Prepared in cooperation with the U.S. Environmental Protection Agency

Geology and Mining History of the Southeast Missouri Barite District and the Valles Mines, Washington, Jefferson, and St. Francois Counties, Missouri

Scientific Investigations Report 2016–5173

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph. Family digging for barite (Witman, 1941), National Archives Catalog.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	61.02	cubic inch (in^3)
	Flow rate	
	Mass	
microgram (ug)	0.00000003527	Ounce, avoirdupois (oz)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations and Symbols

Ba	barium
BaO	barium oxide
C	carbon
CO_2	carbon dioxide
CO_3	carbonate
Cu	copper
EPA	U.S. Environmental Protection Agency
Fe	iron
GIS	geographic information system
IMOP	Inventory of Mines, Occurrences and Prospects
MGS	Missouri Geological Survey
NPL	National Priorities List
O	oxygen
Pb	lead
PbO	lead oxide
S	sulfur
SO_3	sulfur trioxide
SO_4	sulfate
USGS	U.S. Geological Survey
Zn	zinc
ZnO	zinc oxide

Geology and Mining History of the Southeast Missouri Barite District and the Valles Mines, Washington, Jefferson, and St. Francois Counties, Missouri

By Douglas N. Mugel

Abstract

The Southeast Missouri Barite District and the Valles Mines are located in Washington, Jefferson, and St. Francois Counties, Missouri, where barite and lead ore are present together in surficial and near-surface deposits. Lead mining in the area began in the early 1700's and extended into the early 1900's. Hand mining of lead in the residuum resulted in widespread pits (also called shafts or diggings), and there was some underground mining of lead in bedrock. By the 1860's barite was recovered from the residuum by hand mining, also resulting in widespread diggings, but generally not underground mines in bedrock. Mechanized open-pit mining of the residuum for barite began in the 1920's. Barite production slowed by the 1980's, and there has not been any barite mining since 1998. Mechanized barite mining resulted in large mined areas and tailings ponds containing waste from barite mills.

The U.S. Environmental Protection Agency (EPA) has determined that lead is present in surface soils in Washington and Jefferson Counties at concentrations exceeding health-based screening levels. Also, elevated concentrations of barium, arsenic, and cadmium have been identified in surface soils, and lead concentrations exceeding the Federal drinking-water standard of 15 micrograms per liter have been identified in private drinking-water wells. Potential sources of these contaminants are wastes associated with barite mining, wastes associated with lead mining, or unmined natural deposits of barium, lead, and other metals. As a first step in helping EPA determine the source of soil and groundwater contamination, the U.S. Geological Survey (USGS), in cooperation with the EPA, investigated the geology and mining history of the Southeast Missouri Barite District and the Valles Mines.

Ore minerals are barite (barium sulfate), galena (lead sulfide), cerussite (lead carbonate), anglesite (lead sulfate), sphalerite (zinc sulfide), smithsonite (zinc carbonate), and chalcopyrite (copper-iron sulfide). The Cambrian Potosi Dolomite is the most important formation for the ore deposits, followed by the Eminence Dolomite. Because galena, sphalerite, and barite are less soluble than dolomite, chemical weathering of the ore-bearing dolomite bedrock resulted in the concentration of ore minerals in the residuum. Most of the barite and lead mining was in the residuum, which averages 10 to 15 feet thick.

Lead mining by French explorers may have begun in 1719 along Old Mines Creek at Cabanage de Renaudiere, which was followed shortly by the discovery of lead and the development of lead mines at Mine Renault (also called Forche a Renault Mine), Old Mines, and at other places along the Big River, Mineral Fork, and Forche a Renault Creek. Lead mining began sometime between 1775 and 1780 at Mine a Breton, the name of which was later changed to Potosi. Other mining areas were developed in the early part of the 19th century, including Fourche a Courtois (Palmer Mines), the French Diggings, and the Richwoods Mines. Zinc became a valuable resource after the Civil War, and the Valles Mines was an important supplier of zinc as well as lead, with at least some production up until the 1920's. Lead mining declined in the early part of the 20th century as mining in the Old Lead Belt, Mine La Motte, and the Tri-State District expanded.

The earliest lead mines were diggings in the residuum and were round holes (shafts) about 4 feet in diameter dug with pick and shovel about 15–20 feet deep, with drifts dug a short distance laterally from the bottom of the shafts. This mining process was repeated a short distance away until a large area was covered with pits. Some mining in bedrock began by about 1800, with shafts as deep as 170 feet and as much as several hundred feet of lateral drifts.

Smelting of the lead ore to elemental lead was first done using a log furnace, which was inefficient; estimates have been made that only about 50 percent of the lead was recovered, and the remainder was lost to the ashes (slags) and to volatilization. Starting in 1798, ash furnaces were used to smelt the ashes from the log furnaces. These two furnaces were worked in tandem for many years but were gradually replaced by other furnaces, including the Scotch hearth. Estimates of lead recovery as high as 80–90 percent have been made for the Scotch hearth. By the mid-1870's the air furnace was being used, also with estimated lead recovery as high as 80–90 percent. Zinc furnaces were built when zinc became a valuable commodity, but much of the zinc ore was shipped out of the area, either to a smelter in St. Louis, Missouri, or to other smelters.

The total lead and zinc production from the Southeast Missouri Barite District and the Valles Mines is estimated at 180,000 tons of lead and 60,000 tons of zinc. An estimated 97,000 tons of lead and an estimated 120,000 tons of zinc were lost during smelting. The estimated losses do not include losses at the mine site during mining and preparation for smelting, such as the loss of fine-grained galena during hand cleaning or the discarding of zinc ore before its value was known, for which no estimates are available.

Hand mining for barite in the residuum was active by at least the 1860’s and peaked from 1905 to the 1930’s when several thousand people were engaged in barite mining. Hand mining (diggings) and cleaning of the ore was done in much the same way as earlier lead mining, with the additional use of a rattle box to further clean the barite. Mechanized open-pit mining of old barite diggings began in 1924 to recover barite left behind by hand mining, and washing plants were used to clean the clay from the barite. Hand mining, however, continued to thrive, and washer plants began to close temporarily in 1931; nearly all of the barite produced before 1937 was by hand mining. By the 1940’s, however, all barite mining was mechanized.

Mechanized mining used shovels powered by steam, gasoline, or electricity (and by the 1950’s draglines and front-end loaders) to mine the residuum. The ore was loaded onto rail cars (and by the 1940’s, trucks) for shipment to washer plants. Clay was removed from the barite using a log washer, and a jig was used to concentrate the barite. Overflow from the log washers was waste and went to a mud (tailings) pond. The coarse jig tailings went to tailings piles or were used as railroad ballast and, later, to create roads within the mine pit. Some barite was ground, depending on its final use, and some ground barite was bleached using a hot solution of sulfuric acid to remove impurities such as iron minerals and lead sulfide (galena). An earlier bleaching process used lead-lined tanks.

Large quantities of water were required for milling the barite; some was recirculated water and the remainder came from dammed streams or was pumped from wells. Tailings and wastewater were impounded behind dikes that were built across small valleys and were increased in height as necessary using washer waste and any overburden that had been stripped. In some cases, dikes were built across valleys that had already been mined for barite.

The total production of barite from the Southeast Missouri Barite District and the Valles Mines is estimated to have been about 13.1 million tons. Most of the barite production was from Washington County. Hand mining and processing of barite was inefficient. Estimates of barite recovery range from less than one-fourth to about one-half because pillars between the shafts in the residuum needed to be left unmined for stability. With mechanized mining, large amounts of barite were lost during the milling process. It has been estimated that about 30 percent of the barite was lost and that about two-thirds of the lost barite was fine-grained and was discharged to the tailings ponds. Some galena was lost to the tailings ponds.

A 1972 inventory of tailings ponds by the Missouri Geological Survey identified 67 ponds in the Southeast Missouri Barite District (there are more than this currently documented). Results from samples from four ponds that were drilled were used to estimate that the 67 ponds contained almost 39 million tons (or cubic yards) of tailings averaging about 5 percent barite, for a potential reserve of 1.935 million tons of barite.

It is not known how much lead was removed during barite mining, either by hand or mechanized mining and processing, how much lead was recovered, or how much lead went as fines to the tailing ponds or as coarse material to mine roads or was otherwise lost.

Introduction

The Southeast Missouri Barite District and the Valles Mines are located in Washington, Jefferson, and St. Francois Counties, Missouri (fig. 1), where barite and lead ore are present together in surficial and near-surface deposits. Lead mining in the area began in the early 1700’s and extended into the early 1900’s. Lead minerals were recovered by hand and although hand mining was carried out on a small scale compared to modern mining, the Southeast Missouri Barite District was the most important lead-producing district in the United States for a number of years (Ball, 1916). Although lead and barite were recovered, the Valles Mines was better known for zinc production. Lead mining in residuum (residual soil) resulted in widespread pits (also called shafts or diggings), and there was some underground mining of lead in bedrock.

Barite was discarded with other waste material during lead mining until the mid-1860’s when it became valuable. For many years, barite was recovered from the residuum by hand mining, which also resulted in widespread diggings. Some barite is present in bedrock but was not mined except in cases where accompanying lead made the operation profitable. Mechanized open-pit mining of the residuum for barite began in the 1920’s, and by the 1940’s all barite mining was mechanized. Barite continued to be mined after lead mining had ceased, and more barite was produced than lead. Barite production slowed by the 1980’s, and there has not been any barite mining since 1998. Missouri led the United States in barite production in most years from 1885 to 1971 (Missouri Department of Natural Resources, 2012). Mechanized barite mining resulted in large mined areas and tailings ponds containing waste from barite mills.

The U.S. Environmental Protection Agency (EPA) has determined that lead is present in surface soils in Washington and Jefferson Counties at concentrations exceeding health-based screening levels. Also, elevated concentrations of barium, arsenic, and cadmium have been identified in surface soils, and lead concentrations exceeding the Federal drinking-water standard of 15 micrograms per liter (μg/L) have been

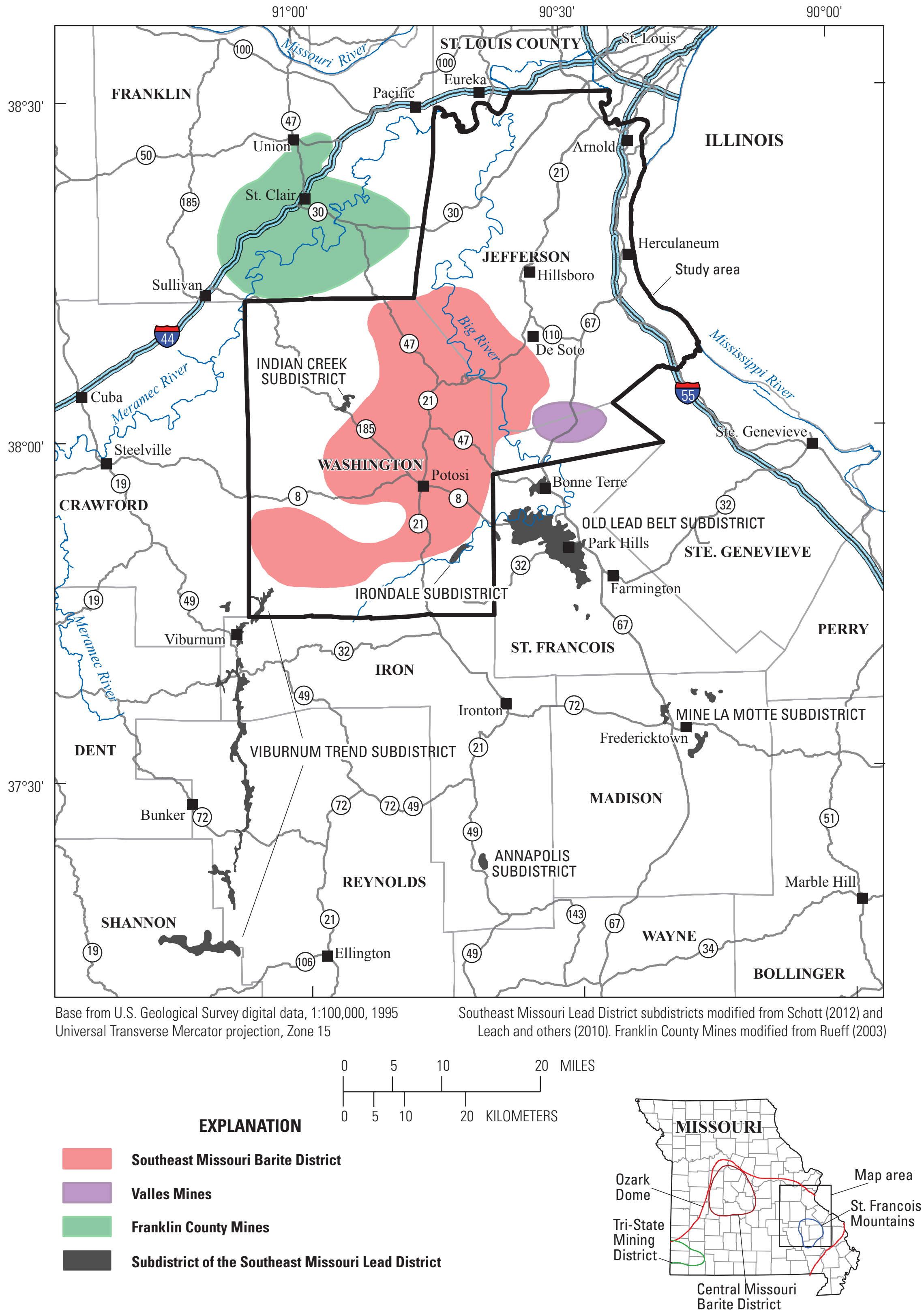


Figure 1. Location of study area, Southeast Missouri Barite District, Valles Mines, Franklin County Mines, and subdistricts of the Southeast Missouri Lead District.

identified in private drinking-water wells (U.S. Environmental Protection Agency, 2016a, 2016b, 2016c). Potential sources of these contaminants are wastes associated with barite mining, wastes associated with lead mining, or unmined natural deposits of barium, lead, and other metals. As a first step in helping EPA determine the source of soil and groundwater contamination, the U.S. Geological Survey (USGS), in cooperation with the EPA, investigated the geology and mining history of the Southeast Missouri Barite District and the Valles Mines.

Purpose and Scope

The purpose of this report is to describe the geology and mining history of the Southeast Missouri Barite District and the Valles Mines (fig. 1), focusing on information that may help the EPA determine the source of soil and groundwater contamination in mine-impacted areas in Washington and Jefferson Counties. Included in the mining history are mining methods and mine production because these may be important factors for soil and groundwater contamination.

The main focus of this report is the widespread surficial or near-surface ore deposits of the Southeast Missouri Barite District. The Valles Mines receives less attention because of its smaller size but is still an important subject of this report. Three subdistricts of the geologically distinct Southeast Missouri Lead District—the Irondale and Indian Creek Subdistricts and the Viburnum No. 29 Mine of the Viburnum Trend Subdistrict (figs. 1 and 2)—are in Washington County, and these subdistricts also are described, although in less detail. The underground Pea Ridge Iron Mine (fig. 2) and tailings pond in northwestern Washington County are not described in this report.

Although barite and lead commonly are present together as part of the same ore deposit, the mining history of each commodity is different. Included in the discussion of lead mining is zinc, which was also recovered from some lead mines but was generally secondary in importance to lead. An exception to this is the Valles Mines where early lead mining was followed by substantial mining of zinc. This report is based on a literature review; no field investigation was carried out.

Description of the Study Area

The study area includes all of Washington and Jefferson Counties, and northern St. Francois County in southeastern Missouri (fig. 1). The study area contains the ore deposits and historic mines of the Southeast Missouri Barite District, the Valles Mines, and the Irondale and Indian Creek Subdistricts of the Southeast Missouri Lead District (fig. 2). It also contains the Viburnum No. 29 Mine of the Viburnum Trend Subdistrict of the Southeast Missouri Lead District, and the Pea Ridge Iron Mine (fig. 2).

The EPA refers to the mining areas of Washington County as the Washington County Lead District and divides the county into four National Priorities List (NPL) Superfund sites: Old Mines, Richwoods, Potosi, and Furnace Creek (fig. 2; U.S. Environmental Protection Agency, 2016b, 2016c). The EPA Southwest Jefferson County site also is an NPL Superfund site. Although the focus of this site is the approximate southwestern quarter of Jefferson County, the entire county is part of the site, with the exception of the lead smelter at Herculaneum (fig. 2; U.S. Environmental Protection Agency, 2016a). Ore deposits of the Southeast Missouri Barite District are not present everywhere in Washington and Jefferson Counties, but because the deposits are widespread and the EPA NPL Superfund sites cover all of Washington and Jefferson Counties, both of these counties are included in the study area. Northern St. Francois County is included in the study area because ore deposits of the Valles Mines and the Southeast Missouri Barite District are close to the Jefferson County border, and, in the case of the Valles Mines, overlap both counties such that production figures for the two counties cannot be separated. Ore deposits of the Old Lead Belt Subdistrict of the Southeast Missouri Lead District are present in St. Francois County southeast of the study area (fig. 1).

The study area is mostly rural with only a few small towns (fig. 2). Potosi in Washington County was the center of much of the historic barite and lead mining in the region. De Soto is the closest town to most of the mining in Jefferson County. Bonne Terre is the closest town in St. Francois County to the Southeast Missouri Barite District and the Valles Mines but is not in the study area; it was the site of important mines of the Old Lead Belt Subdistrict of the Southeast Missouri Lead District.

Mine diggings are present throughout the study area and are a legacy of early barite and lead hand mining. Large areas of mine waste, including tailings dams and ponds, which contain material from more recent mechanized barite mining, are present in the study area. A mine waste pile and tailings pond of the closed Indian Creek Mine of the Indian Creek Subdistrict, the mine site of the underground Viburnum No. 29 Mine of the Viburnum Trend Subdistrict, and the mine site and tailings pond of the underground Pea Ridge Iron Mine are also present in the study area (fig. 2).

