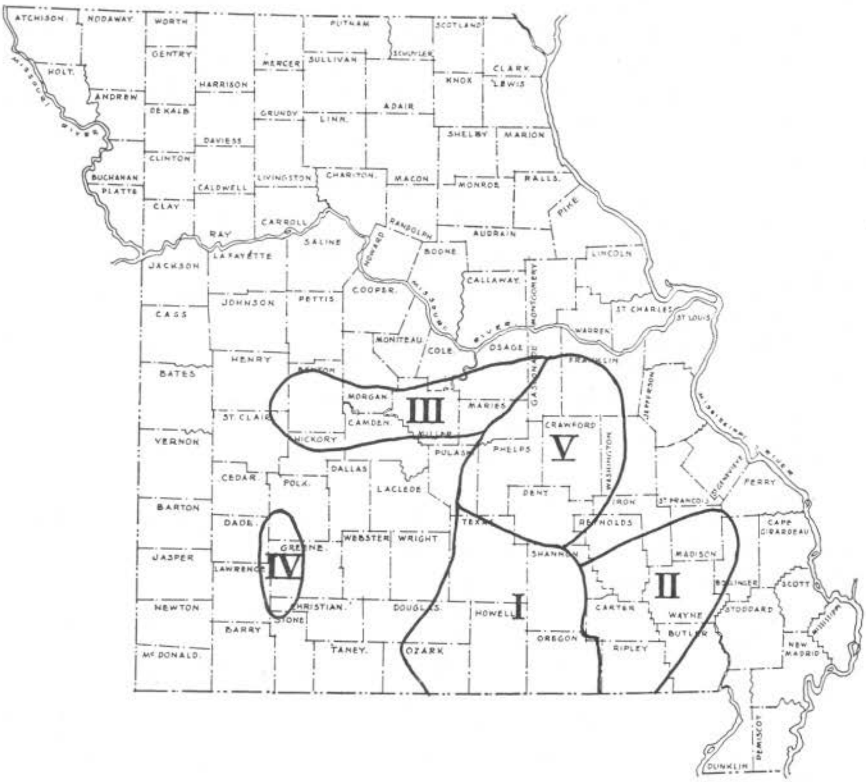

Fig. 1. Sedimentary iron ore districts of Missouri: I. West Plains district, II. Poplar Bluff district, III. Osage River district, IV. Springfield district, V. Steelville district.

The West Plains district consists of Howell and Oregon Counties and adjacent parts of Shannon, Texas, Douglas, and Ozark Counties. Howell County has been a leading producer of brown iron ore in this district and is the most active one at present.

The Poplar Bluff district extends from Carter and Ripley Counties northeastward into Madison County. Brown iron ore mining in this district has been concentrated in Wayne County.

The Osage River district extends eastward from Benton County to Franklin County. This district is so named because a majority of the brown iron deposits within its boundaries are found in the Osage River drainage area.

The Springfield district, in southwestern Polk, western Greene and Christian, and northwestern Stone Counties, contains only brown iron ore deposits.

The Steelville district, consisting mainly of Crawford, Phelps, Dent, and southern Franklin Counties, is known for the occurrence of hematite in filled sinks.

To date few deposits of economic value have been discovered in an area from western Pulaski and Texas Counties west to the central portions of Polk, and Greene Counties, and from Camden County south to Douglas County.

Acknowledgments

During the preparation of this report most of the sedimentary iron mining operations in the state were visited, and the writer wishes to express his sincere thanks for the cooperation of every operator contacted. Without such cooperation and interest, a considerable amount of the information contained herein could not have been obtained.

Special appreciation is extended to Mr. Wade Miller of Miller and Reynolds Mining Company, Mr. Stanley G. Patterson of Patterson Mining Company, and Mr. J. L. Powell of Ozark Mining Company.

The writer gratefully acknowledges the information obtained through his informative conversations with Mr. G. Earl Doane who perhaps has experienced a longer and closer association with the brown iron ores of the state than anyone else.

For an extremely interesting visit of the brown iron ore properties of Shook and Fletcher Supply Company, Russellville, Alabama, the writer is indebted to Mr. E. H. Craddock.

For many helpful discussions and for critical reading of the manuscript, the writer expresses his thanks to John G. Grohskopf, of the Missouri Geological Survey; to G. A Muilenburg, Assistant State Geologist; and to Thomas R. Beveridge, Director of the Missouri Geological Survey. Appreciation is also extended to John W. Koenig of the Missouri Geological Survey staff for careful editing of the paper and to Miss Bonnie L. Wills for typing the manuscript.

MINERALOGY

Terminology

A mineral is a naturally occurring, inorganic substance with a definite chemical composition, a characteristic crystalline structure, and distinct physical properties. Some of the more important terms used to describe a mineral are defined below. The first four terms also indicate some of the physical properties which help to identify many minerals.

Streak—This term refers to the color of a finely powdered mineral. The color of the powder may be determined by crushing, filing, or scratching. Minerals that appear to have the same color may have streaks of entirely different colors.

Hardness—The hardness of a mineral is its resistance to abrasion or scratching and is indicated in terms of Mohs hardness scale which consists of 10 minerals arranged in order of increasing hardness.

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Orthoclase
7. Quartz
8. Topaz
9. Corundum
10. Diamond

Specific gravity—The specific gravity of a mineral is its weight in air compared to the weight of an equal volume of water.

Cleavage—The property of many minerals to split or separate readily along definite planes is called cleavage.

Pseudomorph—A mineral which assumes the external or crystal form of another mineral is said to be pseudomorphic.

Cryptocrystalline—This term is applied to substances which appear to be amorphous without the aid of a microscope but are in reality crystalline.

Iron Ore Minerals

The term *ore* is often loosely used to designate any mineral that is mined. Technically, ore is an aggregate of minerals from which one or more metals may be extracted at a profit. The important iron ore minerals in Missouri are magnetite, hematite, and limonite.

Magnetite.—Pure magnetite ($FeFe_2O_4$) contains 72.40 percent iron and has a specific gravity of 5.20. Crystals of magnetite commonly have a pyramidal shape. Its hardness lies between 5.5 and 6.5, and its streak is black.

Magnetite is strongly magnetic, and some fragments may act as natural magnets. This variety is called *lodestone*. Magnetite occurs in veins and disseminated masses in the igneous rocks of the state and is an important ore mineral at Iron Mountain.

However, the presence of magnetite in a filled-sink deposit has been reported by Cooke (1936, p. 43), but he does not indicate which one. Small quantities of magnetite probably are present in many filled sinks as indicated by the higher readings on instruments used in magnetic field surveys. This type of occurrence of magnetite is also suggested by statements of Schmidt (1873, pp. 68, 73) that hematite from several deposits in Crawford, Dent, and Phelps Counties shows "pronounced magnetic properties".

Hematite.—Chemically pure hematite (Fe_2O_3) contains 69.94 percent iron and has a specific gravity of 5.26. It is frequently found in platy or tabular crystals which somewhat resemble mica. Its hardness ranges from 5.0 to 6.0, and its streak is cherry-red or reddish-brown.