Definition of the Southeast Missouri Barite District and the Valles Mines

The geologic and mining literature contains various formal and informal names for the surficial and near-surface barite-lead deposits of Washington, Jefferson, and northern St. Francois Counties, which are the subject of this report. Mining district and subdistrict names were not formalized at the time of writing of the earliest authors. Areas of early lead mining have been informally called the “lead mines of Missouri” (Schoolcraft, 1819), the “lead mines of Washington County” (Ball, 1916; Swallow, 1855), the “lead mines of Jefferson County” (Swallow, 1855), and more formally the “Washington-Jefferson County Subdistrict of the Southeastern District” (Winslow, 1894). When referring predominantly to barite mining, the area has been called the “Washington

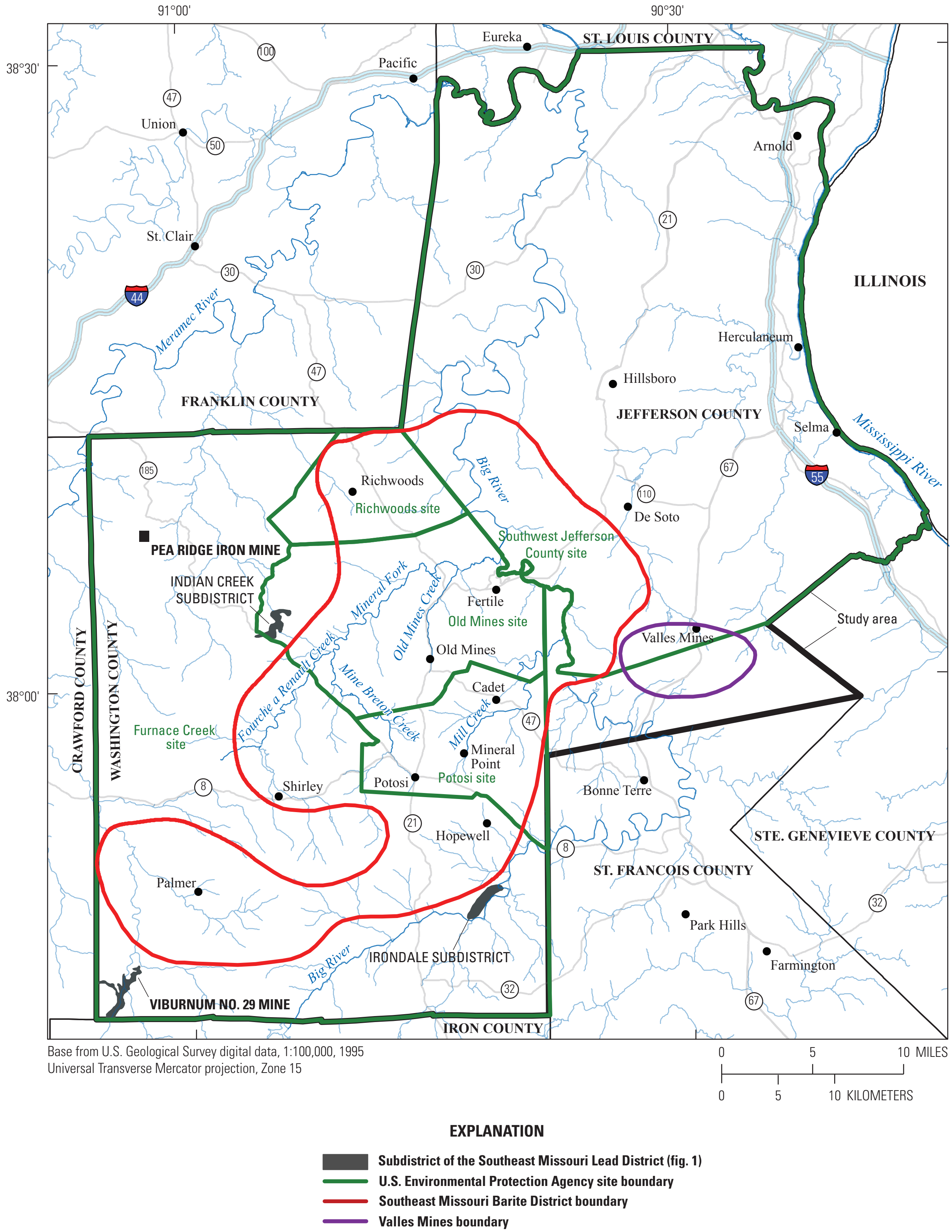


Figure 2. Study area, Southeast Missouri Barite District, Valles Mines, and U.S. Environmental Protection Agency sites in Washington and Jefferson Counties.

County Barite District" (Seeger, 2008; Brobst and Wagner, 1967; Brobst, 1958; Tarr, 1918; Wharton, 1972, 1986; Wagner, 1973), or the "Southeast Missouri Barite District" (Kaiser and others, 1987; Wharton, 1986). Snyder (1968a) describes the "Southeast Missouri Barite-Lead Deposits" as a barite-lead district, referring to the barite-lead deposits mostly in Washington and Jefferson Counties, but also minor deposits in adjacent counties.

The term "Southeast Missouri Barite District" is used in this report although it makes no mention of the lead that was mined starting about 150 years before barite was mined. The term "Southeast Missouri Barite-Lead District" would better describe the resources that were mined, but "Southeast Missouri Barite District" is the accepted term (Cheryl Seeger, Missouri Geological Survey, oral commun., May 16, 2016) and is more easily distinguished from the Southeast Missouri Lead District.

Ore deposits of the Southeast Missouri Barite District are present throughout Washington County, Jefferson County, and extreme northern St. Francois County. It was difficult to draw a district boundary for this report because the deposits are so widespread; the boundary shown in figures 1 and 2 encompasses areas where the ore deposits are most concentrated and where they are mostly in the residuum derived from the Potosi or Eminence Dolomites or in the formations themselves, the most important hosts for the deposits (fig. 3). The mostly scattered deposits in the study area outside this boundary are still considered part of the district; these deposits are mostly in formations younger than the formations that host the deposits within the boundary of the district.

The Southeast Missouri Barite District and the Valles Mines have some similarities but they are different primarily in two ways: (1) most of the mining at the Valles Mines was in bedrock, which is in contrast to the Southeast Missouri Barite District where most of the mining was in the residuum; and (2) the Valles Mines was an important zinc-producing area, and barite was not as important of a product as in the Southeast Missouri Barite District (Cheryl Seeger, Missouri Geological Survey, oral commun., July 7, 2016). For this reason, the Valles Mines is considered a separate entity by the Missouri Geological Survey (MGS) and in this report. The Valles Mines (also spelled Valle) was sometimes referred to as the Valles Mines Group (Winslow, 1894) and consists of several mines in southern Jefferson and northern St. Francois Counties, near the town of Valles Mines (fig. 2). One of these mines is the Valles (or Valle) Mine, also called the Big Lode (Litton, 1855; Winslow, 1894; Valles Mines, Missouri, USA, 2016). Like most other mines in the study area, this mine consists of several shafts, and for this reason the plural of "mine" commonly is used, and the mine is called the Valles Mines. To avoid confusion with the Valles Mines Group, the term "Valles Mines (proper)," instead of the term "Valles Mines," is used in this report for the collection of shafts of the Valles Mine; this term was used by Winslow (1894) and Parizek (1949). For this report, the term "Valles Mines" is reserved for the Valles Mines Group because this is the term commonly used in the literature.

The Southeast Missouri Barite District does not include small lead-zinc-barite and local copper deposits that are present along and near the Meramec River, mostly in Franklin County but also in Crawford County, most of which are in formations younger than most Southeast Missouri Barite District deposits. These deposits are probably what Snyder (1968a) referred to as minor deposits in adjacent counties. Winslow (1894) describes the deposits in Franklin County as the "Franklin County Subdistrict of the Southeastern District". Park (2006) describes these as the "Franklin County Lead District." Wharton (1986) describes these as the "Franklin County Mines," and this term is used in this report (fig. 1).

Zinc commonly is present with lead in ore deposits in Missouri and elsewhere. Zinc is present in the Southeast Missouri Barite District but it is not as common as in other lead-mining areas. Conversely, zinc was the most important resource at the Valles Mines. Zinc was not recovered during the early years of lead mining in the study area because it was not a valuable commodity at that time. Later, after the value of zinc was recognized, the metal was recovered at some mines and was the primary target at a few mines, particularly the Valles Mines. Because zinc was generally of secondary importance or no importance, the term "lead mining" is used in this report to imply recovery of lead, zinc, and in some cases, copper.

Ore deposits of the Southeast Missouri Barite District and the Valles Mines differ from the ore deposits of the Southeast Missouri Lead District, although Wharton (1972, 1986) considered the Washington County barite deposits to be part of the Southeast Missouri Lead District. The lead-zinc deposits of the Southeast Missouri Lead District are present in stratigraphically lower formations (mostly the Cambrian Bonneterre Formation, and less commonly in the upper part of the Cambrian Lamotte Sandstone or the lower part of the Cambrian Davis Formation; fig. 3), are larger, and are lead-zinc deposits that do not contain barite (Snyder, 1968a, Snyder and Gerdemann, 1968; Seeger, 2008). The Southeast Missouri Lead District has four large subdistricts (the Old Lead Belt, the Viburnum Trend, Mine La Motte [also called Mine La Motte-Fredericktown], and Indian Creek) and the smaller Irondale and Annapolis Subdistricts (Snyder and Gerdemann, 1968; fig. 1). Some of these ore subdistricts (for example, the Old Lead Belt and Mine La Motte) have some exposure at the surface (the deposits of the Southeast Missouri Barite District and Valles Mines have surficial exposure), but can extend to greater depths, up to a few hundred feet. Other subdistricts (for example, Viburnum Trend and Indian Creek) have no surficial expression and are several hundred to more than 1,000 feet (ft) deep. The Palmer area in Washington County (also called the Shirley-Palmer area, or the Fourche a Courtois Mines) and the Valles Mines (fig. 2) also have been included as subdistricts of the Southeast Missouri Lead District in some reports (Snyder and Gerdemann, 1968; Seeger, 2008). This inclusion may be because of a relatively large amount of lead and zinc production or because of noneconomic mineralization in the Bonneterre Formation, as is the case at least in the Palmer area

<table>
<tr><th colspan="2">TIME-STRATIGRAPHIC UNIT</th><th colspan="2" rowspan="2">ROCK-STRATIGRAPHIC UNIT</th><th rowspan="2">BARITE, LEAD, or ZINC MINERALIZATION</th></tr>
<tr><th>ERA</th><th>SYSTEM</th></tr>
<tr><td rowspan="15">PALEOZOIC</td><td>PENNSYLVANIAN</td><td colspan="2">Undifferentiated for this report</td><td rowspan="4"></td></tr>
<tr><td>MISSISSIPPIAN</td><td colspan="2">Undifferentiated for this report</td></tr>
<tr><td>DEVONIAN</td><td colspan="2">Undifferentiated for this report</td></tr>
<tr><td rowspan="5">ORDOVICIAN</td><td colspan="2">Undifferentiated for this report</td></tr>
<tr><td colspan="2">Cotter Dolomite</td><td rowspan="2">Contains a small number of barite-lead-zinc deposits of the Southeast Missouri Barite District and deposits in adjacent counties</td></tr>
<tr><td colspan="2">Jefferson City Dolomite</td></tr>
<tr><td colspan="2">Roubidoux Formation</td><td rowspan="2">Contains a small number of barite-lead-zinc deposits of the Southeast Missouri Barite District and deposits in adjacent counties, particularly the Franklin County Mines</td></tr>
<tr><td colspan="2">Gasconade Dolomite</td></tr>
<tr><td rowspan="7">CAMBRIAN</td><td colspan="2">Eminence Dolomite</td><td>The second-most important host of barite-lead-zinc deposits of the Southeast Missouri Barite District and Valles Mines is in the Eminence Dolomite and its residuum</td></tr>
<tr><td colspan="2">Potosi Dolomite</td><td>The most important host of barite-lead-zinc deposits of the Southeast Missouri Barite District and Valles Mines is in the Potosi Dolomite and its residuum</td></tr>
<tr><td rowspan="2">Elvins Group</td><td>Derby-Doerun Dolomite</td><td></td></tr>
<tr><td>Davis Formation</td><td>The lower part of the Davis Formation locally contains lead-zinc mineralization of the Southeast Missouri Lead District</td></tr>
<tr><td colspan="2">Bonneterre Formation</td><td>Contains most of the lead-zinc mineralization of the Southeast Missouri Lead District</td></tr>
<tr><td colspan="2">Lamotte Sandstone</td><td>The upper part of the Lamotte Sandstone contains some lead-zinc mineralization of the Southeast Missouri Lead District, particularly in the Mine La Motte and Indian Creek Subdistricts</td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td>PRECAMBRIAN</td><td></td><td colspan="2">Undifferentiated Intrusive and Volcanic Igneous Rocks</td><td></td></tr>
</table>

NOTE: Geologic names follow the nomenclature of the Missouri Geological Survey.

Figure 3. Stratigraphic column of the study area and vicinity, showing formations that host ore deposits of the Southeast Missouri Barite District, Valles Mines, and Southeast Missouri Lead District.

(Snyder and Gerdemann, 1968). Because the only mining that has taken place in these areas has been in the residuum and in the Potosi Dolomite and younger formations, and not the Bonneterre Formation, these mining areas are considered, in this report, to not be part of the Southeast Missouri Lead District.

Previous Investigations

A large number of publications were reviewed for this report. Cited publications are listed in the "References" section of this report; the more notable publications are described here, in mostly chronological order.

The first known published description of the lead mines of Missouri is a report by Moses Austin, one of the early lead-mine owners in Missouri, on the lead mines of Upper Louisiana. This report was delivered to the U.S. Congress in 1804 by Amos Stoddard, Captain and First Civil Commandant of Upper Louisiana (Stoddard, 1804). Ten mines were described, some of which are in the Southeast Missouri Barite District (this or any other district term was not in use at that time and would not be for many years). General mining and smelting methods were mentioned, as well as some basic geologic descriptions. The report also provided estimates of the area population and number of miners employed at the mines, as well as production estimates, both in terms of pounds of lead produced and dollar values.

Henry Rowe Schoolcraft traveled through the States and territories west of the Appalachian Mountains and lived for a year in the Missouri Territory where he observed mining practices first hand. Schoolcraft (1819) described the landscape of the mining area, including its soils and streams, and provided a history of mining up to 1819, including some of the early exploration for gold and silver and the eventual development of lead mining. Schoolcraft (1819) listed 45 of the more notable past and present (as of 1819) lead mines, 39 of which were in Washington County and 2 in Jefferson County; gave a general description of the ore deposits; and described several mines in detail. He also described mining and smelting practices, and gave a detailed description of a log furnace, an ash furnace, and an estimate of the percentage of lead recovered from each. Production figures for individual mines and the collective production from mines of the area (including some mines from outside the Southeast Missouri Barite District) were estimated, and several recommendations were given for more efficient operations and improved production. Schoolcraft (1819) also noted the presence of barite in the ore deposits, though barite was not recovered at that time.

In 1855, George C. Swallow, Missouri State Geologist, delivered the second annual report of the Geological Survey of Missouri to the Missouri Secretary of State (Swallow, 1855). One of the chapters of the report is "A Preliminary Report of Some of the Principal Mines in Franklin, Jefferson, Washington, St. Francois, and Madison Counties, Missouri," by Dr. A. Litton, M.D. (Litton, 1855), which includes lead mines inside and outside the Southeast Missouri Barite District and a brief history of lead mining in Missouri, which began about 135 years earlier, in 1719. Descriptions were given for many mines, by county, which generally consist of the public land survey location, a description of the ore deposits, the history and production of the mine, and, for several mines, a cross section showing shafts. The information was obtained either by direct observation or from a reliable source such as the present or previous owner when direct observation was not possible. A general description of lead furnaces and their operation was given, by county, and several furnaces were described in more detail, including the public land survey location and historic lead production. No mention of barite mining was made.

A geological survey was done of counties along and adjacent to the Southwest Branch of the Pacific Railroad (Swallow, 1859), including the mining areas of the Southeast Missouri Barite District. Brief descriptions were given of a number of mines in Jefferson County, some of which were also described by Litton (1855). A table in Swallow (1859) lists 86 mines and 17 furnaces in Jefferson and Washington Counties.

Pulsifer (1888) traced the history of world lead mining, as well as the processing and manufacture of white lead (hydrous lead carbonate commonly used as a paint pigment). Chapters on mining, and smelting and refining in the United States describe the early history of lead mining in Missouri, including the Southeast Missouri Barite District.

Winslow's (1894) three-part report is the definitive report on lead and zinc mining as of 1894. Part One gives an overview of world lead and zinc mining, a more detailed description of United States lead and zinc mining, and a chapter by Robertson (1894a) on worldwide industries and production statistics of lead and zinc, including the metallurgy of lead and zinc. Details of several types of lead furnaces are given, including drawings and histories of different furnaces, with improvements in lead recovery and reductions in lead losses to the environment through improvements in technology. Zinc furnaces are also described. Part Two contains a history of lead mining in Missouri, including the Southeast Missouri Barite District and the Valles Mines, with a section on early development (from discovery in 1719 until 1800), and subsequent sections covering periods of one or two decades. The development of different mines throughout Missouri is presented, and mining and metallurgy practices at various mines and some production and employment figures are given. General descriptions of the lead-ore deposits of Missouri are given, including the form, mineralogy, structure, and genesis. Also in Part Two is a chapter by Robertson (1894b) describing the lead smelting and manufacturing industries in Missouri in 1894, including a description of the different furnaces in use at the time, and a series of tables giving production statistics by county. Part Three contains detailed geologic descriptions of the more important lead and zinc mines in Missouri, including a section on the "Washington County Subdistrict" (Washington, Jefferson, Crawford, and extreme northern St. Francois Counties) of the "Southeastern District." These descriptions include maps, cross sections, some photographs, and some individual mine production figures. Barite, which by then had some commercial value, is described as being of such quantity as to be an "object of independent search" (Winslow, 1894, p. 677).

Ingalls (1908) presented a history of lead and zinc mining and smelting in the United States through 1908. A chapter describes the history of mining and smelting in Missouri, including mines of the Southeast Missouri Barite District. Descriptions of smelting methods, including production and losses to the environment, and drawings of furnaces are given.

Buckley (1908) described the geology and mines of the "Disseminated Lead Deposits of St. Francois and Washington Counties." Although the lead deposits of the Southeast Missouri Lead District were Buckley's (1908) main focus, descriptions also were given of the geology of the barite-lead deposits of the Southeast Missouri Barite District so a comprehensive theory of the genesis of southeastern Missouri lead ores could be proposed. Buckley (1908) also provided some production figures that demonstrate the growth and prominence of the Southeast Missouri Lead District and the relative decline of the "Washington County Subdistrict." He described, and located on an accompanying map, 33 barite diggings in a portion of the Southeast Missouri Barite District and implied that by 1908 barite had replaced lead as the primary resource of interest in the district.

Steel (1910) described the geology, mining, and processing of barite in Washington County. The geology was described in some detail, though generally not for individual deposits. The geologic history of Washington County was summarized, and a genetic model for the barite deposits was proposed. Mining methods were described in detail, including the process of digging shafts, drifting from the shafts, and cleaning of the ore at the mine site, and other mining practices were described such as prices paid per ton of ore and payment of royalties. One barite mill process was described in detail, from raw feed to finished product, and a flow diagram was given.

Ball (1916) described the geology and mining of lead in Washington County in 1916. Mechanized mining was by then producing large tonnages of lead ore in other parts of Missouri, but "mining methods of a century ago prevail" (Ball, 1916, p. 807), and these were described, including the activities that filled a miner's workday and other aspects of the life of a lead miner. A sketch map of Washington County shows the location of numerous lead diggings.

Hill (1917) gave an account of the barite industry in the United States in 1915 and described the general geology of barite deposits, mining and processing methods, production by State (Missouri ranked first), marketing and prices of barite, several barium products and their manufacturing processes, and the uses of barium products. A list of suppliers of crude barite was given, 18 of which were located in Missouri, and a list of manufacturers of ground barite is given, 3 of which were located in Missouri.

Tarr (1918) provided a comprehensive description of the geology of Missouri barite deposits as of 1918, particularly those of the Southeast Missouri Barite District (the Central Missouri Barite District [fig. 1], a lesser but still important district, also was described). The general geology of Washington County was given, including stratigraphy, structure, and geologic history; and the barite deposits were described, including mineralogy, and concentration by weathering of the barite deposits. Different ideas regarding the genesis of the deposits were discussed, and an ore genesis model was proposed. Mining and processing methods were described, and 39 uses of barite were listed. Tarr (1919) described the barite deposits of Missouri in a more condensed report.

Weigel (1929) described the barite industry in the Southeast Missouri Barite District and the Central Missouri Barite District. The geologic setting and economic geology of the districts were described, and the genesis of the ore deposits was considered. By 1929, mining and processing methods had become mechanized with steam shovels and mechanical washing and concentrating, although hand methods continued. The marketing and uses of barite also were described.

Dake (1930) reported on the stratigraphy, structure, and geologic history of the Potosi and Edgehill 15-minute quadrangles, which are mostly south of Washington County; however, central and south-central Washington County is in the Potosi quadrangle, and because of the importance of barite mining in Washington County in 1930 and the importance of lead mining at an earlier time in Washington County, the economic geology of the deposits was described, including the Palmer, Potosi, and Old Mines areas. Lines of evidence supporting barite and lead deposited by descending, rather than ascending, waters were given.

Harness and Barsigian (1946) described barite mining and marketing throughout the United States and briefly described the geology of the barite deposits of southeastern Missouri. Different mining and processing methods employed in 1946 in different parts of the country were described, including Missouri. Older hand-mining methods were described, and legal and economic factors contributing to the decline of hand mining and the rise of mechanized mining were discussed. Also described were the process of grinding and bleaching barite, and various barite uses.

The U.S. Bureau of Mines examined the Krueger zinc deposit, which lies about 6 miles (mi) west of Potosi and was the site of earlier lead mining to a depth of about 100 ft (Ballinger, 1948). Twenty-four holes were drilled as deep as 259 ft; 13 of the holes intersected what was termed either "good" ore or "low-grade" ore. Several years later, Ligasacchi (1959) reported on the Krueger zinc deposit and nearby barite deposits in bedrock. Several forms of ore, including barite in a dolomite breccia matrix, were described and illustrated in photographs.

Chaney (1949) described the barite industry in the United States, including the geographic distribution of ore deposits, geology, mining methods, processing, production, and uses of barite. He described the barite industry in the important barite producing States of Arkansas, Georgia, and Missouri, as well as in other States of lesser importance. He described the geology of the barite deposits of the Southeast Missouri Barite District and summarized evidence and conclusions from previous authors regarding the genesis of the ores. A history of barite mining methods in the district was given, from older hand mining to mechanized mining in 1949, and processing methods in use in 1949 were described, including flow sheets for two different mining operations.

Muilenburg (1954, 1957) provided descriptions of the barite industry in Missouri in the 1950's. The geology of both the Southeast Missouri Barite District and the Central Missouri Barite District, and mining and milling practices in the 1950s were described. Some production figures were provided.

Thompson (1955) provided a series of articles that described the development of lead mining in southeastern Missouri. Both the Southeast Missouri Barite District and the Southeast Missouri Lead District were covered. Descriptions were given of early exploration for metals, mines, and mineral processing, in large part citing previous reports, including Schoolcraft (1819).

Brobst (1958) reviewed the history of the barite industry in the United States, the geochemistry of barium, and the mineralogy of barite deposits. He reviewed the geology of several districts in different States, including the "Washington County District." Mining and benefication (processing) methods were briefly described, exploration methods were explained, domestic production and consumption figures were given, and barite resources were described.

In a publication prepared for the 200th anniversary of founding of the city of Potosi, Showalter (1963) traced the history of lead and barite mining in southeastern Missouri, with an emphasis on mining in the Potosi area. Profiles of several historical figures important to mining in the Potosi area were given. Mining methods were described, and descriptions of the life of a miner were given.

A report on the water and mineral resources of Missouri published jointly by the U.S. Geological Survey and the Missouri Division of Geological Survey and Water Resources contains a chapter on barite (Brobst and Wagner, 1967). The history and uses of barite were described, annual production of barite in Missouri since 1900 was given, the geology of the Southeast Missouri Barite District was described, and projections of barite reserves and future production were given. Another chapter in the same report described the lead and zinc industry in Missouri (Kiilsgaard and others, 1967). The history and production of lead mining in Missouri was described, and although much of the chapter discussed the large lead districts in Missouri, the history, production, and geology of the Potosi-Palmer mining area in Washington County and the Valles Mines in Jefferson and St. Francois Counties were briefly described.

Snyder (1968a) briefly described different types of mineral deposits throughout the midcontinent United States. He provided separate discussions of the "Southeast Missouri Barite-Lead Deposits" and the Southeast Missouri Lead District, and provided criteria for defining each and distinguishing one from the other. Results of seven lead isotope analyses from the Southeast Missouri Barite District were summarized; galena from the district is described as overlapping but being slightly more radiogenic than galena from the "Lead Belt" (Old Lead Belt Subdistrict of the Southeast Missouri Lead District).

Wharton (1972) made an inventory of barite tailings ponds, mostly in Washington County, for the purpose of determining tonnage and grade of potential barite reserves in the ponds. Four ponds were drilled and core samples were collected and analyzed for barium concentrations using x-ray fluorescence spectrometry. The lead content of the tailing ponds was not reported. Metallurgical tests were run to determine barite grain size. A map showing the location of 67 inventoried tailings ponds was given, and detailed maps and cross sections were given for each of the 4 ponds that were drilled, showing locations of drill holes, barite grade and thickness at each drill location, and areas of different grades of barite in each pond. The report also briefly described the geology of the district and the history of mining and milling methods and current (1972) methods, and discussed mill recovery and losses.

Wagner's (1973) Ph.D. dissertation is an important contribution to the understanding of the geology of the Southeast Missouri Barite District. The study area covered a large part of the district, about 160 square miles (mi^2), but did not include some mining areas such as the Richwoods area in northeastern Washington County, the Palmer area in southwestern Washington County, and the Valles Mines in southern Jefferson and northern St. Francois Counties (fig. 2). Barite-lead deposits were examined in detail both in the field and in the laboratory (thin and polished sections were studied, and x-ray diffraction tests were done) for the purpose of understanding the mineralogy of the deposits, the types of mineralization in the residuum and bedrock, the stratigraphic and structural controls on mineralization, and the development a genetic model for the district. Research focused on the original sedimentary lithologies and their influence on mineralization, particularly algal stromatolites; the relation of the deposits to geologic structure, including faults; and different types of barite mineralization and their relation to other mineralization, including lead mineralization. Also studied were wall rock alteration, the relation between ore minerals and drusy quartz in the Potosi Dolomite, mineral and textural zoning of the deposits, mineral paragenesis, fluid inclusions, and bedrock mercury anomalies. The physical and chemical controls on mineralization that help explain the environment of deposition and genesis of the deposits were discussed. A detailed stratigraphic section and several maps of the study area were included: a geologic map, a map of trends of fractures and faults, maps showing joint patterns along Mill Creek and Mine Breton Creek, a map of barite mines and tailings ponds in 1973, and a barite deposit textural-zoning map. The same information was summarized several years later in Kaiser and others (1987; Wagner was a co-author), who also used more recent sulfur and oxygen isotope data to interpret the genesis of the barite-lead deposits.

Burford (1978) summarized the history of mining in Missouri from the earliest explorer days until 1978. Although many resources were described, including barite, particular attention was given to lead because of its importance to the economy of Missouri for many years. The history of lead mining throughout Missouri was given, beginning with settlers in southeastern Missouri in the early 1700's.

Wharton (1986) summarized the development of barite mining in Washington County and current (1986) mining and processing methods; this was toward the end of the period of barite mining. A brief history of geologic investigations of the deposits also was given.

Park (2006) provided descriptions of many abandoned mines in Missouri, including mines in the Southeast Missouri Barite District and Valles Mines. The descriptions have the form of a travel guide for exploring old mining areas in Missouri, with brief, but in some cases detailed accounts of mining areas and individual mines, mining methods, production data, and descriptions of historical mining figures. Sketch maps show old mines and furnaces. More emphasis was given to lead mines than barite mines. A historical account of the development of mining in Missouri also was given.

Seeger (2008) reviewed the mine facilities and environmental effects of mining in the Viburnum Trend, and also presented the early history of lead mining in Washington County. As mentioned in the "Description of the Study Area" section, Seeger (2008) and Snyder and Gerdemann (1968) regarded the Shirley-Palmer area and the Valles Mines (fig. 2) as subdistricts of the Southeast Missouri Lead District, along with the Viburnum Trend and other subdistricts. The Shirley-Palmer area and the Valles Mines, however, as stated in the "Definition of the Southeast Missouri Barite District and the Valles Mines" section, are not included in the Southeast Missouri Lead District for this report.

Blount [1950?] compiled video clips of barite mining from what is reported to be the 1930's. This compilation, which may have been produced about 1950, has no audio but contains grainy black and white video clips of hand mining and processing of barite and early mechanized barite mining and processing. Wood (1963) produced a grainy color video showing mechanized mining of barite and a barite processing plant.

The MGS compiled a Mined Lands geographic information system (GIS) shapefile for the Missouri Department of Natural Resources Division of Environmental Quality showing locations of mechanized surface barite mining and tailings ponds (Cheryl Seeger, Missouri Geological Survey, written commun., October 27, 2015). The MGS also maintains an Inventory of Mines, Occurrences, and Prospects (IMOP; Missouri Department of Natural Resources, 2015a). The following description of the IMOP database is mostly from Cheryl Seeger (Missouri Geological Survey, written commun., June 14, 2016): The IMOP database contains information, including location data, for all mineral resource types (lead, coal, limestone, and so forth) in Missouri, categorized as mines (active or past producer), occurrences, and prospects. The database is based on the original U.S. Bureau of Mines Mineral Industry Location System database; however, the database and data have been extensively updated (additional fields have been added and more than 11,000 additional sites have been added). The IMOP database is continually being revised and additional mines sites are being added. Data were compiled by the MGS from historical references, from in-house unpublished documents, correspondence, maps and field notes unavailable elsewhere, as well as from topographic and geologic maps, Digital Orthophoto Quarter Quads, and aerial photographs. This database has location and other data, including some brief descriptions of barite and lead mines, occurrences and prospects in the Southeast Missouri Barite District and Valles Mines, and references for the information in the database.

Geology of the Southeast Missouri Barite District and the Valles Mines

The geology of the Southeast Missouri Barite District and the Valles Mines is given in two sections. The section on the general geologic setting describes the structure and stratigraphy of the study area. The section on the geology of the ore deposits provides more specific geologic descriptions of the ore deposits.

General Geologic Setting

The study area is located within the Salem Plateau of the Ozarks Plateaus Physiographic Province (Fenneman, 1938), also referred to simply as the Ozarks. The Salem Plateau is a large area in southern Missouri and northern Arkansas consisting of Cambrian and Ordovician sedimentary rocks that have been uplifted and dissected by erosion. The topography of the study area is one of rolling hills with incised valleys that are partially wooded. The Big River and its tributaries drain eastern Washington County, western Jefferson County, and northwestern St. Francois County (fig. 2). Western Washington County is drained by tributaries of the Meramec River. Northeastern St. Francois County and eastern Jefferson County are drained by tributaries of the Mississippi River.

Structure

The Ozarks Plateaus Physiographic Province is the physiographic expression of the Ozark Dome, one of several domes and arches which, with intracratonic basins, define the structural framework of the United States midcontinent. The core of the Ozark Dome is the St. Francois Mountains (fig. 1) in southeastern Missouri, an area of exposed Precambrian rocks that also underlie Paleozoic sedimentary rocks throughout the Ozarks (fig. 3). Following an extensive period of igneous activity, the Precambrian rocks were subjected to a long period of erosion, which produced a rugged topography with up to 2,000 ft of relief in the St. Francois Mountains (Thacker and Anderson, 1977). The area slowly subsided during Late Cambrian and Early Ordovician time (Snyder, 1968b) during which the Precambrian terrain stood as an island complex surrounded by a dominantly transgressive shallow sea. Sediments filled valleys and covered all but the highest hills. Later, tectonic uplift resulted in widespread erosion followed by subsidence and deposition of more sediment. This sequence of uplift followed by erosion, subsidence, and sedimentation happened repeatedly throughout the Paleozoic until the end of the Pennsylvanian period (Snyder, 1968b) when the Ozark Dome became a positive topographic feature for the last time.

Bedrock formations generally dip gently away from the St. Francois Mountains, and erosion has resulted in an outcrop pattern of progressively younger formations away from the St. Francois Mountains. The Southeast Missouri Barite District and the Valles Mines are north of the St. Francois Mountains, and the study area displays this outcrop pattern in a general way, with bedrock formations becoming younger toward the northwest, north, and northeast, away from the Precambrian core of the St. Francois Mountains (figs. 1 and 4). This outcrop pattern is not simple, however, because of numerous faults that offset geologic formations and juxtapose formations of different ages. Although some areas are more faulted than others, the greater density of faults shown in figure 4 in the northern part of Washington County and in southern Jefferson and northern St. Francois Counties is partly the result of more detailed geologic mapping at 1:24,000 scale in these areas. The geology shown in figure 4 is from the Missouri Department of Natural Resources (2015b) and reproduces the geology shown in the “Geologic Map of Missouri” (Missouri Department of Natural Resources, 2003). The geologic structures shown in figure 4 also are from the Missouri Department of Natural Resources (2015b) and are revised slightly from what are shown in the “Geologic Map of Missouri.”

Most of the ore deposits in the study area are present in a structural block bounded by three fault systems, or in the fault systems themselves: the Palmer fault system to the southwest, the Big River fault system to the southeast, and the Vineland fault system to the northeast (fig. 4; Wagner, 1973). The Palmer fault system trends northwest-southeast in southeastern Washington County and changes to trend east-west in southwestern Washington County and Crawford County, and consists of subparallel high-angle normal faults with a total of 200 to 1,200 ft of downward displacement to the northeast or north (McCracken, 1971). The northwest-trending Vineland fault system is sometimes called the Valles Mines-Vineland fault zone, and is regarded as a northwest extension of the Ste. Genevieve fault system (fig. 4; McCracken, 1971; Nelson and Lumm, 1985). The Vineland fault system is a zone of high-angle normal faults with downward displacement to the northeast of as much as 800 ft (McCracken, 1971). The northeast-trending Big River fault system is a high-angle normal fault or set of en echelon faults with up to 120 ft of downward displacement to the northwest, and is regarded as a southwest branch of the Ste. Genevieve fault system (McCracken, 1971).

Other faults are present in the study area besides the three bounding fault systems. The Berryman fault (fig. 4) extends northwest from the Palmer fault system and has a downward displacement to the southwest (McCracken, 1971). The Shirley fault zone trends northwest (fig. 4) and consists of several faults with about 300 ft of step-down displacement to the southwest (McCracken, 1971). Wagner (1973) describes the Mineral Point fault system, the Fertile-Cruise Mill fault system, and the Racola fault (not labeled on figure 4) and other unnamed faults and fault systems. Near-vertical joints commonly form two perpendicular joint sets. A third and, less commonly, a fourth joint set can be present (Wagner, 1973).

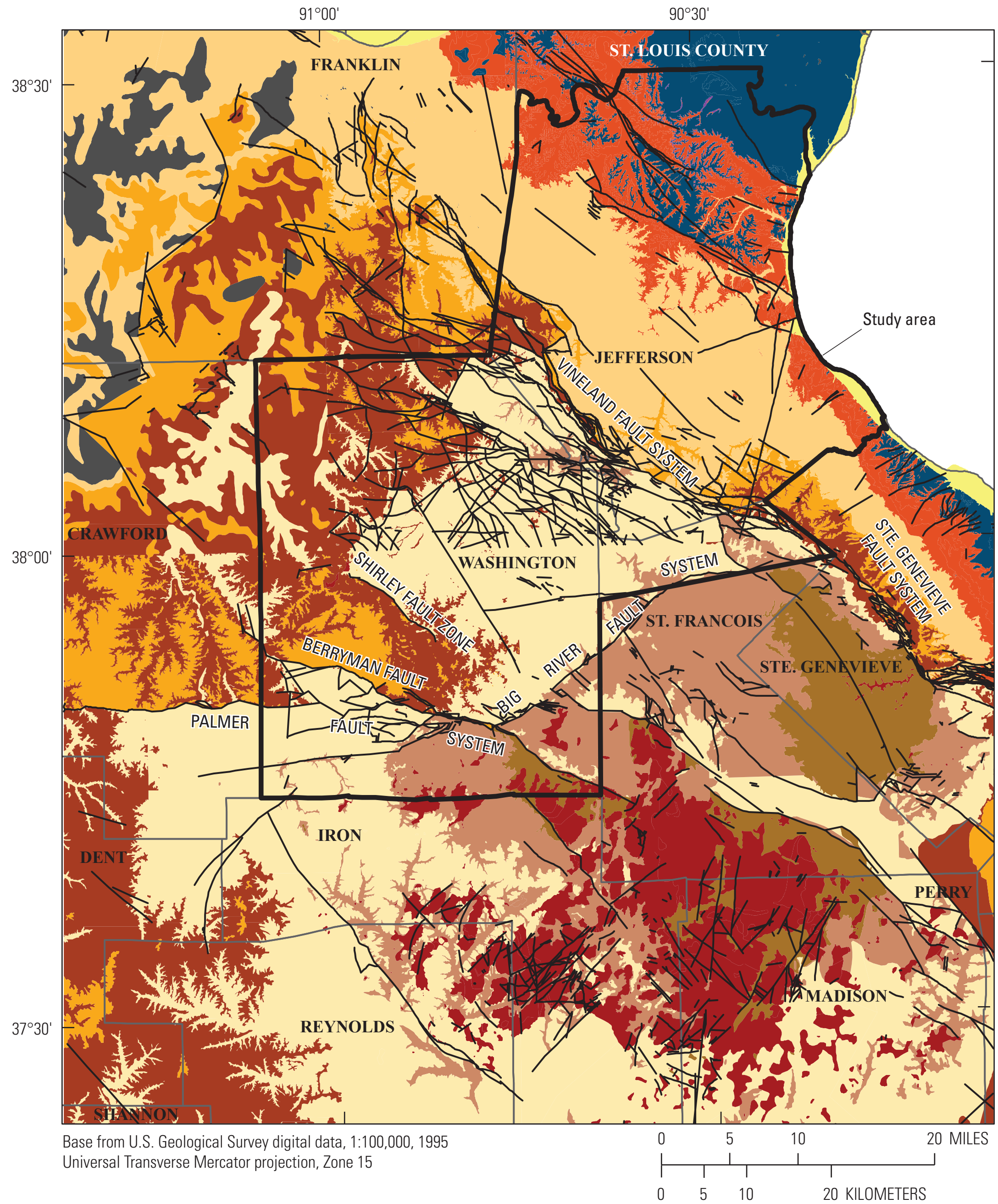
Wagner (1973) and Kaiser and others (1987) recognized a structural pattern, or structural grain, in the Southeast Missouri Barite District. This structural grain is defined by faults and joints that trend northwest-southeast in the northwestern part of the district and east-west in the southeastern part of the district (Kaiser and others, 1987). The greatest displacement within the structural block is on the bounding Palmer and Vineland fault systems, with less displacement along the Fertile-Cruise Mill fault system, Shirley fault zone, and Mineral Point fault system in the interior of the structural block, which form horst and graben structures (Wagner, 1973). More details regarding the geologic structure of the Southeast Missouri Barite District, the relation to regional structural patterns, and possible stress patterns that produced these geologic structures, including tensional stresses responsible for the horst and graben structures, are found in Wagner (1973).