Hematite is found in veinlets intimately mixed with magnetite at Iron Mountain and at other numerous localities throughout the igneous outcrop area of the state.

The chief iron-bearing ore mineral of the filled-sink deposits of the Steelville district is hematite. Two varieties may be discerned: (1) specular hematite, and (2) red hematite. Specular hematite has a metallic luster, often splendent, and is blue to steel gray in color. When this variety is massive, the individual crystal particles cannot be observed, but when it is coarsely crystalline, the crystal faces can be seen and may appear to be micaceous. Red hematite also has a metallic luster but may range in color from deep red through red brown and purple to nearly black. It may be soft and granular or earthy in appearance and is frequently pseudomorphic after pyrite or marcasite.

Limonite.—For many years, limonite (supposed formula $2Fe_2O_3.3H_2O$) was thought to be a distinct mineral species of a colloidal or amorphous nature. It is always of secondary origin and results either from the alteration of other iron-bearing minerals by exposure to air, water, and acids or by precipitation from iron-bearing solutions. It has been found in high temperature veins and igneous rocks only as a secondary product.

It has recently been shown that a compound of this formula cannot be produced in the laboratory, and investigations have indicated that most of the naturally occurring material classed as limonite is actually cryptocrystalline goethite with varying quantities of adsorbed or capillary water. However, the term limonite is retained in this report as a convenient field term for the hydrous iron oxides whose true identities are unknown.

Goethite.—Pure goethite ($HFeO_2$) contains 62.85 percent iron, has a hardness of 5.0 to 5.5, and a specific gravity of 4.28. Handpicked goethite samples, free from visible impurities, frequently assay 57 to 58 percent iron but seldom exceed 60 percent. Most fragments of apparently pure goethite average around 55 percent iron. Because of the many small voids in the fragments, the specific gravity of hand specimens ranges from 3.25 to 3.50. Streaks of different specimens vary from brownish yellow to orange yellow.

Goethite is a common mineral and is the main iron-bearing constituent of the brown iron ores currently being mined.

Turgite.—Turgite (supposed formula $2Fe_2O_3.H_2O$) originally was thought to be a mixture of goethite and hematite with additional water of crystallization. It is now considered to be identical with hematite.

Xanthosiderite.—Xanthosiderite (supposed formula $Fe_2O_3.2H_2O$) previously was regarded as a mineral species or variety of goethite, but recent investigations have shown it to be identical with goethite.

Gangue

Gangue is the rock and mineral waste associated with any ore deposit.

The more prevalent constituents of gangue in the sedimentary iron ore deposits are pyrite, marcasite, chert, and dolomite.

Pyrite.—Pyrite (FeS_2) is commonly called *fool's gold, mundic, iron pyrites,* or *sulfur.* It may either crystallize in cubes or form granular or stalactitic masses. It has a metallic luster and is pale brass-yellow in color. Its hardness ranges from 6.0 to 6.5, and its specific gravity is 5.01. The streak is greenish- or brownish-black. The surface of the mineral frequently tarnishes and becomes irridescent.

Pyrite is more commonly found associated with the deposits of the West Plains and Springfield districts. Either it occupies the center of limonitic boulders or forms stalactitic masses which are partially or completely altered to limonite. Cubes of limonite result from the alteration of cubic pyrite crystals. Pyrite is often found in an unaltered condition in the dolomite which lies beneath and, in some instances, surrounds the residual clays in which brown iron ore deposits occur.

Marcasite.—Marcasite (FeS_2) is frequently called *mundic* or *white iron pyrites.* Crystals of marcasite commonly assume the characteristic forms of "cockscombs" or "spearheads". Marcasite also forms stalactitic masses and boulders with radiating structures and is often found in the form of dull, earthy masses of a greenish-black color. Its hardness ranges from 6.0 to 6.5, and it has a specific gravity of 4.80. On fresh surfaces it is almost tin-white, but a pale bronze-yellow color is more frequently observed. It has a grayish or brownish-black streak. Many specimens are difficult to distinguish from pyrite, but when marcasite is crushed and boiled in a concentrated nitric acid solution, free sulphur is liberated. This does not occur when pyrite is tested in the same manner.

Marcasite, or pseudomorphs of limonite or hematite after marcasite, may be observed in all of the iron ore districts, but it is found almost exclusively in place of pyrite in the Steelville district where it is concentrated in the lower portion of the filled sinks.

Quartz.—Quartz (SiO_2) is commonly referred to as *silica.* It is the second most abundant mineral in the crust of the earth and is perhaps more widespread and found in a greater variety of rocks than any other mineral. Quartz crystals are six-sided. The mineral has a hardness of 7.0 and a specific gravity of 2.65. It may be colorless, but more frequently is milky-white or may have very light tints of yellow, brown, or red. Its streak is white. Quartz fractures in a manner similar to glass, is harder, and has no cleavage. These physical properties distinguish it from calcite.

Quartz may form in masses of small crystals as cavity linings or occur as included quartz sand grains. These features are especially noticeably in the deposits of the Poplar Bluff district.

Calcite.—In the Joplin area, calcite ($CaCO_3$) is commonly called *tiff*, and in the southeast Missouri lead belt it is commonly called *glass tiff*. It is usually clear to milky-white in color or has light shades of gray, brown, or yellow. It has a specific gravity of 2.7 and a hardness of 3.0. It is characterized by three planes of cleavage which give a fragment of the mineral a distinctive rhomboidal shape. The cleavage and hardness of calcite distinguish it from quartz as well as the effervescence or "bubbling" of calcite when a drop of dilute hydrochloric (muriatic) acid is placed on a fragment. Quartz does not effervesce.

In some deposits individual crystals of calcite may be observed, but in others, especially in the granular and earthy types of ores, the mineral is intimately mixed with limonite or hematite. Specimens of limonite obtained from the Springfield district show variously sized depressions or molds from which calcite crystals had been removed by weathering agents.

Dolomite.—Dolomite ($CaMg(CO_3)_2$) is a mineral, but the name is commonly used as a rock term. As a mineral it forms rhomb-shaped crystals which in aggregate produce saddle-shaped forms. Its hardness ranges from 3.5 to 4.0, and its specific gravity is 2.85. Massive dolomite constitutes the bulk of the lime rock in the Ozark region. With the application of dilute hydrochloric acid, dolomite will effervesce only slightly in contrast to the violent effervescence of calcite.

Chert.—Chert (chiefly SiO_2) is a compact, siliceous rock which is commonly called *flint*. It is found in the form of nodules and fragments and is one of the more undesirable gangue materials in iron-bearing deposits. Chert consists of an aggregate of cryptocrystalline grains of quartz and other types of silica. The majority of the chert found in the brown iron deposits was originally contained in limestone or dolomite. Weathering and alteration of the limestone and dolomite has left a residuum composed largely of insoluble clay and chert with minor amounts of limonite or hematite and unaltered portions of pyrite and marcasite.