Stratigraphy

Precambrian rocks are exposed in southeastern Washington County and to a lesser extent in west-central Washington County. More extensive exposures of Precambrian rocks are present south and southeast of the study area (fig. 4). The Precambrian basement in southeastern Missouri consists of rhyolitic porphyries intruded by granites and diabase dikes and sills (Snyder and Gerdemann, 1968; Missouri Department of Natural Resources, 2003; fig. 3).

The Cambrian Lamotte Sandstone (fig. 3) is the oldest Paleozoic formation in southeastern Missouri. It is predominantly a quartzose sandstone but is locally arkosic or conglomeratic and can contain siltstone or dolomite beds (Snyder and Gerdemann, 1968; Thompson, 1995; Thompson and others, 2013). The formation is present in the subsurface throughout most of the study area and is exposed in a small area in southeastern Washington County. It is absent where it pinches out against Precambrian knobs and is up to 500 ft thick elsewhere in the St. Francois Mountains (Thompson, 1995). An isopach map of the Lamotte Sandstone (Thacker and Anderson, 1979a) approximately covers the southern two-thirds of Washington County; the formation has a maximum thickness of about 350 ft in this area. The Lamotte Sandstone locally contains lead-zinc ore in southeastern Missouri and was mined in the Mine La Motte, Indian Creek, and to a lesser extent Old Lead Belt Subdistricts of the Southeast Missouri Lead District (fig. 1).

The Cambrian Bonneterre Formation (fig. 3) is predominantly dolomite in the mining areas of southeastern Missouri (Snyder and Gerdemann, 1968) and contains some shale beds.



EXPLANATION

[Bedrock geology modified from Missouri Department of Natural Resources (2015b)]

- **Alluvium**
- **Pennsylvanian, undifferentiated**
- **Mississippian, undifferentiated**
- **Devonian, undifferentiated**
- **Ordovician, undifferentiated**
- **Jefferson City and Cotter Dolomites**
- **Roubidoux Formation**
- **Gasconade Dolomite**
- **Eminence and Potosi Dolomites**
- **Elvins Group and Bonneterre Formation**
- **Lamotte Sandstone**
- **Precambrian, undifferentiated**
- **Fault**

Figure 4. Geology of the study area and vicinity.

An isopach map of the southern two-thirds of Washington County (Thacker and Anderson, 1979a) shows that the thickness of the formation ranges from zero to about 400 ft in this area and that it is exposed in parts of southeastern Washington County. The Bonneterre Formation is the host rock for the lead-zinc deposits of the Viburnum Trend, Old Lead Belt, Irondale, and Annapolis Subdistricts of the Southeast Missouri Lead District, and is also mineralized at the Indian Creek and Mine La Motte Subdistricts where the Lamotte Sandstone is the main ore host.

The Cambrian Elvins Group (fig. 3) consists of the Davis Formation and the overlying Derby-Doerun Dolomite. The Elvins Group is exposed in small areas in southeastern Washington County, northern St. Francois County, and along the Big River and its tributaries in northeastern Washington County and southwestern Jefferson County. An isopach map of the southern two-thirds of Washington County (Thacker and Anderson, 1979c) shows that the thickness of the formation ranges from zero to about 300 ft in this area; the unit thickens to about 450 ft in northwestern Washington County and central Jefferson County (Imes, 1990). The Davis Formation conformably overlies the Bonneterre Formation and consists of interbedded shale, dolomitic limestone, siltstone, and sandstone (Snyder and Gerdemann, 1968; Wagner, 1973). An isopach map of the southern two-thirds of Washington County (Thacker and Anderson, 1979b) shows that the Davis Formation thickness ranges from zero to about 180 ft in this area; Wagner (1973) states that the average thickness is 165 ft in the Southeast Missouri Barite District. The Davis Formation is conformably overlain by the Derby-Doerun Dolomite, which consists of a lower, argillaceous dolomite and an upper, massive oolitic or algal-reef dolomite (Snyder and Gerdemann, 1968). An isopach map of the southern two-thirds of Washington County (Thacker and Anderson, 1979c) shows that the Derby-Doerun Dolomite thickness ranges from zero to about 150 ft in this area. The Elvins Group generally has low permeability compared to formations above and below it and is considered a regional confining unit (St. Francois confining unit) by the U.S. Geological Survey (Imes and Emmett, 1994).

The Cambrian Potosi Dolomite (fig. 3) conformably overlies the Derby-Doerun Dolomite. The Potosi Dolomite is the most important formation in the Southeast Missouri Barite District and the Valles Mines because the residual soil (residuum) derived from it hosts most of the barite and lead in the Southeast Missouri Barite District, and ore also is present in the formation, particularly at the Valles Mines. The Potosi Dolomite is exposed in a large part of the study area. The bedrock geologic map of the study area (fig. 4), however, shows the Potosi Dolomite and Eminence Dolomite as a single mapped unit because the source of the mapping for figure 4 (Missouri Department of Natural Resources (2015b) groups the two formations as a single mapped unit. Recent revisions to the Cambrian stratigraphy in Missouri (Thompson and others, 2013) name the Potosi-Eminence Dolomite as a formal rock unit in addition to the Potosi Dolomite and the Eminence Dolomite, recognizing the difficulty in picking the contact between these two formations in some areas. Geologic maps at a 1:24,000 scale that show the Potosi and Eminence Dolomites as two separate mapped units are available for northeastern Washington County and for Jefferson County (Missouri Department of Natural Resources, 2015b). Wagner (1973) published a geologic map that shows the two formations as separate units, but this map covers only a portion of the Southeast Missouri Barite District. Wagner (1973) stated that the Potosi Dolomite is exposed in the major valleys and lower hills in about 50 percent of his study area, ranges from about 215 to about 390 ft thick, and appears to thin to the north. Thacker and Anderson's (1979d) isopach map of the southern two-thirds of Washington County shows that the Potosi Dolomite ranges in thickness from zero to about 375 ft. Generally, the Potosi Dolomite is a medium crystalline, massive bedded dolomite with abundant quartz druse that is associated with chalcedony and chert (Wagner, 1973; Thompson, 1995; Thompson and others, 2013). Because of the economic importance of the Potosi Dolomite in the Southeast Missouri Barite District, Wagner (1973) described the Potosi Dolomite in detail, including descriptions of three lithologic types (calcarenite, algal-stromatolite biostrome, and carbonate muds); diagenesis, including the development of drusy quartz; weathering characteristics; and the relation between lithologic characteristics and ore deposits.

The Cambrian Eminence Dolomite (fig. 3) conformably overlies the Potosi Dolomite and is the second most important ore-bearing formation in the Southeast Missouri Barite District, after the Potosi Dolomite. It is exposed in much of the study area and is combined with the underlying Potosi Dolomite as a single mapped bedrock unit in figure 4. Wagner (1973) estimated that the formation is exposed in about 35 percent of his study area and that it varies from about 120 to 195 ft thick. Thacker and Anderson (1979d) estimated that the formation ranges in thickness from zero to about 250 ft in the southern two-thirds of Washington County and thins to the north. Generally, the Eminence Dolomite is a medium to massive bedded, medium to coarsely crystalline dolomite with small amounts of chert (mostly in the upper one-half of the formation), small amounts of quartz druse, and local thin seams of green clay (Wagner, 1973; Thompson, 1995;Thompson and others, 2013). Because of the economic importance of the Eminence Dolomite in the district, Wagner (1973) described the Eminence Dolomite in detail, delineating five lithologic types (calcarenite, algal-stromatolite biostrome, carbonate muds, green clay seams, and a recrystallized dolomite without recognizable structure that makes up about 75 percent of the formation, termed cryptalgal lithology), diagenesis of these lithologies, weathering characteristics, and the relation between lithologic characteristics and ore deposits.

The Gasconade Dolomite (fig. 3) is the oldest Ordovician formation in Missouri. Thompson (1995) states that the Cambrian-Ordovician contact is conformable in parts of Missouri and unconformable elsewhere; Wagner (1973) stated that an unconformity marks this contact in his study area. The Gasconade Dolomite is exposed in a large part of western and northwestern Washington County and small parts of southwestern and southeastern Jefferson County; in some places, this is the result of faulting that has down-dropped the Gasconade Dolomite relative to adjacent Cambrian formations (fig. 4). Wagner (1973) stated that it is the bedrock formation in about 10 percent of his study area, where it is present on most of the higher ridges, and that it is about 220 ft thick in the district. The Gasconade Dolomite is mostly medium to coarsely crystalline dolomite with abundant chert. Thompson (1995) divides the formation into three units: the upper Gasconade, which contains relatively small amounts of chert; the lower Gasconade, which may be up to 50 percent chert; and beneath that a basal unit called the Gunter Sandstone Member, which varies regionally from sandstone up to about 30 ft thick to a sandy dolomite. Wagner (1973) described the Gunter Sandstone Member in his study area as coarsely crystalline dolomite interbedded with finely crystalline argillaceous dolomite with scattered sand grains. A small number of ore deposits are present in the Gasconade Dolomite in the Southeast Missouri Barite District and in adjacent counties.

The Ordovician Roubidoux Formation (fig. 3) overlies the Gasconade Dolomite; the contact is conformable in Wagner's (1973) study area. The formation consists of cherty dolomite, sandy dolomite, dolomitic sandstone, and sandstone (Thompson, 1995). The Roubidoux Formation is exposed in parts of western and northwestern Washington County and small parts of southwestern and southeastern Jefferson County; in some places, this is the result of faulting that has down-dropped the Roubidoux Formation relative to other formations (fig. 4). A small number of ore deposits are present in the Roubidoux Formation in the Southeast Missouri Barite District and in adjacent counties.

The Ordovician Jefferson City Dolomite and the overlying Ordovician Cotter Dolomite (fig. 3) are mapped together as a single unit on figure 4 and are exposed in most of the southwestern two-thirds of Jefferson County on the northeast, down-dropped side of the Vineland fault system. The Jefferson City Dolomite is predominantly medium to finely crystalline dolomite and argillaceous dolomite (Thompson, 1995). The Cotter Dolomite is predominantly medium- to finely crystalline cherty dolomite (Thompson, 1995). A small number of ore deposits of the Southeast Missouri Barite District are present in the Jefferson City and Cotter Dolomites. Younger Ordovician, Devonian, and Mississippian formations form the bedrock in northern and southeastern Jefferson County (figs. 3 and 4).

Clayey residuum overlies carbonate formations in Missouri, including the Cambrian and Ordovician formations in the study area. The residuum is the insoluble residue from weathering. Residuum is mostly clay but also contains chert, sand and sandstone, and drusy quartz and chalcedony, particularly where the residuum is developed from the Potosi Dolomite. The bedrock surface is sometimes pinnacled (that is, the surface is irregular because of weathering along fractures). Early miners noted that the bedrock surface was locally soft and friable and called this sand rock; this was not quartz sand but instead was loosely consolidated dolomite rhombohedra resulting from the solution and recrystallization of the dolomite bedrock (Muilenburg, 1957; Tarr, 1918).

Geology of the Ore Deposits

This section describes the various characteristics of the ore deposits, such as ore and gangue mineralogy, paragenesis, location and types of mineralization, zoning, and the structural and stratigraphic controls of mineralization, as well as how they acted together to affect ore deposition. These characteristics, including their variability, not only describe an ore district or subdistrict but also lead to hypotheses of the genesis of the ore deposits. Although these characteristics have genetic implications, ore genesis of the Southeast Missouri Barite District and the Valles Mines is beyond the scope of this report.

Mineralogy and Paragenesis

Minerals of an ore deposit are described as primary, which are minerals deposited by the ore fluids, and secondary, which are minerals that form later as an alteration of the primary minerals as a result of a change in environmental conditions, such as a change to an oxidizing and lower temperature environment. Primary minerals are commonly described as hypogene, which means they were deposited by warm ascending ore fluids; secondary minerals are commonly supergene, which means they are formed by cooler, descending fluids. Minerals are further described as ore minerals, which are recovered for their economic value, and gangue minerals, which have no economic value.

Barite (barium sulfate; table 1) is a primary ore mineral; however, some barite is secondary (Wagner, 1973). The primary, and most important lead-ore mineral, is galena (lead sulfide; table 1). Secondary lead minerals are cerussite (lead carbonate; also called dry bone by the early miners; table 1) and anglesite (lead sulfate; table 1). These secondary lead minerals commonly are present as alteration products of galena and were locally important ore minerals, despite being discarded during the early lead-mining years before their value was realized (Litton, 1855). The primary zinc ore mineral is sphalerite (zinc sulfide; table 1); smithsonite (zinc carbonate; table 1) is a secondary mineral that also was mined as an ore mineral and was more important than sphalerite in some deposits, including the Valles Mines (Kiilsgaard and others, 1967). Chalcopyrite (copper-iron sulfide; table 1) also is present in the ore deposits as a primary mineral; the IMOP database (Missouri Department of Natural Resources, 2015a) indicates that copper was recovered as the primary resource in a few mines (chalcopyrite was also mined in some deposits in the nearby Franklin County Mines; fig. 1).

Table 1. Chemical formula, physical properties, and chemical composition of barium, lead, zinc, and copper ore minerals in the Southeast Misouri Barite District and Valles Mines.

[Ba, barium; S, sulfur; O, oxygen; SO_4, sulfate; BaO, barium oxide; SO_3, sulfur trioxide; Pb, lead; C, carbon; CO_3, carbonate; PbO, lead oxide; CO_2, carbon dioxide; Zn, zinc; ZnO, zinc oxide; Cu, copper; Fe, iron; physical and chemical data from Hurlbut (1971)]

Mineral	Description	Chemical formula	Specific gravity	Hardness[a]	Chemical composition when pure
Barite	Barium sulfate	$BaSO_4$	4.5	3.0–3.5	65.7% BaO; 34.3% SO_3
Galena	Lead sulfide	PbS	7.4–7.6	2.5	86.6% Pb, 13.4% S
Cerussite	Lead carbonate	$PbCO_3$	6.55	3.0–3.5	83.5% PbO, 16.5% CO_2
Anglesite	Lead sulfate	$PbSO_4$	6.2–6.4	3.0	73.6% PbO, 26.4% SO_3
Sphalerite	Zinc sulfide	ZnS	3.9–4.1	3.5–4.0	67% Zn, 33% S
Smithsonite	Zinc carbonate	$ZnCO_3$	4.35–4.40	4.0–4.5	64.8% ZnO, 35.2% CO_2
Chalcopyrite	Copper-iron sulfide	$CuFeS_2$	4.1–4.3	3.5–4	34.6% Cu, 30.4% Fe, 35.0% S

[a]Hardness is referenced to Mohs scale of relative hardness from 1 (softest) to 10 (hardest; Hurlbut, 1971).

Some gangue minerals were pre-ore-stage (that is, they were deposited before barium, lead, or zinc mineralization); these include the silica minerals (quartz, chalcedony, and chert), possibly marcasite (iron sulfide), and some dolomite (calcium-magnesium carbonate; Wagner, 1973; Kaiser and others, 1987). Primary gangue minerals are dolomite and pyrite (iron sulfide). Secondary gangue minerals are malachite (copper carbonate), aurichalcite (copper-zinc carbonate), melanterite (iron sulfate), gypsum (calcium sulfate), limonite (hydrous iron oxide), and jarosite (potassium-iron hydrous sulfate) (Wagner, 1973).

The general order (paragenesis) of ore-stage mineralization is pyrite, galena and sphalerite, white barite, chalcopyrite (rare to minor), clear barite, and calcite (rare to minor) (Kaiser and others, 1987; Wagner, 1973; Tarr, 1918). Not all minerals are present at all locations, and overlapping periods of deposition of minerals was common. For example, most of the sulfide mineralization pre-dates barite mineralization, but small amounts of sulfides were deposited throughout the period of barite deposition (Kaiser and others, 1987). The sulfide minerals are, in decreasing order of abundance, pyrite, galena, sphalerite, and chalcopyrite (Wagner, 1973). Alteration of minerals to secondary minerals happened after ore-stage mineralization.

Location and Description of the Ore Deposits

Ore deposits of the Southeast Missouri Barite District are present mostly in the clayey residuum that overlies bedrock and, to a lesser extent, in bedrock beneath the residuum. Most deposits are present in the residuum overlying the Potosi Dolomite, followed in importance by residuum overlying the Eminence Dolomite. Lesser ore is present in the residuum overlying younger formations and in the Gasconade Dolomite, Roubidoux Formation, Jefferson City Dolomite, and Cotter Dolomite. In addition to mineralogical differences, the ore deposits of the Valles Mines differ from the ore deposits of the Southeast Missouri Barite District by being present more in the bedrock and less in the overlying residuum (Cheryl Seeger, Missouri Geological Survey, oral commun., July 7, 2016). The Cambrian Potosi and Eminence Dolomites form the bedrock in the Valles Mines area. Outside the study area, the Gasconade Dolomite and Roubidoux Formation host the ore deposits of the Franklin County Mines (fig. 1). To illustrate the relation between bedrock formations and ore mineralization, figure 5 shows mines, prospects, and occurrences in the study area and bedrock age in three groupings: combined Cambrian Potosi and Eminence Dolomites, older than the Potosi Dolomite, and younger than the Eminence Dolomite. Sites of mineralization are from the MGS IMOP database (Missouri Department of Natural Resources, 2015a). All resources (lead, zinc, barite, mixed barite and lead, and so forth) are grouped together, and two types of sites are shown: past producers, and prospects and occurrences grouped. Although the information for some sites may be limited and some sites may not be precisely located because of the age or quality of the reference for the site (which may be as old as the early 1800's), or because of conflicting location data from different sources, figure 5 serves to illustrate the widespread nature of barite, lead, and zinc mineralization in the study area, and that most mineralization is present where the bedrock formation is the Potosi Dolomite or Eminence Dolomite. Brobst and Wagner (1967) stated that about 95 percent of the deposits are present in the upper one-half of the Potosi Dolomite and the lower two-thirds of the Eminence Dolomite. Also, the stratigraphic column in figure 3 describes the relative amounts of ore in the different formations in the study area and vicinity, including the Southeast Missouri Lead District.