Manganese minerals.—Small quantities of manganese oxide minerals, such as psilomelane (MnO_2) and pyrolusite (MnO_2), have been reported from filled-sink deposits and from several brown iron deposits. These manganese minerals are uniformly distributed through the ore in the Poplar Bluff district. It is difficult to distinguish between these two minerals in the field, and the term *wad* is commonly used for any soft, black, powder-like manganese material.

Copper and zinc minerals.—Crystals of sphalerite (ZnS) have been reported by Crane (1912, p. 74) from the Springfield district. Nontechnical terms for sphalerite are *resin jack, black jack,* and *blende.* Chalcopyrite ($CuFeS_2$) is found in several filled-sink deposits, particularly in those where there is an abundance of marcasite. Some of these deposits have been mined for their copper content. Various copper carbonates are also present in many filled-sink deposits.

STRATIGRAPHY

The generalized geologic time chart (Fig. 2) prepared by Wallace B. Howe of the Missouri Geological Survey is presented here to familiarize the reader with the major periods of geologic time. During some of these periods iron ores were deposited within the state. Interested readers may also obtain a geologic map of the state which shows the surface distribution of the various rock units deposited during geologic time. This map may be purchased from the Missouri Geological Survey and Water Resources for the price of $1.00.

Although limonite is known to be present in nearly all of the surface formations of the state, most of the deposits and known outcrops of limonite occur in the residuum of the Jefferson City dolomite, Roubidoux sandstone, and Gasconade dolomite of Ordovician age. In the Springfield district, limonite deposits are found on the erosional surface of the Burlington limestone of Mississippian age. The hematite ores of the filled sinks occur in the Ordovician formations mentioned above.

SEDIMENTARY IRON ORE DISTRICTS

Steelville District

In earlier reports the iron deposits of this district have been variously referred to as "specular ores in sandstone", "Central Missouri specular ores", "specular ore of the sandstone region", and "hematites of the filled sinks". The latter reference was adopted by Crane (1912, p. 84) because of the widespread association of the hematite ores with sink structures.

A characteristic surface expression of a sink structure is a roughly circular or elliptical outcrop of sandstone which dips toward the center of the structure. This *rim rock* roughly defines the horizontal extent of the deposit. Some ore bodies are irregular in shape and, rather than becoming narrower with depth many maintain essentially the same horizontal dimension.

GEOLOGIC TIME SCALE, TYPES, AND USES OF MISSOURI ROCKS

MAJOR DIVISIONS: ERAS	MAJOR DIVISIONS: PERIODS	TYPE AND DISTRIBUTION OF ROCK	ECONOMIC
CENOZOIC	QUATERNARY (0) 1,000,000 PLEISTOCENE & RECENT	*Glacial deposits; loess; silt, sand, and gravel in modern streams and rivers*	*Parent material for much of state's soil; important source of water; chief source of sand and gravel*
CENOZOIC	TERTIARY (1) 59,000,000	*Sand, gravel, clay, and shale; largely restricted to "Bootheel" region of southeast Missouri*	*Water, ceramic materials (including bleaching clay)*
MESOZOIC	CRETACEOUS (60) 70,000,000	*Clay and sand: restricted to southeast Missouri as above*	*Water*
MESOZOIC	JURASSIC (130) 25,000,000	*No rocks of Jurassic age in state*	
MESOZOIC	TRIASSIC (155) 30,000,000	*No rocks of Triassic age in state*	
PALEOZOIC	PERMIAN (185) 25,000,000	*Sandstone; known from single locality in Atchison County*	*No economic utilization*
PALEOZOIC	PENNSYLVANIAN (210) 25,000,000	*Limestone, shale, sandstone, clay, and coal; present over wide areas-western and northern parts of the state*	*Coal, ceramic materials (including fireclay), raw material for cement, oil, gas, water, an important source of limestone over much of the state, asphaltic sandstone, and iron (?)*
PALEOZOIC	MISSISSIPPIAN (235) 30,000,000	*Predominantly limestone and shale; principal areas of outcrop are southwestern, central, and northern parts of state*	*Lime, limestone, marble (Carthage), raw material for cement, water, tripoli, lead, zinc, and iron*
PALEOZOIC	DEVONIAN (265) 55,000,000	*Predominantly limestone; exposed in central, eastern, and south-eastern Missouri*	*Limestone, marble (Ste. Genevieve Co.)*
PALEOZOIC	SILURIAN (320) 40,000,000	*Predominantly limestone; exposed in northeastern and southeastern Missouri*	*Little economic utilization*
PALEOZOIC	ORDOVICIAN (360) 80,000,000	*Dolomite (magnesian limestone), limestone, sandstone, and shale; extensively exposed in Ozark area as far north as Missouri River and west to Bolivar*	*Sand for glass and silica brick, lime-stone, dolomite, water, oil (St. Louis county), building stone, raw material for cement, and iron*
PALEOZOIC	CAMBRIAN (440) 80,000,000	*Dolomite, sandstone, and shale; outcrops restricted to St. Francois Mountain area*	*Lead, zinc, silver, cobalt, nickel, copper, barite, iron, and water*
PRECAMBRIAN (520) *Includes several divisions of Era rank. Total time involved may have been as much as three billion years*		*Igneous and metamorphic rocks; exposed in St. Francois Mountain area*	*Building stone and monument stone (granite), iron ore*

NOTE: AGE DATA ARE ESTIMATES; CHART NOT TO SCALE; 0-520 - CUMULATIVE AGE - MILLIONS OF YEARS

Fig. 2. Generalized geologic time scale.

The ore consists chiefly of a soft red hematite and varying quantities of hard blue specular hematite in the form of boulders. Limonite is found in soft granular form, but it occurs less conspicuously as boulder ore. Both the hematite and limonite boulder ores may occur in the soft granular hematitic or limonitic portions. Marcasite is present in many of the deposits, and pseudomorphs after marcasite may be observed in all of them.

A chemical analysis of the blue specular hematite ore from the Cherry Valley mine, Pit No. 1, E½ SW¼ sec. 4, T. 37 N., R. 3 W., Crawford County, is given in Table 2.

Table 2

Chemical analysis of handpicked blue specular hematite

Reference: Crane, 1912, p. 97.

Iron (Fe)	Silica (SiO_2)	Phosphorous (P)	Sulphur (S)	Magnesia (MgO)	Lime (CaO)	Alumina (Al_2O_3)	Water (H_2O)
65.96	3.06	0.022	0.159	0.07	0.28	1.27	0.98

Poplar Bluff District

The brown iron deposits may be regarded as either of primary or of secondary origin. It is difficult to distinguish between fragments of ore from either of these two classes of deposits. The primary deposits are thought to be formed by the direct deposition of hydrous iron oxide, and the secondary deposits are believed to have been formed by the alteration of pyrite or marcasite to limonite at normal temperatures.

The Poplar Bluff district is characterized by the presence of a number of primary limonite deposits as well as secondary deposits. The following descriptions of deposits in the Poplar Bluff area pertain to primary deposits. Characteristics of the secondary deposits are discussed under the West Plains district.