Although barite and lead commonly are present together in the Southeast Missouri Barite District, the degree to which they are present together does not seem to be the same everywhere because occurrence was characterized differently by different authors. Winslow (1894), describing lead mines at a time when barite also was mined, stated that the quantity of barite associated with galena was such that it often was an object of independent search. Dake (1930, p. 211), also describing lead mines, stated that barite was an "almost universal accompaniment." Tarr (1918), describing

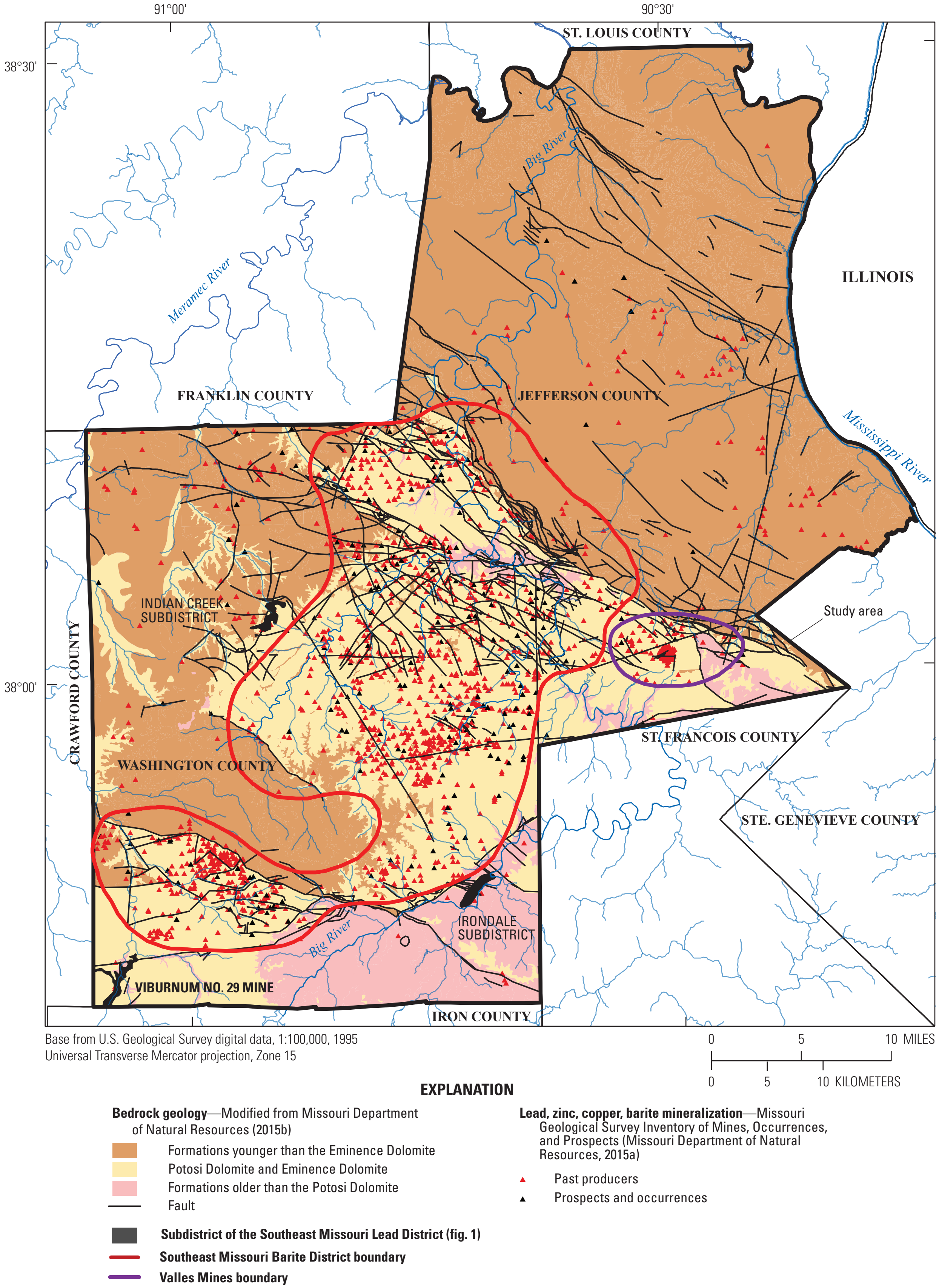


Figure 5. The relation of Southeast Missouri Barite District and Valles Mines ore mineralization to bedrock geology, and locations in the study area of ore deposits of the Indian Creek Subdistrict, Irondale Subdistrict, and Viburnum No. 29 Mine in the Viburnum Trend Subdistrict in the Southeast Missouri Lead District.

barite deposits, stated that although some barite diggings do not contain any galena, most contain at least a specimen of galena, and that the major part of the district is covered by old abandoned holes of the lead mines (diggings). Kaiser and others (1987) stated that minor amounts of sulfides accompany barite, and Wagner (1973) stated that galena and sphalerite tend to be present together and are more restricted in areal distribution than barite. Rueff (2003) showed generalized areas where barite and lead mining took place; although the two areas overlap to a large extent, the area of lead mining is about twice the size of the area of barite mining, and a large part of southern Washington County is shown as having had lead mining only. Barite, though present, was not an important resource at the Valles Mines, where zinc was the most important resource (Cheryl Seeger, Missouri Geological Survey, oral commun., July 7, 2016).

A more detailed depiction of barite and lead distribution in the study area using the MGS IMOP database is shown in figure 6. Four categories of mineralization are shown: barite only, without lead, zinc, or copper; lead, zinc, or copper but not with barite (less commonly zinc, and sometimes with other metals such as copper or nickel); lead or zinc with barite (and in some cases with copper or nickel); and a few occurrences of iron, with or without lead, zinc, or barite, including the Pea Ridge Iron Mine (fig. 2). These four categories are simplified from the many groupings of resources in the IMOP database, such as lead, zinc, lead with zinc, zinc with lead, lead with copper, barite, barite with lead, lead with barite, and many other combinations, including some with other metals. Also, some resources are listed in the IMOP database as questionable, for example, "Barium; Lead?," which means that barium (meaning barite) is present and lead was strongly suggested by sources but not definitively specified (Cheryl Seeger, Missouri Geological Survey, oral commun., August 13, 2014). This listing is simplified for this report by dropping the query and referring to this category as "lead or zinc with barite" in figure 6. Although barite and lead commonly are present together or in close proximity to each other, there are areas where mostly lead is reported or, conversely, where mostly barite is reported (fig. 6); however, because some of the IMOP data sources may list only the principal metal that was present and not accessory metals that also were present, the number of sites in figure 6 where lead or zinc is present with barite may be underrepresented.

Descriptions of ore in bedrock (lode deposits) by different authors were mostly for the purpose of describing ore in lead mines (or zinc, especially in the case of the Valles Mines), because barite was never the focus of bedrock mining. Although barite is present in bedrock with lead and zinc, mining of barite only extended into bedrock when there was enough lead or zinc ore to justify the expense, with barite being a byproduct (Tarr, 1918).

Most of the ore of the Southeast Missouri Barite District that is present in bedrock is one of two types of ore: (1) runs or channels described by Dake (1930), and also described by Buckley (1908) and Ball (1916) using different terminology; or (2) vertical crevice ore described by Ball (1916), and also described by Buckley (1908), Dake (1930), Weigel (1929), and Tarr (1918) using different terminology. Ore in bedrock at the Valles Mines seems to be similar to ore in bedrock in the Southeast Missouri Barite District, except for mineralogy. Winslow (1894) described ore in bedrock at several mines of the Valles Mines.

The runs, or channels, described by Dake (1930) are deposits with a greater horizontal than vertical extent, with the vertical extent ranging from 1 to 6 ft, and sometimes present in different levels. Dake (1930) stated that these were solution channels, sometimes called caves, that were rarely entirely filled and were presumably controlled by intersecting joints, and that most of the ore was this type. Buckley (1908) and Ball (1916) described these deposits as pipes or pipe veins. Ball (1916) stated that these are semi-cylindrical in form, follow horizontal bedding planes, and are 3 to 8 ft wide and average 6 inches (in.) thick. The semi-cylindrical form is the result of ore deposited at the intersection of a joint and a favorable bed (Ball, 1916). Minor pipes can lead off of main pipes at or close to a right angle, and systems of pipe veins can be present at several horizons. Winslow (1894) also used the term channel to describe horizontally aligned ore deposits at the Valles Mines. Kiilsgaard and others (1967) state that these deposits are relatively flat lying but thin, and extend over a large horizontal area.

The vertical crevice ore described by Ball (1916) consists of vertical, tabular deposits that pinch out with depth and form along joints. Cross-veinlets of ore form along secondary joints and cross the main joint at right angles; east-west and north-south crevices are the most common and can be present as sets along parallel joints. Buckley (1908) described these crevices as vertical channels (using the term channel differently than Dake [1930]) with a larger vertical than horizontal extent. Buckley (1908) states that the upper 100 to 150 ft of bedrock, particularly the Potosi Dolomite, was characterized by channels and other openings; the depth of mining, however, is reported to locally have been as deep as 250 ft, with barite present with galena (Tarr, 1918). This type of ore is probably what Dake (1930) described as fissures that are traceable for one-half of a mile or more, but are less important than the channel ore he described. The vertical crevice deposits are probably what Weigel (1929) and Tarr (1918) described as barite in veins; Tarr (1918) stated that most of the veins strike north-south. Winslow (1894) described vertical chimneys of ore at the Valles Mines.

Ball (1916) also described breccia-filling ore, which consists of vertical tabular masses of ore cementing either fault or solution breccia. Tarr (1918) also stated that barite cements breccia. Ore in bedrock is mostly open-space filling (Kaiser and others, 1987) and less commonly a replacement of the host dolomite (Buckley, 1908). In addition to the open-space mineralization in channels, crevices, and breccia, some disseminated mineralization is present in the host dolomite. Tarr (1918) described small masses of barite up to about 2 in. in size that fill vugs in the dolomite or replace it, and stated

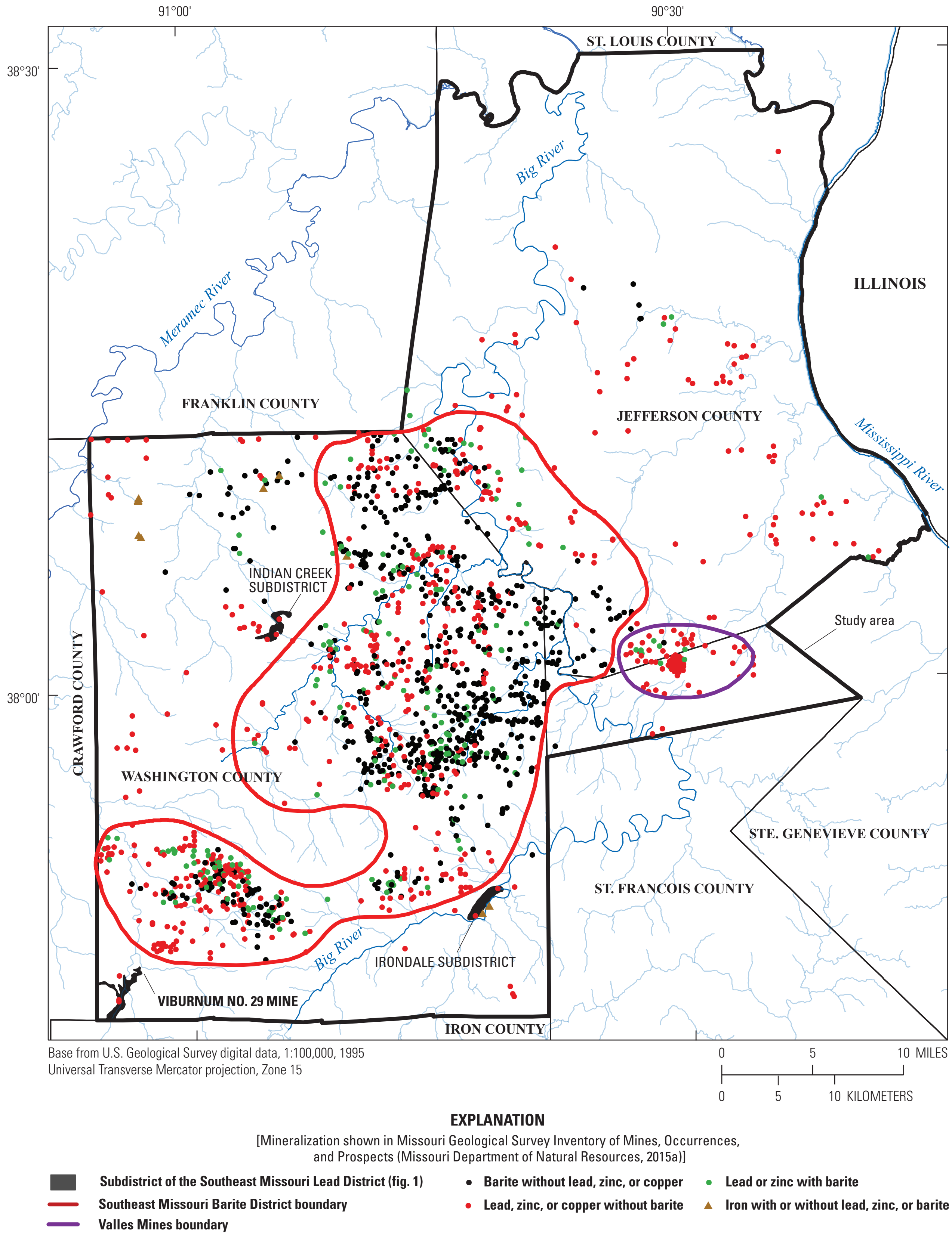


Figure 6. The distribution and types of Southeast Missouri Barite District and Valles Mines ore mineralization, and locations in the study area of ore deposits of the Indian Creek Subdistrict, Irondale Subdistrict, and Viburnum No. 29 Mine in the Viburnum Trend Subdistrict in the Southeast Missouri Lead District.

that this is more abundant near the veins, which indicates a genetic relation to the veins. Some of this may be what Kaiser and others (1987) referred to when describing a preference for barite to fill vugs along stromatolite structures in the dolomite.

Because galena, sphalerite, and barite are less soluble than dolomite, chemical weathering of the dolomite bedrock resulted in the concentration of ore minerals in the residuum, and most of the barite and lead mining was in the residuum. Some particularly early studies, for example Buckley (1908) and Dake (1930), suggested that there was not enough ore in the bedrock to account for the ore in the residuum and that the ore was therefore deposited by descending groundwater. At the time of writing, exposures of the bedrock were limited to natural outcroppings along streams, the bottom of barite and lead shafts in the residuum (many of which had been filled and were not accessible for study), and the small number of lead mines in bedrock (many of which were not accessible). Later open-pit mining of the residuum for barite resulted in better exposures of the bedrock surface and more observation of ore minerals in the bedrock, which has been judged to be abundant enough to account for the ore in the residuum (Wharton, 1986).

Various estimates of the thickness of the ore-bearing residuum have been made. Muilenburg (1957) estimated that the residuum ranges in thickness from a few inches to 40 or 50 ft, with an average of 10 to 15 ft, whereas Schoolcraft (1819) stated that the earliest lead mines were normally 15–20 ft deep in the residuum. Weigel (1929), describing the geology of barite deposits, stated that the richest barite is found on gentle slopes rather than at the top of hills, and that barite is seldom found in valleys. Barite and lead concentrations can be randomly distributed in the clay residuum or evenly distributed from top to bottom, but usually the richest ore was found at the bottom of the residuum near the bedrock surface (Muilenburg, 1957; Dake, 1930). Early miners recognized rich runs or leads of irregular shape and extent alternating with less rich or barren ground. These alterations have been interpreted, for example by Muilenburg (1957), as representing original concentrations in fractures or solution channels—removal of the dolomite by solution left the relatively insoluble ore in roughly the same position as it was in the dolomite. Hillside creep and slumping further distributed the ore over a somewhat wider area. Mechanical removal and distribution of ore minerals by erosion of the residuum is evidenced by the fact that some placer galena was recovered from streambeds in the early days of mining (Ball, 1916; Stoddard, 1804).

Drusy quartz is nearly always present in the Potosi Dolomite bedrock and its residuum, and is present as 0.5-millimeter (mm) to 5-centimeter (cm) quartz crystals on numerous thin layers of chalcedony (Wagner, 1973). Barite miners referred to drusy quartz as moory (Tarr, 1918) or mineral blossom (Thompson, 1995). It is widespread throughout Missouri in the Potosi Dolomite; was interpreted by Wagner (1973) and Kaiser and others (1987) to have been deposited following karstification that accompanied the development of unconformities, probably in Ordovician time; and is unrelated to barite-lead mineralization. Chert replacement of dolomite is another form of silicification (Wagner, 1973).

Barite, known as tiff to the miners, varies in size from minute grains to large masses of as much as several hundred pounds but is more commonly in pieces from about 1 to about 10 in. in size, with much of the finer material lost during processing (Dake, 1930; Weigel, 1929). Barite is present in a variety of forms for which a variety of local descriptive terms were used (Muilenburg, 1957). Ball tiff is a botryoidal form of barite with a radiating, bladed structure (Muilenburg, 1957). Chalk tiff is a finely crystalline aggregate of barite (Ball, 1916). Other terms used are dry bone, sheep nose tiff, split tiff, spar, rock tiff, gravel tiff, and clay tiff (Muilenburg, 1957). Wagner (1973) described two major types of barite: white barite and clear barite. The white barite was deposited during the main stage of ore mineralization and forms fine to coarsely crystalline aggregates of blade-like crystals. The white color is the result of an abundance of fluid inclusions. Clear barite lacks fluid inclusions. Kaiser and others (1987) stated that clear barite was also known as glass tiff, but spar is the term Washington County miners used for clear barite, according to Muilenburg (1957); glass tiff was used by Central Missouri Barite District (fig. 1) miners to describe clear barite and was used by Washington County miners to describe calcite. The clear barite was both a late-stage hypogene mineral and a supergene mineral (Wagner, 1973; Kaiser and others, 1987).

Galena is present as cubes or aggregates of cubes, known as block mineral (Buckley, 1908) or cog lead (Dake, 1930); a lesser amount of octahedral galena is present. Ball (1916) stated that galena usually is present as small cubes disseminated in chalk tiff, and less so in ball tiff; however, galena was sometimes found in masses as large as several hundred pounds (Winslow, 1894). Wagner (1973) stated that galena is present in some areas and that sphalerite without galena is rare. He described sphalerite as layers and isolated clusters of black, greenish-black, light red, and tan crystals. Dake (1930) stated that sphalerite is not common and that there was not much recovery of sphalerite because it was difficult to separate from barite.

Oxidation of sulfide minerals to secondary minerals is mentioned in numerous places in the literature. Wagner (1973) stated that nearly all the sulfides in the residual deposits were weathered to some degree, and that fresh sulfides can be found 10–15 ft into the underlying bedrock. Kaiser and others (1987) stated that that the district contains minor sulfides that are largely oxidized. Tarr (1918, p. 56) stated that galena “always shows evidence of attack by ground water,” that galena in residuum rarely shows crystal faces, and that there was a layer of gray or white cerussite in one-half of the specimens he observed. Ball (1916) stated that galena cubes commonly have rounded corners and corroded surfaces (evidence of leaching), and galena cubes are commonly partly altered to cerussite, which can be white and crystallized or a gray powder. He further stated that cerussite was for many years not recognized as an ore mineral and was thrown out on the mine dump. Dake (1930, p. 211), however, described cerussite as being present sparingly and stated that anglesite has been reported. Wagner (1973) stated that anglesite is widespread as thin, gray, earthy coatings on galena. Sphalerite is oxidized to smithsonite, which forms crusts on sphalerite, barite, and dolomite (Tarr, 1918). Dake (1930) stated that most of the zinc production was from smithsonite. Zinc-ore minerals at the Valles Mines are mostly smithsonite (Kiilsgaard and others, 1967). Limonite is abundant as an alteration product of marcasite and pyrite, commonly coats barite and other minerals (Weigel, 1929), and may be pseudomorphous after marcasite or pyrite (Dake, 1930; Wagner, 1973).

Mineral Zoning and Structural and Stratigraphic Controls of Mineralization

Wagner (1973) recognized barite textural zoning and mineralogic zoning in large, linear ore runs from about 1 to at least 6 mi long and from 200 yards (yd) to about 2.5 mi wide in the Southeast Missouri Barite District. Barite textural zoning consists of a central zone of coarsely crystalline barite that grades (or sometimes more abruptly changes) outward to a zone of finely crystalline barite. Mineralogic zoning coincides spatially with the barite-textural zoning, with sulfides concentrated mostly in the center of runs. Sphalerite is present in the central parts of runs; galena is more widespread but is more concentrated in the central parts of runs and is present in minor amounts in the outer parts of the runs. Zoning is centered on a controlling structure (a fault or concentration of joints) and complex zoning patterns may result from mineralization along intersecting structures. Wagner (1973) also recognized that individual ore deposits are not geologically isolated but are parts of ore runs. Residual ore deposits that were once part of a continuous ore run are isolated from each other by topographic lows where the ore deposit was removed by erosion. Also, an ore run may be longer than its surficial expression in the case where it extends in the subsurface, where it remains unweathered with no surficial expression.

Wagner (1973) interpreted the distribution of barite textural zones and mineralogic zones around faults and zones of joints as indicating structural and stratigraphic controls of mineralization, the combination of which created a plumbing system for the ore fluids. Ore fluids would have moved up from depth along faults and joints until they intersected permeable rock and migrated laterally. The zoning is a result of changing geochemical conditions with increasing distance from the controlling structures. The stratigraphic controls of ore mineralization were the unconformity-related open spaces in the dolomite that developed during an earlier dissolution (karstification) event (Kaiser and others, 1987; Wagner, 1986). These open spaces are solution vugs along stromatolite structures or laterally connected networks of fractures and solution cavities along bedding planes (Kaiser and others, 1987), where in many cases silica minerals had already been deposited.

Mining History of the Southeast Missouri Barite District and the Valles Mines

Lead mining commenced in the Southeast Missouri Barite District and the Valles Mines before barite mining, and the production history of the two commodities is presented in this order. Lead-ore minerals and barite commonly are present together, and some deposits that were first mined for lead were later mined for barite, with lead sometimes recovered as a byproduct of barite mining. Zinc also was recovered at some mines but was mostly less important than lead. Zinc mining, processing, and production are discussed in the section on lead mining. Zinc was the most important commodity at the Valles Mines. Copper was recovered in a few mines. In the following review, each section has three subsections: (1) the development of mining, (2) mining and processing methods, and (3) mine production and losses during processing. Most of this section concerns the Southeast Missouri Barite District, but mention is made of the Valles Mines where appropriate. In addition, brief mention is made of the mining history at the Irondale, Indian Creek, and Viburnum Trend Subdistricts of the Southeast Missouri Lead District.

Lead Mining

Early lead mining in Missouri was by shallow diggings in surficial deposits, mostly in the Southeast Missouri Barite District and the Southeast Missouri Lead District, and later in central and southwestern Missouri. Because the development of mining in the Southeast Missouri Barite District is part of the broader development of mining in Missouri, limited mention is made in this report of mining in these other areas, particularly at Mine La Motte (fig. 1) of the Southeast Missouri Lead District, where some of the earliest mining took place. The distinction between the two districts is relevant for this report but was not during the time of early lead mining and early reports on lead mining because definitions of mining districts and subdistricts did not evolve until much later.

The names of the early lead mines may be singular, such as Mine Renault, or plural, such as Old Mines, but both cases generally refer to multiple diggings (shafts). Most of the lead and zinc mines discussed in this section are shown in figure 7, and in most cases these are actually groups of mines covering several acres to several thousand acres (Dake, 1930). These mines are listed in table 2, which also shows the primary sources of information. Because reliable location data for some mines are not available, either because of the age of the mines or because different sources give different locations or no locations, some mines discussed in this section are shown in figure 7 only approximately or not at all.

There were many more lead mines than are described in this section. This section describes only those mines that seem to be the principal mines by virtue of production or longevity

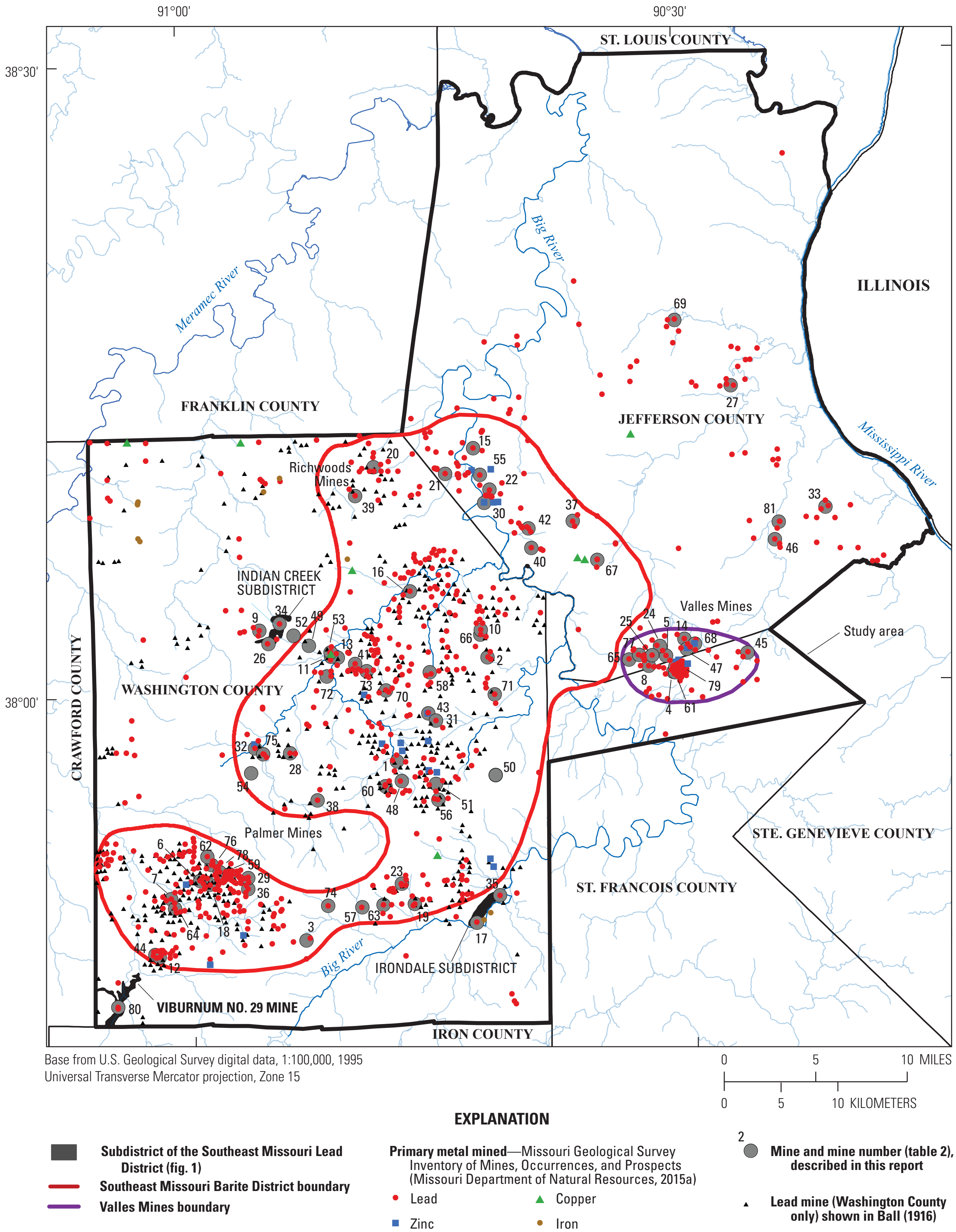


Figure 7. Locations of mines of the Southeast Missouri Barite District and Valles Mines where lead, zinc, or copper was the primary metal recovered; locations of mines of the Indian Creek Subdistrict, Irondale Subdistrict, and Viburnum No. 29 Mine in the Viburnum Trend Subdistrict in the Southeast Missouri Lead District within the study area; and locations of iron mines within the study area.

Table 2. Lead and zinc mine names, districts, and references for mine information and location (described or mentioned in this report) in the Southeast Missouri Barite District, Valles Mines, and the Southeast Missouri Lead District.

[Mine references are for mine information or location; IMOP, Inventory of Mines, Occurrences, and Prospects (Missouri Department of Natural Resources, 2015a)]

Mine number (fig. 7)	Mine name	Mining district or area	Mine reference
1	Austin's Mines	Southeast Missouri Barite District	Stoddard (1804); Hearthstone Legacy Publications (2004); Showalter (1963); Gracy (1992); Park (2006)
2	Bellefontaine Mines	Southeast Missouri Barite District	Litton (1855); Showalter (1963); Winslow (1894); IMOP
3	Benning's Diggings	Southeast Missouri Barite District	Dake (1930)
4	Bisch's Mines	Valles Mines	Litton (1855); Winslow (1894); Parizek (1949); Park (2006); IMOP
5	Bisch and Daly Mines	Valles Mines	Swallow (1859); IMOP
6	Bit Diggings	Southeast Missouri Barite District	Litton (1855); Dake (1930); IMOP
7	Bluff Diggings	Southeast Missouri Barite District	Litton (1855); Dake (1930); IMOP
8	Bogy's Diggings	Valles Mines	Swallow (1855); Winslow (1894); IMOP
9	Brock Diggings	Southeast Missouri Barite District	Litton (1855); IMOP
10	Cannon's Mines	Southeast Missouri Barite District	Litton (1855); Park (2006); IMOP
11	Casey and Clancey's Diggings	Southeast Missouri Barite District	Litton (1855)
12	Coffee-Pot Diggings	Southeast Missouri Barite District	Litton (1855); Dake (1930); IMOP
13	Cook's Diggings	Southeast Missouri Barite District	Litton (1855)
14	Corn Stalk Diggings	Valles Mines	Winslow (1894); Parizek (1949); Park (2006); IMOP
15	Darby Mines	Southeast Missouri Barite District	Winslow (1894); IMOP
16	Elliot's Mines	Southeast Missouri Barite District	Litton (1855); Showalter (1963); IMOP
17	Eversole Mine	Southeast Missouri Lead District	IMOP
18	Flint Hill Diggings	Southeast Missouri Barite District	Litton (1855); Dake (1930); IMOP
19	Forker Diggings	Southeast Missouri Barite District	Dake (1930); IMOP
20	French Diggings	Southeast Missouri Barite District	Litton (1855); Park (2006); Winslow (1894); Burford (1978)
21	Frissel's Mines	Southeast Missouri Barite District	Swallow (1859); Winslow (1894); IMOP
22	Frumet Mines	Southeast Missouri Barite District	Winslow (1894); IMOP
23	Furnace Creek Diggings	Southeast Missouri Barite District	Dake (1930); IMOP
24	Garatee Mines	Valles Mines	Winslow (1894); Parizek (1949); IMOP
25	Garrity and Butcher's Diggings	Valles Mines	Swallow (1859); IMOP
26	Goose Creek Mine	Southeast Missouri Lead District	Hagni (1995); Kiilsgaard and others (1967); IMOP
27	Gopher Mines	Southeast Missouri Barite District	Swallow (1859)
28	Grainger Diggings	Southeast Missouri Barite District	Dake (1930); IMOP
29	Grave-Yard Diggings	Southeast Missouri Barite District	Litton (1855); Dake (1930)
30	Gray's Mines	Southeast Missouri Barite District	Swallow (1859); Winslow (1894); Burford (1978); IMOP
31	Gulf Prospect	Southeast Missouri Barite District	Dake (1930); IMOP
32	Heffner Diggings	Southeast Missouri Barite District	Dake (1930); IMOP
33	Howe's Diggings	Southeast Missouri Barite District	Swallow (1859); Winslow (1894); IMOP
34	Indian Creek Mine	Southeast Missouri Lead District	Hagni (1995); Kiilsgaard and others (1967); IMOP
35	Irondale Mine	Southeast Missouri Lead District	Buckley (1908); IMOP
36	Ismael Diggings	Southeast Missouri Barite District	Litton (1855); Dake (1930)
37	Kelly's Diggings	Southeast Missouri Barite District	Swallow (1859); IMOP
38	Krueger Mine	Southeast Missouri Barite District	Ballinger (1948); Ligasacchi (1959); IMOP
39	La Beaume Mines	Southeast Missouri Barite District	Litton (1855); Winslow (1894); Burford (1978); IMOP
40	Lee's Diggings	Southeast Missouri Barite District	Swallow (1859); Winslow (1894); IMOP
41	Lupton Diggings	Southeast Missouri Barite District	Litton (1855); IMOP
42	Mammoth Mine	Southeast Missouri Barite District	Litton (1855); Swallow (1859); Winslow (1894); State Historical Society of Missouri (2013); Park (2006); IMOP
43	Masson Diggings	Southeast Missouri Barite District	Dake (1930); IMOP
44	Maury Diggings	Southeast Missouri Barite District	Litton (1855)
45	McCormack Diggings	Valles Mines	Litton (1855);Winslow (1894); IMOP
46	McCormick's Diggings	Southeast Missouri Barite District	Swallow (1859); Winslow (1894); IMOP
47	Miller's Diggings	Valles Mines	Swallow (1859); IMOP

Table 2. Lead and zinc mine names, districts, and references for mine information and location (described or mentioned in this report) in the Southeast Missouri Barite District, Valles Mines, and the Southeast Missouri Lead District.—Continued

[Mine references are for mine information or location; IMOP, Inventory of Mines, Occurrences, and Prospects (Missouri Department of Natural Resources, 2015a)]

Mine number (fig. 7)	Mine name	Mining district or area	Mine reference
48	Mine a Breton	Southeast Missouri Barite District	Stoddard (1804); Schoolcraft (1819); Dake (1930); Winslow (1894); Showalter (1963); Hearthstone Legacy Publications (2004); Park (2006); Carrollscorner.net (n.d.)
49	Mine a Liberty	Southeast Missouri Barite District	Schoolcraft (1819); Winslow (1894); Park (2006)
50	Mine a Martin	Southeast Missouri Barite District	Schoolcraft (1819); Winslow (1894)
51	Mine a Robina	Southeast Missouri Barite District	Stoddard (1804); Schoolcraft (1819); Winslow (1894); Park (2006)
52	Mine a Straddle	Southeast Missouri Barite District	Winslow (1894); Showalter (1963); Park (2006)
53	Mine Renault	Southeast Missouri Barite District	Stoddard (1804); Schoolcraft (1819); Winslow (1894); Ekberg and others (1981); Showalter (1963); Park (2006); IMOP
54	Mine Silvers	Southeast Missouri Barite District	Schoolcraft (1819); Park (2006)
55	Nashville Mines	Southeast Missouri Barite District	Swallow (1859); Winslow (1894); IMOP
56	New Diggings	Southeast Missouri Barite District	Schoolcraft (1819); Litton (1855); Park (2006); IMOP
57	N. Wool Diggings	Southeast Missouri Barite District	Dake (1930); IMOP
58	Old Mines	Southeast Missouri Barite District	Stoddard (1804); Winslow (1894); Showalter (1963); Park (2006); Dake (1930); Burford (1978)
59	Parole Mine	Southeast Missouri Barite District	Winslow (1894); IMOP
60	Pierce and Willoughby's Diggings	Southeast Missouri Barite District	Litton (1855); IMOP
61	Perry's Mine	Valles Mines	Litton (1855); Winslow (1894); Parizek (1949); IMOP
62	Pigeon Roost Diggings	Southeast Missouri Barite District	Litton (1855); IMOP
63	Plaffy Diggings	Southeast Missouri Barite District	Dake (1930); IMOP
64	Polecat Diggings	Southeast Missouri Barite District	Litton (1855); IMOP
65	Poston and Tyler's Mines	Valles Mines	Swallow (1859); Winslow (1894); IMOP
66	Prairie Diggings	Southeast Missouri Barite District	Litton (1855); IMOP
67	Robinson's Diggings	Southeast Missouri Barite District	Swallow (1859); IMOP
68	Rocky Diggings	Valles Mines	Swallow (1859); IMOP
69	Sandy Mines	Southeast Missouri Barite District	Litton (1855); Swallow (1859); Winslow (1894); IMOP
70	Scott and Bee Diggings	Southeast Missouri Barite District	Litton (1855); IMOP
71	Shibboleth Mines	Southeast Missouri Barite District	Schoolcraft (1819); Litton (1855); Winslow (1894); Burford (1978); Showalter (1963); Park (2006); IMOP
72	Shore's Diggings	Southeast Missouri Barite District	Litton (1855); Winslow (1894); IMOP
73	Sixteenth Section Mines	Southeast Missouri Barite District	Litton (1855); IMOP
74	Smith Diggings (1 of 2)	Southeast Missouri Barite District	Litton (1855); IMOP
75	Smith Diggings (2 of 2)	Southeast Missouri Barite District	Litton (1855); IMOP
76	Strawberry Diggings	Southeast Missouri Barite District	Litton (1855); Park (2006); IMOP
77	Tarpley Mines	Valles Mines	Litton (1855); Swallow (1859); Winslow (1894); Parizek (1949); Park (2006); IMOP
78	Trash Diggings	Southeast Missouri Barite District	Litton (1855); IMOP
79	Valles Mines (proper)	Valles Mines	Litton (1855); Winslow (1894); Valles Mines, Missouri, USA (2016); Park (2006); State Historical Society of Missouri (2013); Parizek (1949); Kiilsgaard and others (1967)
80	Viburnum No. 29 Mine	Southeast Missouri Lead District	Seeger (2008)
81	Yankee Diggings	Southeast Missouri Barite District	Swallow (1859); IMOP

or by being described in the literature rather than just mentioned, and most of the literature references state that there were more mines than they could mention. To present a more comprehensive, yet still incomplete, portrayal of the scope of lead mining in the study area, figure 7 also shows lead and zinc mines that are in the MGS IMOP database and the mines shown in Ball's (1916) sketch map of lead mines, which he stated shows many but not all mines. The IMOP database is not complete, given the age of the mining and incomplete record keeping, and there are some mines listed in literature sources that have not yet been examined for the IMOP database (Cheryl Seeger, Missouri Geological Survey, written commun., June 14, 2016).