Within the Poplar Bluff district, most of the primary deposits are found on or near the crests of ridges. The deposits on the ridges tend to occur in localized groups with most of the deposits within a group being situated at approximately the same elevation. The ore consists of boulders of limonite irregularly distributed in cherty clay residuum. Crane (1912, p. 79) states that the limonite has, at least in part, replaced the residuum in which it occurs. However, this type of replacement is difficult to explain in view of what is known today concerning the chemical actions of replacement. The boulders may range in size from small fragments to masses of several tons and in places may form solid ledges.

Portions of the ore may be cellular, soft, and earthy or very cherty and sandy. In some places a dense, hard, light brown limonite may be observed. The hardness is caused by the presence of very small disseminated grains and fragments of quartz. Because of the included silica, this variety of ore usually contains a lower percentage of iron than other varieties.

The soft earthy type of ore contains more manganese than other varieties. In some areas the manganese content is over 3 percent and appears to be characteristically higher than in the secondary deposits.

Of the several types of primary ore, the porous, cherty variety is by far the most common.

The average results of chemical analyses of 32 carload shipments of ore from 11 mines in the Poplar Bluff district are given in Table 3.

Table 3

Averaged chemical analyses of ore from the Poplar Bluff district

Reference: Crane, 1912, p. 71.

Iron (Fe)	Silica (SiO_2)	Phosphorous (P)	Manganese (Mn)	Water (H_2O)
46.21	16.48	0.068	1.319	3.59

In general, the deposits appear to have a much greater horizontal than vertical extent. The shape and size of the deposits are irregular and are not indicated by any means other than by the distribution of surface boulders. In this regard, one might be cautioned that the surface distribution may cover a much greater area than the size of the deposit, especially on a slope where fragments of the ore may have rolled downhill.

West Plains District

Brown iron ore deposits of the West Plains district are of secondary origin and are associated with and embedded in a thick blanket of residual clay and chert. The residual covering is made up of the more insoluble portion of strata now removed by erosion. This somewhat obscures the relationship of the deposits to the underlying geologic formations, but the majority of the deposits seem to be in or on the Gasconade, Roubidoux, or Jefferson City formations of Ordovician age.

The residuum consists mainly of clay, chert, and sand derived from the chemical decomposition of the dolomites and from the disintegration of the sandstones. At the town of Birch Tree in southwest Shannon County, the residuum reaches a maximum known thickness of 252 feet.

Most of the deposits occur on hillslopes or near the crests of ridges, although some are known to occur in valleys. Undiscovered deposits may be present in the valleys where they are covered with material washed down from the hillslopes.

The deposits range in size from a few feet in diameter to several acres in extent and have been found to a depth of over 100 feet. The maximum depth to which ore may eventually be found is apparently limited by the thickness of the residuum.

Outcrops of fragments and boulders of limonite have led to the discovery of all known deposits, and to date none of the brown iron ore deposits have been found except by such surface indications.

On the surface, the shape of the deposits may be roughly circular or elliptical. They have steep sides and usually become narrower with depth. Some, however, are irregular in outline and elongated. The deposits do not occur as veins and cannot be traced across country from one outcrop to another. Each outcrop appears to indicate a concentration in the residuum, and it is not known that any two local deposits are connected.

Limonite is the chief ore mineral of these deposits, and it occurs in irregular masses, boulders, stringers, and pockets. It is not found continuously through a deposit, but enriched areas are separated by waste material that is very lean in iron-bearing minerals. These waste areas are often referred to as "horses". Hematite is also found but in minor amounts.

Silica impurities are chert, quartz-lined cavities, and quartz sand grains. Marcasite and pyrite are found in many of the deposits, chiefly in the center of boulders. Where marcasite or pyrite is found in this manner, the change from the iron sulfide to the hydrous iron oxide on the outer portion may be clearly seen. Even where pyrite and marcasite may not be detected, pseudomorphs of limonite after the sulfides have been found in nearly all of the deposits in the district. Manganese, although rarely observed, is present in small quantities as indicated by chemical analyses.

Four types of limonite masses may be observed in the area: *boulder ore* (or *dornick ore*), *tabular ore, pipe ore,* and *ocher*. The boulder ore is the most common and constitutes the greater part of most of the deposits. In places it is cellular and porous and in other places hard and compact. It may be found in roughly spherical masses known locally as "bombs" and may have iron sulfide in the center, or the center may be partly filled with clay. A variety of this type of ore is called *pebble ore* and consists of small fragments broken from larger masses of boulder ore or tabular ore. A considerable portion of many deposits contains pebble ore.

Tabular ore occurs in stringers and broken fragments which form flat tabular masses. This form of occurrence indicates that the material was deposited on a pre-existing surface as a coating, or that it completely filled a pre-existing rock fracture.

Pipe ore is the result of the alteration to limonite of stalactite masses of iron sulfide. The size of a single pipe may range in diameter from a fraction of an inch to almost a foot and in length from a few inches to several feet. The very small diameter pipes are sometimes referred to as *needle ore.* Pipes may occur either singularly or in parallel groups. In cross section the pipes may show a radial structure or a concentric color banding or both. Some pipes consist entirely of marcasite or of limonite. Others, consisting of marcasite and limonite, show the alteration from the iron sulfide to the iron oxide.

Ocher in many instances forms a considerable portion of a deposit but contains such a large quantity of admixed clay that it is not at present considered an ore.

The following table indicates the chemical characteristics of pipe ore in relation to boulder and ocherous ore. It must be remembered that all ore mined in the early 1900's was hand picked and, therefore, these analyses are considerably higher in iron content than analyses of current ore shipments.

Table 4

Averaged chemical analyses of pipe ore (1), and boulder and ocherous ore (2)

Reference: Crane, 1912, pp. 61-62.

Iron (Fe)	Silica (SiO_2)	Phosphorous (P)	Manganese (Mn)	Water (H_2O)
(1) 55.27	7.56	0.082	0.138	4.77
(2) 52.98	10.40	0.091	0.133	4.23

(1) Averaged pipe ore analyses from 10 mines; represents 51 shipments.

(2) Averaged boulder ore and ocher analyses from 10 mines; represents 105 shipments.

Springfield District

The bedrock of this district is largely composed of the Burlington and Keokuk limestones of Mississippian age. However, numerous areas of the district are covered by Pennsylvanian sandstones and shales.

Crane (1912, p. 72) indicates that the deposits in this area are of primary origin, but recent investigation has shown that most of them are probably secondary brown iron deposits. In nearly all of the deposits, pseudomorphs of limonite after pyrite or marcasite may be found.

The ore is found in fragments and large boulders surrounded by a cherty clay residuum formed by the concentration of the more insoluble parts of the Burlington and Keokuk limestones. The thickness of this residuum is generally less than 50 feet.

Most of the deposits are irregular but elongate in outline. One deposit has been worked to a depth of 30 feet and was still in ore when operations ceased. Recent exploratory drilling indicates that thicknesses of 75 to 80 feet may be expected.

Limonite is the chief ore mineral in the district, and some small quantities of hematite have been observed associated with the limonite. Boulders or "bombs" (sometimes hollow), crusts or coatings on rock, and broken fragments form the major part of the ore.

In some deposits a considerable part of the ore has been deposited in the form of pyrite on calcite crystals, probably in open channels or fractures in the enclosing limestone. Large molds are preserved in the limonite (now pseudomorphic after the pyrite) where calcite crystals have been removed by weathering. Molds of sphalerite crystals are also present, and a relatively small quantity of sphalerite is reported in some deposits.

A characteristic feature of the ore from this district as compared to the ore from other secondary limonite districts appears to be its slightly higher content of phosphorous. The averaged results of chemical analyses of 56 carload shipments from 9 mines in the Springfield district are given in Table 5.

Table 5

Averaged chemical analyses of ore from the Springfield district

Reference: Crane, 1912, p. 76.

Iron (Fe)	Silica (Si)	Phosphorous (P)	Manganese (Mn)	Water (H_2O)
50.45	10.98	0.204	0.765	4.49

Osage River District

Although this district contains more known deposits than the Springfield district, it has been one of minor production.

Brown iron deposits are found scattered throughout the district and consist mainly of secondary boulder and pipe ore. In the eastern part of the district, the limonite occurs in the residuum overlying the Jefferson City dolomite and the Roubidoux sandstone of Ordovician age, whereas, in the western part, the residuum directly overlies the Burlington limestone of Mississippian age.

Several hematite deposits are located in central and southeastern Miller County.

PROSPECTING AND DEVELOPMENT

Leasing

Although it is not the policy of the Missouri Geological Survey to establish or even suggest mineral lease terms, it is believed that a statement of some general terms and amount of payments may be of benefit both to the landowner and lessee.

Customarily, mineral leases are let for a term of from 1 to 3 years. Usually no cash bonus is paid to the landowner for a lease. If an ore deposit appears to be particularly high grade or is favorably situated, the lessee may offer a cash bonus to obtain a lease. If at the end of this period no mining has been done, the lease may be extended annually for as much as 5 years. In some instances, a *delay rental*, based on acreage or a lump-sum payment, is made for each year of extension. The average delay rental for a year's extension ranges from \$0.25 to \$1.00 per acre.

Usually a mineral lease will be held beyond the primary lease term without payment of any delay rental as long as mining operations continue. A royalty payment, based on the tonnage of ore shipped, is usually agreed upon and this generally ranges from \$0.20 to \$0.40 a ton. In exceptional cases, the royalty may be as high as \$0.60 or \$0.75 per ton.

The royalty rate is a very important item to both the owner and developer, and several factors should be taken into consideration before determining the royalty rate for a specific deposit. Some of these factors are as follows:

1. Size of the deposit.
2. Depth of overburden.
3. Availability of water.
4. Areas for waste disposal and slime ponds.
5. Grade of the raw ore. This should include not only the percentage of iron but also the percentages of silica, phosphorous, and other deleterious material present.
6. Physical characteristics of the ore that determine the amount of crushing and washing required.
7. Amount, form, and size of chert fragments which determine the amount of crushing and hand picking.
8. Trucking distance and road conditions to railroad loading facilities.
9. Unit price of iron ore.
10. Freight rate.

In some instances, a lease may contain an option to purchase either the mineral or surface rights or both. This is true especially if the deposit is of considerable size or covers two or more individually owned tracts of land.

It must be remembered that if prospecting is planned on privately owned land, permission to do so should be obtained from the landowner. A mineral deposit belongs to the person who owns the land or the mineral rights. The owner or holder of the mineral rights may give permission to prospect on his respective property without fear of losing his ownership.

In Missouri, public lands on which a mining claim can be located are very limited. The area of public lands in the state probably total less than a section or one square mile, according to the Bureau of Land Management.

Most of the State Forest lands, which total about 165,000 acres are located mainly in Shannon, Reynolds, Carter, Wayne, and Iron Counties. They are open to public and normal surface examination, and exploration may be made except in certain areas that have been set aside for specific uses. No digging or drilling may be done without obtaining a permit to prospect from the Conservation Commission, Jefferson City, Missouri. The minimum tract for which such a permit may be issued is 40 acres, and the cost of such a permit is about $0.25 per acre.

On some of the State Forest land, the mineral rights are still held by individuals, but on the major portions of the land, mineral rights as well as surface rights are held by the State.

A prospector cannot stake a claim on National Forest lands and must proceed in much the same manner as in the case of State Forest lands in obtaining a permit to prospect or lease. Such permits are obtained from the Bureau of Land Management, Washington, D. C.

By law, all mines are open to the State Mine Inspector, and a copy of the *Mine Inspection Laws of the State of Missouri* may be obtained from the Division of Mine Inspection, Jefferson City, Missouri.

Surface Indications

To date all the sedimentary iron ore deposits of Missouri have been discovered by surface indications.

In the Steelville district, outcrops of blue specular, hard red or brown ore have been indicative of the filled-sink type deposit. Some deposits have shown very limited exposures of iron-bearing minerals where the associated, dipping, sandstone rim-rock indicated a larger area of possible ore. Where the surface extent of ore is relatively small, it is advisable to determine if a rim-rock is present and to note its extent. This will usually indicate the maximum horizontal extent of the deposit.

The surface indications of both primary and secondary brown iron deposits usually consist of fragments and boulders of limonite mixed with residuum. The lateral extent of these deposits is difficult to determine from surface outcrops because in several instances the surface extent has been found to be smaller than at depth. Conversely, float fragments may be washed down slope, and unless the observer recognizes this possibility, the inferred size of the deposit may be exaggerated.

Trenching and Prospect Pits

In order to determine more advantageously the horizontal extent of a deposit, particularly in regard to the brown iron ores, prospect pits or trenches may be dug at intervals. In the West Plains district, numerous operators have used bulldozers for excavating trenches to determine the lateral extent of a deposit.

The ore is usually more concentrated at the surface than at depth because of the partial removal of the surface clay and lighter chert fragments by erosion. By exposing the material to a depth of several feet, the quantity of ore in a cubic yard of material may be better estimated.

Exploratory Drilling

In order to determine the grade and extent of the ore, recent prospecting methods make extensive use of data gathered from drill holes. Exploratory drilling was used in connection with the magnetite-hematite deposits of the igneous region as early as 1890. Drilling of any of the brown ore or filled-sink deposits was not begun until about 1904 when a churn (cable-tool) drill hole was drilled in a filled-sink structure in Franklin County. Very little drilling had been done on any of the brown iron ores until 1943 when the U. S. Bureau of Mines drilled eight properties in the Poplar Bluff district. At present, churn drilling by ordinary water-well, cable-tool rigs and by small exploratory rigs employing a churn action is being used.

There are two main types of drills that have been used in exploration work: (1) the churn type that has a vertical up and down motion which crushes the rock material into small fragments, and (2) a rotary type that has a cutting action.

Churn drills have been the most common tools used for drilling exploratory test holes since their first application to the iron deposits in Missouri. Several of the larger filled-sink deposits have been explored by means of churn drilling, and to date approximately 40 of the brown iron deposits have been drilled. By far the majority of the drilling has been accomplished in the past two years.