Development of Lead Mining

French missionaries and explorers were the first to encounter lead mines in Missouri, when the region was part of the French-controlled Louisiana Territory. Father James Gravier, a missionary priest, wrote an account of his voyage in 1700 and mentioned a rich lead mine along the Meramec River (Burford, 1978). At about the same time, Pierre Charles LeSeur led the first mineral exploration of the Mississippi River valley and learned of lead mines along the Meramec River that were worked by Native Americans. Although lead deposits are present along the Meramec River and its tributaries in Franklin, Crawford, and Washington Counties, these reports may have been referring to the Big River (Park, 2006), which is a major tributary of the Meramec River and drains parts of the Southeast Missouri Barite District, the Valles Mines, and the Southeast Missouri Lead District (fig. 1).

In 1712, King Louis XIV granted a royal charter to Anthony Crozat, giving him exclusive rights to commerce, including minerals, and appointed Sieur Antoine de La Motte Cadillac Governor of the Territory (Park, 2006). Claude DuTisne followed a Native American trail through Washington County in 1714 and returned with samples of lead ore, but mine development did not immediately follow. In 1715, La Motte led an expedition into Madison County that resulted in the discovery of lead ore at what would become Mine La Motte (fig. 1), one of the major subdistricts of the Southeast Missouri Lead District where lead ore was mined from the lower Bonneterre Formation and locally from the upper Lamotte Sandstone (fig. 3) until 1959; however, Crozat went bankrupt and relinquished his charter, La Motte returned to France, and the lead ores at Mine La Motte were not developed until several years later (Park, 2006).

Following Crozat's bankruptcy, the Company of the West was formed in 1717 to promote the development of the Louisiana Territory, and claims were made of the mineral wealth in the Territory to encourage emigration from France. Lead was mined by Sieur de Renaudiere in 1719 along Old Mines Creek (fig. 2) where cabins were built, known as Cabanage de Renaudiere (not shown in figure 2; Burford, 1978; Showalter, 1963). This prompted further immigration to the Territory, including a prospecting expedition in 1719–20 by the Company of St. Philippe, a subsidiary of the Royal Company of the Indies, which was formed by the merger of the Company of the West with the Company of the Indies (Park, 2006). This expedition was led by Philippe Francois Renault, who left France with workmen and reportedly purchased slaves in Santo Domingo (Showalter, 1963), although this has been disputed (Ekberg and others, 1981). Prospecting parties, led by Renault and La Motte, who had prospected the Territory earlier, were sent out from the French settlement of Kaskaskia (in what is now Illinois) on the Mississippi River. The result was the discovery of lead and the development of lead mines in the Southeast Missouri Barite District at Mine Renault (fig. 7 and table 2; also called Forche a Renault Mine, located somewhere near the headwaters of Mineral Fork, perhaps along Fourche a Renault Creek [Ekberg and others, 1981; Park, 2006]) and at Old Mines (together, these two are sometimes called the Meramec Mines or the Mineral Fork Mines [Park, 2006]); at other places along the Big River, Mineral Fork, and Forche a Renault Creek (Showalter, 1963); in the Southeast Missouri Lead District at Mine a Gerbora (Winslow, 1894; Burford, 1978; not shown on fig. 7); and at the previously discovered Mine La Motte (fig. 1). The development of these mines, which consisted of shallow diggings in the surficial residuum, began the first period of sustained lead mining in Missouri (Burford, 1978). Referring to Old Mines, Dake (1930, p. 215) stated "The area embraced in this group…covers several square miles, and the number of individual shafts and pits was very great." By 1725, about 1,500 pounds (lb) per day of lead were smelted into pigs and carried by pack horses from mines in Washington County to Ste. Genevieve on the Mississippi River for shipment to France (Showalter, 1963). Permanent settlements were not established at these mines at this time, but a settlement was established at Ste. Genevieve (Burford, 1978). Although the Royal Company of the Indies was bankrupt by 1731 and lost its charter, Renault continued to mine until 1744 when, because of lack of funds and attacks by Native Americans, he returned to France with most of his workers.

Lead mining continued sporadically after the closure of Renault's mines until the end of the 18th century (Winslow, 1894). Some miners remained after Renault's departure, particularly at Old Mines and Ste. Genevieve, and probably operated farms during the growing season and worked the mines at other times at the already developed mining areas of Old Mines, Mine La Motte, and Mine a Gerbora (Winslow, 1894); and at Bonne Terre (fig. 2) and Mine a Joe (Park, 2006; Mine a Gerbora, Bonneterre, and Mine a Joe are located in what would become the Old Lead Belt and are not shown in fig. 7). Park (2006) stated that 100,000 lb of lead were produced from the Meramec Mines in 1752. In 1762, France ceded land holdings on the east side of the Mississippi (not including New Orleans, Louisiana) to England and ceded land holdings on the west side of the Mississippi to Spain. Many French settlers east of the Mississippi migrated west to what is now Missouri, preferring Spanish rule to British rule. Mining by the French continued under Spanish rule, including renewed mining at

Mine La Motte by Francois Valle in about 1763 (Park, 2006). Valle had migrated from Quebec to Kaskaskia and later built a cabin at what is now Valles Mines (figs. 2 and 7) in 1749 to buy lead from Native Americans who mined it in the area. The Valles Mines would later become an important zinc and lead mining area.

As early as 1760 but perhaps between 1775 and 1780 (Park, 2006), Francis Azor, called The Breton because of his birthplace in Brittany, France, and Peter Boyer discovered lead at the surface at what would become known as Mine a Breton (fig. 7 and table 2; sometimes written as Mine a Burton), but the name later changed to Potosi (Showalter, 1963; Carrollscorner.net, n.d.; Hearthstone Legacy Publications, 2004; Park, 2006). Other settlers came and a mining camp developed along the south side of what would be named Mine Breton Creek, which flows through Potosi, and on the hill known as The Citadel. Mine a Breton became a larger center of mining activity than Mine La Motte, covered an area of several thousand acres with many shafts (Dake, 1930), and a road was built from Mine a Breton to Ste. Genevieve in 1791 (Park, 2006) to transport lead for shipment to New Orleans. Ore was discovered at Mine a Robina (fig. 7 and table 2) at about the same time as the discovery at Mine a Breton (Winslow, 1894). Winslow (1894) stated that Mines a Layne and Mine a Maneto in St. Francois County and Mine a La Platte in southeastern Washington County, all of which are probably in the Southeast Missouri Lead District and are not shown in figure 7 or listed in table 2, were started in the last few years of the 19th century.

A major advancement in lead mining in Missouri happened with the arrival of Moses Austin, an American, who transformed lead mining from a seasonal endeavor carried out between the end of the harvest and winter to a year-round industry (Burford, 1978; Gracy, 1992). Austin was originally from Connecticut and had been operating lead mines in Virginia, when he heard of the rich lead deposits in Missouri. He visited Missouri in 1797, obtained a land grant from the Spanish Government of more than 6,000 acres northwest of Potosi, including a large part of Azor's previous grant at Mine a Breton, moved his family to Mine a Breton in 1798 to become the first permanent white settlers in Potosi (still called Mine a Breton at that time), and built a large home there in 1799 (Showalter, 1963; Hearthstone Legacy Publications, 2004). In describing Mine a Breton, Austin stated "The mines may be said to extend over two thousand acres of land; but the principal workings are within the limits of one hundred and sixty acres; and perhaps no part of the world furnishes lead ore in greater quantities and purity" (Stoddard, 1804, p. 189). Until this time, most of the ore in the district was dug from shallow diggings, usually only 10 ft deep or less (Winslow, 1894). A shaft was sunk to a depth of 80 ft in 1799 at Austin's Mines (fig. 7 and table 2) and a shot tower was erected about 1 mi northwest of Potosi (Hearthstone Legacy Publications, 2004; a shot tower is a tall structure from which molten lead was dropped into a pool of water, forming spheres of lead that were used as shot in firearms). Austin also established the port town of Herculaneum on the Mississippi River in 1809 (fig. 2) and built a shot tower there. Most of the lead produced in Potosi and surrounding areas was shipped over a newly built road to Herculaneum for shipment down the Mississippi River (Park, 2006).

Spain transferred ownership of the Louisiana Territory back to France in 1801, who shortly thereafter sold the Territory to the United States in 1803 as the Louisiana Purchase. This prompted Austin's 1804 report to Congress on the condition of mining in the area (Stoddard, 1804) in which four mines of the Southeast Missouri Barite District (Mine a Breton, Mine a Robina [referred to as Robuna in Stoddard, 1804], Old Mines, and Mine Renault; fig. 7 and table 2) and six mines of the Southeast Missouri Lead District are described. A leasing system was instituted by the U.S. Government in 1807 by which land was leased for as many as 3 years with a 10-percent royalty paid to the Government. This system was not welcomed by those with previously valid mining claims, and others ignored both property rights and government regulations, with the result that mine productivity lagged for several years (Park, 2006; Burford, 1978). Still, other mines in the Southeast Missouri Barite District were developed in the early part of the 19th century, including mines at Fourche a Courtois in southwestern Washington County (also known as the Palmer Mines or the Shirley-Palmer area); the French Diggings and La Beaume Mines at what would become known as the Richwoods Mines in northeastern Washington County; the Shibboleth Mines, Mine a Straddle, Bellefontaine Mines, Elliot's Mines, Cannon's Mines, and Mine a Martin in Washington County; Gray's Mines in Jefferson County; and others (Burford, 1978; Showalter, 1963; Winslow, 1894; fig. 7 and table 2).

In describing the state of the lead mines of the region (all of southeastern Missouri, but particularly Washington County) in 1819, Schoolcraft (1819, p. 21) stated that the mines were "worked in a more improved manner than at any former period," "are more extensive than when the country came into the hands of the United States," that "every season is adding to the number of mines," that "the ores may be considered of the richest kind," that "we cannot resist the belief that in riches and extent, the mines of Missouri are paralleled by no other mineral district of the world," and describes the region as "the land of ores—the country of minerals." He listed 39 lead mines in Washington County as of 1819, of which the most noted and extensive mines are Mine a Burton (Breton; apparently this includes Moses Austin's mines), Shibboleth Mines, La Beaume Mines (Richwoods Mines), Old Mines, Mine a Robina, Mine a Straddle, Mine Renault, New Diggings, Mine a Liberty, Cannon's Mines, Mine Silvers, and Mine a Martin (fig. 7 and table 2). Schoolcraft (1819) included the Palmer (Forche a Cortois) mines (fig. 7) in his list of 39 mines in Washington County, but did not include them in his list of the most noted and extensive mines in Washington County. There had been a rush to the Palmer area in 1814 and dozens of small lead mines were opened over a large area. Schoolcraft (1819) noted the presence of zinc ore and tiff (barite) in some of these 39 mines.

Winslow (1894) stated that lead production in the years from 1820 to 1830 was probably about the same as in the preceding years, with some increase in the latter part of the decade because of an increase in the import duty for lead. Deposits were discovered and mining was initiated at Sandy Mines in Jefferson County and at mines of the Valles Mines (Bisch's Mine, Perry's Mine, and the Valles Mines [proper]) in northern St. Francois County (fig. 7 and table 2; Winslow, 1894). The literature on the Valles Mines is unclear—the mining area is named after Francois Valle who came to the area in 1749 to buy lead from Native Americans, but it is unclear if any mines were operated at that time. Instead, Valle operated the Mine La Motte mines about 30 mi to the south (fig. 1). Although Litton (1855) and Winslow (1894) stated that the first mining at Valles Mines (probably meaning the Valles Mines [proper]) began in 1824, the Valles Mining Company records state that there was earlier mining followed by the sinking of a shaft in about 1819, that a major discovery of lead there and at the Mammoth Mine (fig. 7 and table 2) several miles to the northwest led to the sinking of other shafts, and that "Valles Mines became one of the most significant areas of lead production in the state, as well as one of the most long-lived" (State Historical Society of Missouri, 2013). Zinc became a valuable resource after the Civil War, and the Valles Mines became an important supplier of zinc as well as lead, with at least some production up until the 1920's. Other mines that began production in the 1820's are the McCormick Mines (McCormick's Diggings) and Nashville Mines in Jefferson County (Winslow, 1894; fig. 7 and table 2). The Palmer Mines had grown into an important mining area and by 1831 Palmer was a community of 200 miners (Winslow, 1894). Mining continued there into the early 1900's, including the mining of zinc ore in the latter years after the value of zinc had been realized.

The period from 1830 to 1850 was a period of increased lead production in the Southeast Missouri Barite District and elsewhere in southeastern Missouri, and saw the discovery of lead and initiation of lead mining in southwestern Missouri (Tri-State District) in 1848 (Winslow, 1894; Park, 2006; fig. 1). Winslow (1894) stated that new mines in Jefferson County include Howe's Diggings, Frissel's Mines, Tarpley Mines (of the Valles Mines), Lee's Diggings, and Mammoth Mines (the Valles Mining Company records place the initiation of mining at the Mammoth Mines several years earlier [State Historical Society of Missouri, 2013]; fig. 7 and table 2). Winslow (1894) also mentioned several other mines that were being worked during that period: Perry's Mine and Bisch's Mine, both of the Valles Mines, in St. Francois County; and Old Mines, Shibboleth Mines, the Casey and Clancey's Diggings, Shore's Diggings, La Beaume Mines, French Diggings (fig. 7 and table 2), and the Fourche a Courtois Mines (Palmer Mines) in Washington County (fig. 7).

During the period from 1850 to 1860 lead mining activity increased in the Tri-State District and continued in the southeastern part of the State (Winslow, 1894). The status of lead mining in Washington, Jefferson, and St. Francois Counties in the mid-1800's is provided by Litton (1855), who visited and described many, but not all, of the mines in the district, and by Swallow (1859), who compiled data from Litton (1855) and others. Litton (1855) and Swallow (1859) described the depths of shafts at some mines, apparently using the term shaft to include a range of depths, from shallow pits (diggings) a few feet deep to shafts in rock more than 100 ft deep.

Litton (1855) described the lead mining in Washington County to have been almost uninterrupted since it began and to have taken place throughout most of the county. He stated that it would not be possible to describe all of the mining up to that time, that Washington County "may be considered as one extensive lead diggings," and that "there is scarcely a township on which there has not been, at some period, more or less mining and, perhaps, scarcely a section on which mineral has not been actually found" (Litton, 1855, p. 41). He provided brief descriptions of a number of mines that he visited or for which he could obtain reliable information, and stated that it is was just a small list of the places where mining had taken place. Litton (1855) also gave some production figures. Most of the mines that he described are located on figure 7 and listed in table 2. The Old Mines concession (Old Mines) was one of the first mining areas in Missouri, dating back to the early 1700's. Mining was still active in 1854, with about 20 shafts as deep as 60 ft. The Shibboleth Mines, which had first been worked in the early 1800's, were still being worked in 1854 with shafts as deep as 50 ft over an area about 0.75 mi long northwest to southeast and about 0.25 mi wide. The Bellefontaine Mines, which also began in the early 1800's, were in an area of about 40 acres with shafts as deep as 75 ft, although most of the mining may have been in the residuum. The Cannon Mines, which also date back to the early 1800's, extended for about 1.5 mi north-south by about 0.75 mi east-west, with most of the ore coming from the residuum at depths up to 15 ft. The Scott and Bee Diggings covered about 160 acres, with shafts as deep as 65 ft. Litton (1855) stated that there was little mining being done at that time in the immediate vicinity of Potosi, but the Potosi Lead Company began a mining operation for a short time in 1853, consisting of an open cut and several shafts. Previous mining at Burt's Diggings west of Potosi (not on fig. 7 or listed in table 2) left an area covered with holes; a little mining was still being done in 1855 from two shafts in the rock, as much as 55 ft deep. A short distance southwest of Potosi was the Pierce and Willoughby's Diggings, on about 10 acres of Moses Austin's original land grant. Mining had taken place over the years and was being conducted in 1855 from a 110-ft-deep shaft. Mining at New Diggings, previously described by Schoolcraft (1819), was over an area of about 0.25 mi east-west by about 0.5 mi north-south and was still active in 1854. Lupton Diggings extended about a 0.5 mi north-south by about 150 yd wide, with the deepest shaft being 79 ft deep (fig. 7 and table 2). Adjacent to this was mining in the Sixteenth Section Mines, which consisted of 7 shafts an average of about 64 ft deep and with drifting up to 300 ft, described by Litton (1855) as more extensive than at most points in Washington County. Casey and Clancey's Diggings, which extended over an area about 0.5 mile east-west by a 0.25 mi north-south, previously had two shafts that were 90 ft deep, but mining was being conducted at shallower depths in 1855. To the east was Cook's Diggings, with shafts just 20 ft deep. The Brock Diggings, which covered about 10 acres and had not been worked since 1841, were in the residuum only. Shore's Diggings consisted of several shafts as deep as 100 ft, with drifts up to 160 ft long. The Prairie Diggings consisted of five or six shafts from 28 to 40 ft deep. Shafts of the Elliot's Mines were up to 60 ft deep, and at least some of the mining was in rock. Litton (1855) mentioned, but did not describe, that there were several mines along both sides of Forche a Renault Creek and that two sections were covered with shafts, but more precise locations are lacking.

Litton (1855) listed 23 mines of the Fourche a Courtois (Palmer) Mines over a large area in the southwestern part of Washington County (fig. 7) and provides descriptions of several of these: the Ismael Diggings (the most productive in recent years), the Pigeon Roost Diggings and Trash Diggings (also very productive), the Strawberry Diggings (on the same ridge as the Pigeon Roost and Trash Diggings), the Flint Hill Diggings and Bit Diggings (on the same ridge as each other), Bluff Diggings, Polecat Diggings, Coffee-Pot Diggings, Maury Diggings, and Grave-Yard Diggings (fig. 7 and table 2). The Palmer area in southwestern Washington County was an important mining area for a number of years, mentioned first by Schoolcraft (1819) and continued to be important for many more years. The MGS IMOP database lists about 180 lead, zinc, or lead and zinc past producers in the Palmer area (fig. 7), exceeding the 23 mines listed by Litton (1855). Dake (1930) presented a map showing the location of 94 lead diggings (these locations also are in the MGS IMOP database) and several barite mines in the Palmer area. Although there were as many as 200 miners in the Palmer area in 1831, there were only about 30 miners employed in 1855 (Litton, 1855). Mining was in the residuum and rock, and shafts were as deep as 146 ft (Winslow, 1894).