There are several disadvantages to churn drilling. The high cost is perhaps the greatest deterrent. The purchase price may be prohibitive for the small operator. Even if the exploratory holes are drilled by contract, the cost to explore a deposit properly is considerable. However, if it is contemplated to mine a deposit, it is recommended that the deposit be explored by drilling to determine the thickness of the ore. The thickness of known deposits ranges from a few feet to over 100 feet, and it would be shortsighted to set up a washing plant for a deposit that would later turn out to be only a few feet thick.

The limited mobility and water requirements of this type of drilling are also disadvantages.

Comparatively good samples may be obtained by churn drilling except when large boulders are encountered. When this occurs, the bit has a tendency to work off the edge and to push the boulder away from the hole farther into the surrounding clay. Thus, the samples at this point are not truly representative. Four- to six-inch diameter bits are commonly used. Because the practical depth limitation for the churn drill is in excess of 4,000 feet, holes may be drilled by this tool to explore the thickest known deposits in the area.

Churn drills have been used in the West Plains and Springfield districts and in the hematite deposits of the Steelville district.

An exploratory type drill with a churn action has recently been used by several operators in the West Plains district. It is comparatively light—total weight 1,300 pounds including gasoline power unit—and is capable of drilling to depths of around 100 feet. Water is fed into the hole, and the cuttings are returned to the surface through the drill rods. Regular rock bits 1¾ to 2¼ inches in diameter are used.

The mobility of this type of exploratory drill is a very desirable feature, and one man is adequate for its operation. Several models of this type drill are available at prices from $1,200 to $1,400.

The most simple type of rotary drill used in exploratory work has been the power auger. Brown iron ore deposits of Alabama were drilled with power augers in 1945. Advantages found were the mobility of the equipment because of its relative light weight, no water requirement, and low cost. Augering is limited to around 75 feet in depth, and samples so obtained are somewhat undependable as to exact depth. This method has not proved to be a satisfactory exploration method for brown iron ore deposits and is certainly not adaptable for prospecting the filled-sink hematite deposits because of the hardness of the hematite boulders.

In the early 1930's, placer deposits in California were drilled by using a rotary bucket drill, and in 1943 this method was used in southeastern Missouri for the exploration of five brown iron deposits. A bucket with a conically shaped bottom with cutting edges is used as the cutting tool. The knife blades slice and the bucket catches and holds peelings of the material being penetrated. A 16-inch diameter bucket was found to be adequate in the Missouri tests and gave good samples.

Rotary core drilling was attempted in Alabama in 1945. A 5-foot double core barrel that cut a 3-inch core was used. The core recovery for the entire core drilling program was 65.9 percent. Core drilling in clay is difficult at times, and when a clay in which limonite occurs as boulders and irregular masses is drilled much of the clay may be washed out of the hole. There is also the disadvantage of not being able to recover portions of large boulders or fragments that are pushed into the clay instead of being penetrated by the drill. Core drilling also requires considerable water, and the initial cost for equipment is high. Low speed, light weight on the bit, and high water pressure form the best combination for coring in clay. When coring sand, the opposite of these factors should be used for best core recovery.

Samples taken from drill cuttings are usually evaluated by inspection and are not assayed. Because the greater part of the clay in which the limonite is embedded is washed away by drilling, assays do not give a true representation of the raw ore. It is difficult to determine if the chert fragments in the cuttings are from small nodules and fragments or if they have been chipped from larger fragments.

Cuttings that contain more than 40 or 50 percent limonite fragments are usually considered to represent ore. In this manner the horizontal and vertical limits of a deposit may roughly be determined.

Geophysical Methods

Magnetic.—During 1929 and 1930, magnetic surveys were made by the Missouri Bureau of Geology and Mines of several filled-sink and some brown iron deposits. The instruments used were the relatively simple Hotchkiss Superdip magnetometer and the more sensitive Askania magnetometer. As both magnetometers are used to measure the earth's natural magnetic field, it is at once obvious that only a deposit that contains magnetic minerals (such as magnetite) can be found or mapped by magnetic methods.

In several filled-sink deposits, a high reading indicating an anomaly was obtained over a concentration of blue specular hematite. When surface indications shows the existence or possible presence of a filled-sink iron deposit, the most concentrated area of specular hematite may be located within the deposit.

The magnetic field at any point is influenced by the total effect of all the underlying rocks. Precambrian rocks are at considerable depth but contain a greater quantity of magnetite than the sedimentary rocks between them and the surface. A magnetic "high" may be caused by near surface concentrations of magnetic material, a Precambrian structural high, a concentration of magnetic material in the Precambrian, or by a different rock type in the Precambrian.

At present it appears somewhat doubtful that magnetic surveys would indicate a concentration of brown iron ore.

Electrical resistivity.—This method of geophysical prospecting is dependent upon the different electrical properties of different rock types. In 1929, an electrical resistivity survey was made by the Missouri Bureau of Geology and Mines of a filled-sink iron deposit. The data gathered from this and later surveys are not entirely conclusive. Readings taken over a deposit usually indicate relatively low resistivity, while readings around the edge indicate relatively high resistivity. However, instruments and interpretations have so improved during the last 20 years that this method should be tested thoroughly before considering it inadequate.

It is not known if this method has ever been used to delimit the extent of brown iron deposits. Because this method is widely used in prospecting for deposits of sulfide ores and because of the presence of iron sulfides in the brown iron deposits, it is possible that electrical resistivity methods may prove adaptable to these deposits.

Self potential.—A sulfide deposit in the zone of weathering tends to generate electrochemical reactions below the surface. The potential differences may be measured at the surface to indicate the size and shape of the mineral deposit.

As far as is known, surveys of this method have not been attempted on any of the brown iron deposits, but several such surveys were made of some filled-sink deposits (with doubtful results) in the early 1940's.

Other methods.—Radio waves have recently been used with varying success in exploring certain ore deposits. This is a new geophysical technique which employs radio waves to detect the electrical contrasts that exist between a mineral deposit and the surrounding rock. In operation, radio-frequency energy from a transmitter is fed into the ground. A receiver is located at a distance from the transmitter, and readings are taken as the receiver is moved away in a straight line from the transmitter. This method has not been tried on any of the Missouri iron deposits but is mentioned because of its potential value if adapted to these types of deposits.

Numerous instruments are on the market for which claims are made concerning their ability to discover ores and minerals. One should verify such claims to his complete satisfaction before buying instruments or before paying someone to make a mineral survey with an "ore detector".

EXTRACTION AND TREATMENT OF ORE

Mining

Surface indications of the hematite ores of the filled-sink deposits led to their development by open pit methods of mining. During the early 1930's, some of the larger deposits were mined by underground methods when it became apparent that the deposit extended to considerable depth. In some deposits small relatively rich ore bodies were found to be concentrated in or radiating outward from the bottom of the deposit. These localized ore bodies were also mined by underground methods to a maximum reported depth of 325 feet.

At present only one hematite deposit of the filled-sink type is being mined. However, several are being prospected and explored, and one is currently being developed prior to actual mining operations.

The currently operating mine is reworking a deposit previously mined by both open pit and underground methods. A large quantity of material has caved and slumped, thus necessitating the removal of considerable waste before the main ore body may be mined. However, hematite boulders are scattered throughout much of the material and are separated from the waste by hand picking in the pit before the material is loaded. Some areas contain enough small boulders to be ore. This material is removed and loaded either by a 1-cubic yard shovel or a hydraulically operated "hi-lift". The operator plans to mine the deposit by a continuation of open pit methods. Ore is hauled a short distance (approximately 400 feet) by 2-ton dump trucks for later size separation.

Although some of the brown iron deposits may in the future be mined to a depth of over 200 feet, it appears doubtful that underground methods would prove applicable to these deposits. All of the brown iron deposits are mined by open pit methods, and in all but three deposits the raw ore is moved with shovels. Capacity of the buckets currently being used ranges from ¾ to 1½ cubic yards. The smaller shovels have the advantage of being moved from one locality to another with a minimum amount of disassembling, and the smaller buckets provide for more selectivity in separating ore from waste in actual operations.

One deposit in the Poplar Bluff district is being mined by means of a hydraulically operated "hi-lift". A drag line is being used to extract raw ore from two of the larger deposits in the West Plains district. The drag line has proved to be less selective than the other methods but has the advantage of not being on the bottom of the pit. In this manner the trucks may be loaded on a bench above the level of the pit floor, and heavy equipment is less likely to bog down during rainy weather.

Ore haulage from the mine is by means of dump trucks with rated capacities of from 2 to 2½ tons. On an average each truck can haul approximately 5 cubic yards or about 6 tons of raw ore.

Customarily, an earthen ramp is constructed so that ore may be dumped from the trucks into an elevated hopper that controls the feed for later benefication.

Beneficiation

Until recently, hematite ores from the filled sinks were hand picked and the large boulders broken by a sledge. At present, ore from 1/4 inch to 4 inches in diameter is for blast furnace feed, and ore from 4 inches to 24 inches in diameter is for open hearth, provided that the minimum grade of 56 percent iron is maintained.

Ore from the trucks is dumped directly onto a grizzly (a grating of iron or steel bars or a screen that separates coarse from fine material). The grizzly is constructed of T rails which are turned upside down and set parallel with enough slope so that the larger boulders will roll to the lower part of the grizzly. The parallel rails in the upper part are set with a 4-inch clearance while those in the lower part provide a 12-inch clearance. Ore boulders that are oversize are usually broken with a sledge hammer. Some of the larger boulders may contain a core of marcasite. Thus, by breaking the oversize, such boulders may be recognized and rejected.

The dumps around many of the filled-sink deposits contain small pebble size fragments of hematite that were included as waste when handpicking (cobbing) methods were used. During 1956, some of these dumps were being beneficiated by a log washing method similar to the methods used on the brown iron ores.

Profitable mining and concentration of the brown iron ores had been difficult until about 1955. The majority of the deposits are small, and the ratio of waste to ore is high. Until a favorable price was established, operations were small, and a large percentage of the work was hand labor.

Beneficiation is accomplished in all instances at the present time by log washers. The raw ore feed from the hopper is controlled either by being washed with water under pressure from a nozzle or by chain feed in the bottom of the hopper, or a combination of both may be used. In most operations, a workman controls the nozzle and washes the raw ore from the hopper.

From the hopper the ore passes over a grizzly. It is constructed as previously described except that the opening between the rails is 3 to 4 inches wide for its entire length. In one operation a vibrating screen is used as a grizzly, and the raw ore is fed over the screen dry.

The oversize from the grizzly or screen is inspected by workman and waste material such as chert boulders or fragments consisting mainly of pyrite or marcasite are pulled to one side. In some operations, oversize ore boulders are broken by hand, but in the majority of plants the oversize passes to a jaw crusher. It is common practice to crush to minus 3 inches. Most crushers are 24 by 36 inches and are powered by individual power units, usually gasoline motors.

In most instances the undersize from the grizzly (and crusher when used) is fed to a log washer. The primary function of a log washer is the removal of the dirt, clay, silt, and fine sand by agitation in water. A log washer is neither designed nor expected to separate ore fragments from chert or flint. Another important action of the log washer is breaking and crushing the larger fragments of the more porous or "cindery" ore so that clay-filled voids may be exposed to the washing action.

It is not known when the first log washer was used in brown iron ore beneficiation, but in 1912 there were nine washing plants in the West Plains and Poplar Bluff districts and one in the Springfield district. These early washers consisted of a single log, and at present at least two plants are using single-log washers.

A double-log washer has proved to be 2½ to 3 times as effective as a washer with a single log. A double-log washer can either handle more tonnage with equal washing action or the same tonnage with more washing action. The initial cost of a washer with a double log is less than twice that of one with a single log.

An ample water supply is mandatory for proper action in the washers. Most washers are capable of handling from 40 to 60 cubic yards of raw ore per hour which requires from 200 to 300 gpm of water. Overflow from the washer is ponded, and some of the water recirculated.

Until 1955, the operators had depended upon surface water for supply. The drought years of 1952-1956 caused a serious shortage of surface water which caused operations to shut down. In 1955, the first deep water well was drilled to insure a continuous adequate water supply. At present, six operations are obtaining water from wells ranging in depth from 800 to 1,200 feet and yielding from 150 to 250 gpm.

The length of the logs ranges from 20 to 31 feet. It has been demonstrated that the maximum effective length of logs used for brown iron ore beneficiation is about 28 to 30 feet.

Another important construction feature is the arrangement, size, and shape of the paddles. On several manufactured steel logs, they are set in four longitudinal rows on each log. In practice it is thought that a spiral arrangement of the paddles is more effective, and most logs fabricated locally are of this design. A considerable number of locally fabricated logs consist of paddles which are welded onto the log. The paddles are hard surfaced and may be resurfaced when worn. Other paddles have a plate of hardened steel bolted onto the paddle blade. Some of the latter are designed with a recessed central portion to provide two ridges to aid in crushing and breaking the feed.

The slope of the logs ranges from 5 to 8 degrees. As the waste to ore ratio increases, the slope is decreased to provide more crushing and washing action. Some of the later installations are constructed so that the slope may be adjusted by raising or lowering the head of the washer. The speed of rotation of the logs ranges from 17 to 28 rpm.

Even well constructed logs may not operate efficiently when the feed is too high, too low, or uneven. The quantity of water used is also an important factor for maximum washing of the feed.

In all currently operating installations, the ore is dropped from the head of the washer onto a conveyor belt by which it is elevated to the ore bin or stock pile. The old fashion method of ore beneficiation, cobbing, is still used in virtually all operations. While the material is on the conveyor, waste fragments consisting mainly of chert, pyrite, marcasite, and sandy limonite are hand picked off the belt and thrown aside. From one to four pickers are used depending upon the quantity of waste material.

Perhaps the most critical factor that determines if a deposit may be worked is the ratio of raw ore in place to a ton of ore concentrate. This ratio has a wide range from one deposit to another as well as within a single deposit. It has been the practice to express this ratio by the number of cubic yards of raw ore in place to a ton of ore concentrate. Within a single deposit, it may require as much as 7 cubic yards of raw ore to produce 1 ton of ore concentrate, and in a few instances the material was actually direct shipping ore. Although detailed records are not available, the average ratio of the number of cubic yards of ore in place to a ton of ore concentrate is about 4 to 1.

In 1950, beneficiation of a deposit in Wayne County was attempted without success by means of a spiral classifier. During the period of 1905 to 1910, hand jigs were used in some operations to separate the chert from the ore.

A company with major operations in the Alabama brown iron ore district is planning a heavy media separation unit and jigging operation at one of the deposits in Shannon County in the West Plains district. This will be the first attempt at heavy media separation of any of the Missouri iron ores and by far the best designed jig operation of the brown ores. Another company is in the initial stages of setting up jigs for treatment of brown ore in Greene County in the Springfield district.

Marketing

Years of greater production of the sedimentary iron ores of Missouri have a close relationship to the economy of the Nation. During the period of 1905 to 1910, sustained production was maintained from the filled sinks and the brown iron deposits. Except during 1931, production of the hematite ores gradually declined to practically nothing by 1945. Brown iron production declined even more noticeably except for a period during World War I and the depression of the early thirties.

It was not until the average price was well over $4.00 per ton that the brown iron ores were worked on a large scale. Figure 3 indicates the average value per ton of hematite and limonite ores sold annually in the United States from 1937 to 1953.

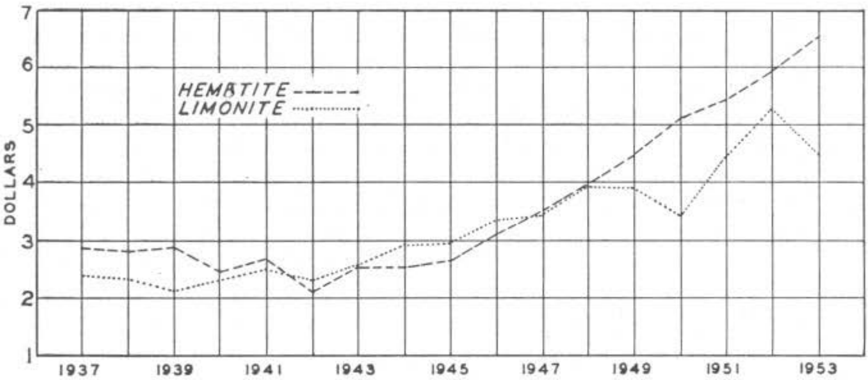

Fig. 3. Average value of hematite and limonite mined in the United States from 1937 to 1953. Data from U. S. Bur. Mines, Minerals Yearbooks, 1937-1953.

During June 1957, the price for open hearth Missouri hematite ores below 60 percent iron (dry) was about $11.00 per long ton and was $12.50 per long ton for ore over 60 percent iron (dry), F.O.B. shipping point. The price for Missouri brown ores of 50 percent combined iron and manganese was about $6.75 per long ton, F.O.B. shipping point.

Payment schedules for the brown ores are usually based on units per gross ton. The long ton of 2,240 pounds is used in the iron ore industry.

For brown iron ores containing less than 5.0 percent manganese, payment is made on the combined percentage of iron and manganese.

A typical price schedule for the brown ores is shown in Table 6.

Table 6

Typical price schedule for Missouri brown iron ore, June 1957

Combined Fe *and* Mn *(dry)* *Percent*	*Price F.O.B. shipping point per unit per gross ton*
40 to 45	$0.100
45 to 47	0.105
47 to 50	0.125
50 to 53	0.135
53 and over	0.140

Some difficulty of correctly reading assay reports has been encountered by the inexperienced. A unit is 1/100 of a long ton or 22.4 pounds. For example, if an assay shows 51.0 percent combined iron and manganese, from the above price schedule the price per unit would be 13.5 cents. In order to determine the payment per gross ton, multiply 51.0 times 13.5 cents which gives $6.885 per long ton. Ore containing 40 percent combined iron and manganese would sell for 10.0 cents per unit or $4.00 per long ton.

The percent of iron, or of combined iron and manganese, may be reported on the basis of either *natural* or *dry*. Ore received at the smelter is damp and contains some water on the fragments and in the clay not removed by washing. The percent of iron in this material is reported on a *natural* basis. Another portion of a sample is dried to remove the moisture, and the percent of iron is reported on a *dry* basis. An ore containing 50 percent iron (natural) and 10 percent moisture would contain approximately 55.5 percent iron (dry).

The average grade of ore shipped today is considerably lower than analyses of ores shipped in the early 1900's. This is because hand picking and "high grading" of the raw ore is not used in the present mechanized mining methods, and the leaner deposits are being mined. The combined iron and manganese weighted average of 56,216 tons of ore shipped in 1956 from the West Plains and Poplar Bluff districts was 46.66 percent (natural), and the average silica content of these ores was 13.924 percent. The weighted average price of these ores was $5.525 per long ton (dry), F.O.B. shipping point.

Specifications for open hearth hematite ores and blast furnace brown iron ores are given in Table 7.

Table 7

Typical furnace specifications for Missouri hematite and brown ores

	Open Hearth (Hematite ores) Percent	*Blast Furnace (Brown ores) Percent*
Fe (dry) minimum	56.00	40.00
Silica maximum	10.00	15.00
Sulphur maximum	0.15	0.15
Phosphorous maximum	0.15	0.25
Size in inches	4-24	¼-4

A desirable feature of the brown ores of the Poplar Bluff and West Plains districts is their low phosphorous content which is generally less than 0.10 percent. The hematite ores from the Steelville district are even lower, averaging about 0.02 percent. The phosphorous content of the brown ores from the Springfield district averages somewhat higher, about 0.20 percent.

Cost of Mine Equipment

Mining equipment and beneficiation plants in the brown ore districts reflect a wide range in their initial cost. Many operations are using second-hand equipment and have been constructed with a minimum of expense, while others are using practically all new equipment.

Table 8 shows the estimated cost of equipping a mine using new and used equipment.

Table 8

Estimated cost of mine equipment

Item	*New*	*Used*
Power shovel, 1 c.y.	$35,000	$10,000
Log washer, 30-foot	14,000	3,000*
Jaw crusher, 24 x 36 inches	11,000	5,000
Conveyor, 50-foot	1,500	1,500†
Power units (2)	6,000	2,500
Dump trucks (2)	5,000	2,500
Water well, 1000-foot	5,000	5,000†
Water well pump	3,000	3,000†
Power unit for pump	2,000	750
Misc. small tools, equipment, and labor	3,000	2,500
R. R. loading ramp	1,200	1,200
Estimated total cost	$86,700	$37,450
For operation not crushing ore	$74,200	$31,000
For operation crushing ore and using surface water	$76,700	$28,700

*Logs only, does not include washing trough.

†New price, used for items that cannot be purchased locally as used equipment.

Depending upon the type of operation, source of water, quantity of new or used equipment, and the equipment on hand, the cost of equipping a mine may range from $10,000.00 to as much as $90,000.00.

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