Litton (1855, p. 53) stated that lead mining had been active at the Richwoods Mines for the previous 40 years and that "the points at which mining has been carried on are very many." Included in this is the La Beaume Mines (fig. 7 and table 2), active since the early 1800's and covering an area of about 30 acres; mining was as deep as 80 ft, although most of the mining was from 6 to 20 ft deep. Also included in the Richwoods Mines is the French Diggings (fig. 7 and table 2), also dating back to the early 1800's. Litton (1855) stated that these mines had not been worked in recent years but had yielded abundantly from shallow diggings prior to 1843. Other diggings in the area are briefly mentioned. The mines described by Litton (1855) were listed, without description, by Swallow (1859).

Three mines were described by Litton (1855) as being the principal mines in Jefferson County: Sandy Mines, Mammoth Mine, and Tarpley Mines (of the Valles Mines) (fig. 7 and table 2). Mining at the Sandy Mines was along a line nearly 1 mi in length, first as diggings in the clay residuum and later in the rock. A cross section of the Sandy Mines in Litton (1855) shows several shafts, and the depth of mining was as great as 115 ft. The MGS IMOP database indicates that there were more than 100 shafts by 1863. This mine is an outlier with respect to most of the mines of the Southeast Missouri Barite District; it is in the Jefferson City or Cotter Dolomites or both (fig. 3), rather than the Potosi or Eminence Dolomites, which host most of the ore. Litton (1855) showed a cross section of the Mammoth Mine with a single shaft that is over 60 ft deep, and the length of the mining was given as more than 530 ft. Mining had been inactive there since 1852. The Mammoth Mine plots in the outcrop area of the Gasconade Dolomite and is therefore also in rocks younger than most Southeast Missouri Barite District ore deposits. The Tarpley Mines had several shafts, the deepest of which was 180 ft. Lead mining was more widespread in Jefferson County than is indicated by the three principal mines described by Litton (1855). The MGS IMOP database has many more lead mines, and Swallow (1859) listed 42 mostly previously worked mines in Jefferson County, including the three described by Litton (1855), and provided brief descriptions of 19 of these mines: the Gopher Mines, Mammoth Mine, Sandy Mines, Howe's Diggings, Yankee Diggings, McCormick's Diggings (different than nearby McCormack Diggings in St. Francois County), Lee's Diggings, Robinson's Diggings, Kelly's Diggings, Frissel's Mines, Nashville Mines, Gray's Mines, and the following mines of the Valles Mines: Poston and Tyler's Mines, Tarpley Mines, Garrity and Butcher's Diggings, Bisch and Daly Mines (different than the nearby Bisch's Mines in St. Francois County), Bogy's Diggings, Rocky Diggings, and Miller's Diggings (fig. 7 and table 2). In addition to these mines, Parizek (1949) included the Garatee Mines and the Corn Stalk Diggings in Jefferson County as part of the Valles Mines (fig. 7 and table 2). Winslow (1894) also described the Garatee Mines.

The principal mines in St. Francois County described by Litton (1855) are mines of the Valles Mines: the Valles Mines (proper), Perry's Mine, Bisch's Mines, and the McCormack Diggings (fig. 7 and table 2). The Valles Mines (proper), Perry's Mine, and Bisch's Mines were on contiguous properties in northern St. Francois County, apparently mining the same deposit on about 50 acres. There were at least 30 shafts at these 3 mines by 1855, the deepest of which was 170 ft. Litton (1855, p. 34) described the Valles Mine (proper) and Perry's Mine as "more generally known than any other lead mines in Missouri; known, not only on account of the length of time during which mining has been carried on, but also by the large amount of ore which has been obtained." The McCormack Diggings (different than McCormick's Diggings in Jefferson County) consisted of 65-ft- and 85-ft-deep shafts in 1855.

Referring to Missouri in general, Litton (1855) stated that zinc is found with lead, particularly at Perry's Mine, and that zinc is the most abundant ore metal at many localities. The potential for zinc had not yet been fully realized, although Litton (1855) speculated that the use of zinc oxide as a paint pigment and other emerging uses of zinc could create greater demand for the metal.

The lead mines in southeastern Missouri continued to operate during the Civil War, though at reduced production. Winslow (1894) specifically mentioned the Valles Mines (proper) in St. Francois County and the Darby Mines in Jefferson County as having continued to operate during this period, along with some other mines. The state of lead mining in the Southeast Missouri Barite District for the next 30 or 40 years is uncertain. Showalter (1963) stated that surface lead deposits in Washington County ran out at the close of the Civil War and that lead mining and smelting declined as the barite industry began to develop. Buckley (1908) stated the production in Washington County decreased from 1869 to 1906. Winslow (1894, p. 677), however, referring to the "Washington-Jefferson County Sub-District" in which he includes northern St. Francois County and Crawford County, stated that lead production had been "uniformly large for the past hundred years, and is maintained up to the present time." Although production may not have diminished during the post-Civil War years, the importance of the Southeast Missouri Barite District did diminish because of increased production from other districts in Missouri. The organization of the St. Joseph Lead Company in 1864 and the introduction of the diamond drill in 1869 led to the discovery and large-scale mining of buried lead and zinc deposits of the Southeast Missouri Lead District. Also, large-scale mining in the Tri-State District in southwestern Missouri, northeastern Oklahoma, and southeastern Kansas began in the 1870's (small scale mining had been active for about 20 years) as the use of zinc expanded (Tri-State was a zinc-dominant district rather than a lead-dominant district). Winslow (1894) provided little information about mines of the Southeast Missouri Barite District and the Valles Mines that operated during the last 20 or 30 years of the 19th century, but does mention the Perry's Mine and the Valles Mines (proper) in St. Francois County (which produced much zinc), the Frumet Mines in Jefferson County (fig. 7 and table 2), and the McArthur Mines (not shown on fig. 7 or listed in table 2), which Winslow (1894) described as an area of 10,000 acres that includes Mine a Breton and other mines in the Potosi area. The Tenth Census in 1880 (Winslow, 1894) showed 14 mines in Washington County, 4 in Jefferson County, and 3 in St. Francois County (this includes the St. Joseph Lead Company Bonne Terre Mine of the Old Lead Belt of the Southeast Missouri Lead District). Dake (1930) stated that the maximum production of the Palmer Mines was in 1873.

Lead mining in the Southeast Missouri Barite District declined in the early part of the 20th century as mining in the Old Lead Belt, Mine La Motte, and the Tri-State District expanded. Dake (1930) stated that the last important operations at Old Mines were during about 1901–2, and that shallow lead was picked up occasionally. Kiilsgaard and others (1967) stated that a few carloads of zinc carbonate ore were shipped from the Palmer area in 1915 and 1916, but that no lead mines in the Potosi-Palmer area had been productive in prior decades. Dake (1930) stated that there was no systematic lead production from the Palmer Mines during his field work in 1922–28. The Valles Mines operated into the early part of the 20th century. Kiilsgaard and others (1967) stated that the Valles Mines were most active in the late 1800's and 1909–17 and, except for some mine dump material that was shipped during World War II, the area had been inactive since 1917; however, Park (2006) stated that zinc was intermittently mined until 1948. There was some production from the Krueger Mine (fig. 7 and table 2) in 1917, where lead had been previously mined at shallow depths (Ballinger, 1948). A shaft was sunk to 112 ft, some drifting was performed at this depth, and about 100 tons of lead ore was shipped. Exploration drilling for zinc was conducted at that time and again in 1930 and 1947, but no additional ore was mined. Dake (1930) described several mines that were inactive: two Smith Diggings (two mines with the same name), Heffner Diggings, Grainger Diggings, Gulf Prospect, Masson Diggings, Benning's Diggings, N. Wool Diggings, Forker Diggings, Furnace Creek Diggings, and Plaffy Diggings (fig. 7 and table 2). Lead was recovered from some barite diggings and, apparently, the practice of digging for lead also continued, at least to some extent. In describing the lead mines of Washington County, Ball (1916, p. 807) stated that "mining methods of a century ago prevail" and that although many miners had left Washington County to work in the large underground mines in the Southeast Missouri Lead District in St. Francois County, others did not leave, preferring to work for themselves in the diggings.

In an attempt to supply lead and zinc for the war effort during World War II, mine waste was transported to what was called the Chat Pile at Valles Mines for processing (Valles Mines, Missouri USA, 2015). This washer operation was not very successful, and fine-grained lead, zinc (in the form of smithsonite), and barite were washed with the clay waste into a stream. Later, the feasibility of processing old mine dumps in the Valle Mines area for lead, zinc, and barite was evaluated (Weigel, 1977). The estimated ore grades were 1–2 percent galena, trace to 0.5 percent anglesite, trace to 0.5 percent cerussite, 5–8 percent smithsonite, trace to 1 percent sphalerite, and 10–15 percent barite.

There is little information in the literature on the Irondale Subdistrict of the Southeast Missouri Lead District in southeastern Washington County (fig. 2). The MGS IMOP database shows two underground lead mines—the Irondale Mine and the Eversole Mine (fig. 7 and table 2). The ore deposits were small concentrations of sulfides around igneous knobs (Snyder and Gerdemann, 1968), and the period of underground mining in the subdistrict may have been brief. Buckley (1908) showed production by the Irondale Lead Company only for 1902. Surface mining probably preceded underground mining, which was the pattern in the Old Lead Belt and Mine La Motte Subdistricts of the Southeast Missouri Lead District where, beginning in 1869, diamond core drilling showed that the surficial deposits extended to greater depths.

Exploration by the St. Joseph Lead Company to replace depleting lead reserves in the Old Lead Belt resulted in the discovery in 1948 of the Indian Creek Subdistrict of the Southeast Missouri Lead District in Washington County (figs. 1 and 2). The Indian Creek Subdistrict consists of two underground mines where ore in the lower Bonneterre Formation and upper Lamotte Sandstone was mined: the Indian Creek Mine and the nearby Goose Creek Mine (fig. 7 and table 2). The mines, which were accessed from a 950-ft-deep shaft, were operated from 1953 to 1982 (Hagni, 1995; Kiilsgaard and others, 1967) and were collectively called the Indian Creek Mine.

Continued exploration resulted in the discovery of the Viburnum Trend Subdistrict of the Southeast Missouri Lead District. Several mines were developed, including the Viburnum No. 29 Mine (fig. 7 and table 2), which is the northernmost mine of the Viburnum Trend and is in southwestern Washington County. Mine production began in 1964 from a 595-ft-deep shaft (Kiilsgaard and others, 1967).

Lead Mining, Processing, and Smelting Methods

In the earliest days of mining, lead ore was simply removed from the soil surface. In his 1804 report to the U.S. Congress describing lead mines in Upper Louisiana, Moses Austin stated that ore was present within 2 ft of the surface at Mine a Breton, and "In short, the country for twelve or fifteen miles round the Mine a Burton exhibits strong appearances of mineral. In all the small creeks mineral is found washed down from the hills, and it is not uncommon to find in the draughts leading to creeks and rivers, and in the gulleys made by the spring rains, mineral in pieces from ten to fifty pounds weight brought down by the torrents. Some hundreds have been collected in this way" (Stoddard, 1804, p. 190). Ball (1916) described these as galena pebbles which, along with blossom rock (drusy quartz), were used as prospecting guides to upstream sources.

Lead mining in the Southeast Missouri Barite District and the Valles Mines was primitive by modern standards, and production from individual mines was small compared to future production from underground mines of the Old Lead Belt and Viburnum Trend. Still, lead mining was widespread and extended from the early 18th century into the early 20th century (Ball, 1916). Mines were commonly seasonal, active when men were not farming. Others mines, particularly the later, larger, and deeper operations, employed a larger number of men and probably operated continuously. Slaves were used in some mines before the Civil War.

The earliest lead mines were diggings (also called pits or shafts) in the residual soil and were normally 15–20 ft deep (Schoolcraft, 1819). Round holes about 4 ft in diameter were dug with pick and shovel, and a hand windlass and bucket were used to hoist material to the surface. Two men normally worked a digging, one in the shaft and the other at the surface hoisting the ore and separating the ore minerals from clay and other gangue. Some of the deeper shafts employed a horse whim or a steam-powered windlass to hoist the ore to the surface (Ball, 1916). The shafts were normally dug to bedrock where the ore commonly was concentrated, and drifts about 4 ft by 4 ft were dug a short distance laterally from the bottom of the shafts, undermining the residuum. When it became too dangerous to drift any farther, the shaft was abandoned and the process was repeated a short distance away, until a large area was covered with pits (Ball, 1916). Not all shafts were productive; sometimes prospect shafts were dug following a fissure or some other surficial feature that might indicate ore at depth (Ball, 1916). Pumps were uncommon for many years, so work normally stopped if groundwater was encountered. Although there were sometimes indications that the ore continued into the bedrock, mining normally stopped at the bedrock surface and a new shaft was started. Digging with pick and shovel was apparently practiced into the early 20th century, as this method was described in the present tense by Ball (1916).

The first shaft that resembled a modern shaft was dug reportedly to 80 ft at Mine a Breton by Moses Austin in 1799 (Winslow, 1894; fig. 7 and table 2). Schoolcraft (1819) stated that the ore was in crevices in rock, which he described as both compact and locally friable (weathered). Thompson (1955) maintained that Austin's shaft went only to about 40 ft depth and stopped at bedrock, although the mining did follow deeper ore in crevices or soft rock. Winslow (1894, p. 284) mentioned that "deep shafting was undertaken" in Missouri during the period from 1830 to 1850. From Litton's (1855) descriptions of some mines, with shafts as deep as 170 ft (Valles Mines) and up to several hundred feet of lateral drifting, mining had progressed into the rock by that time. Litton (1855) estimated that three-fourths of the mineral mined in Missouri up to that time had come from diggings in the residuum, inferring that the balance had come from mining in rock. Although there were many diggings at Potosi, more mining had been done in rock during later years, with shafts 100 ft or more deep (Winslow, 1894). The Jumbo shaft at the Parole Mine (fig. 7 and table 2) of the Palmer Mines was 146 ft deep (Winslow, 1894). The depths of many other shafts that were deep enough to have gone into bedrock and descriptions of lateral drifting are given by Litton (1855) and Winslow (1894).

The material brought to the surface consisted of lead ore, which was mostly galena, with lesser cerussite and anglesite mixed with clay, dolomite, druzy quartz, zinc minerals, and barite. Galena was cleaned by cobbing with a hammer to remove clay and other gangue prior to smelting. Waste, which included cerussite, anglesite, zinc ore, and barite, was discarded in dumps until the value of these minerals increased sufficiently to warrant recovery. Winslow (1894) reported that cerussite was first recovered in 1838. Jigs also were used to concentrate or clean the ore of waste material. Winslow (1894) stated that crude hand jigs were universally used by the 1860's and were still common as of 1894 but provides no further details such as when they were first used or how efficient they were. Park (2006) also described the use of hand jigs and the Parson's mechanical jig, which was introduced later and was used at least at Old Lead Belt mines. The IMOP database (Missouri Department of Natural Resources, 2015a) mentions five locations where there were mills, two of which were called Joplin-type mills (fig. 8).

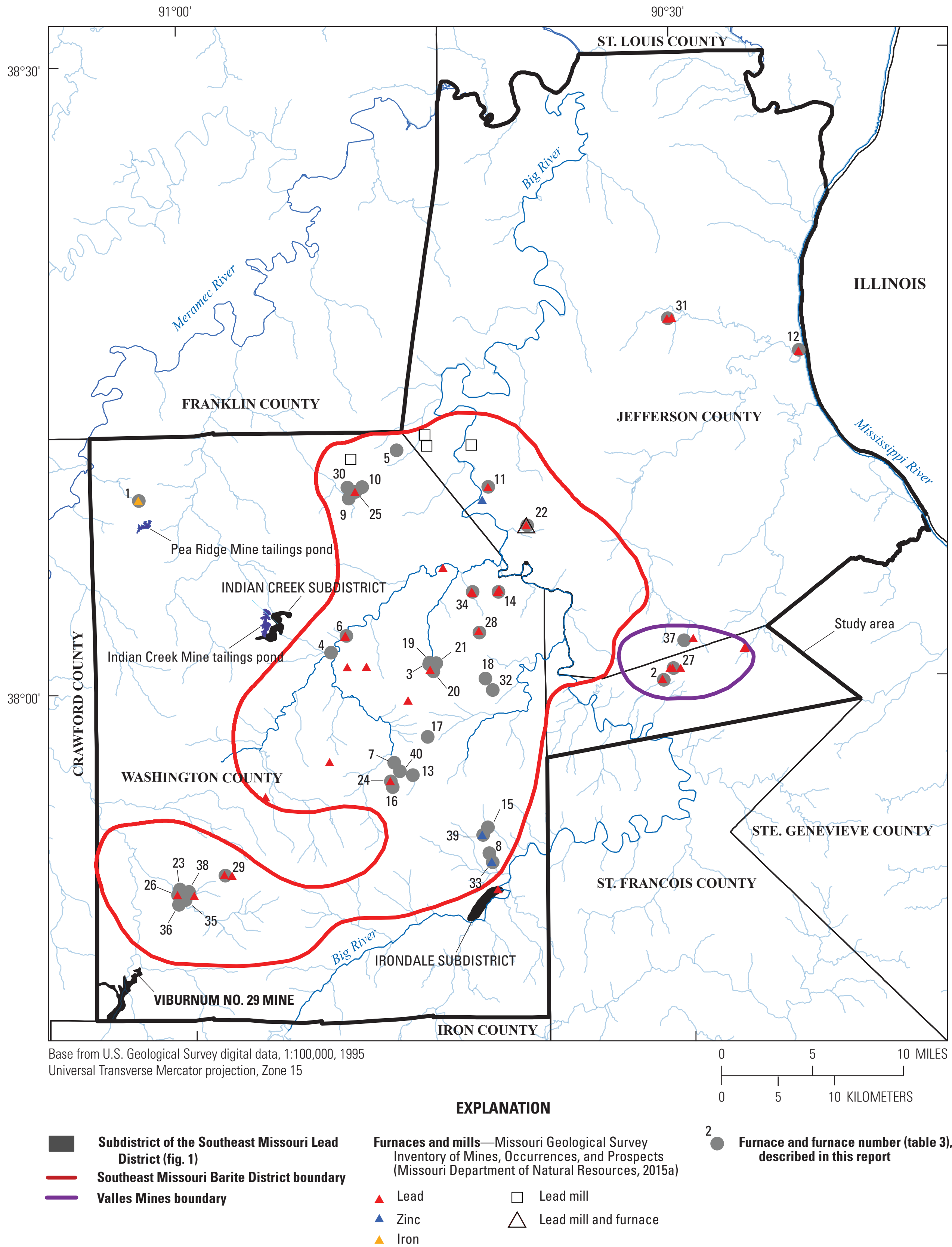


Figure 8. Locations of lead furnaces, zinc furnaces, and lead mills of the Southeast Missouri Barite District and Valles Mines, and locations in the study area of the Indian Creek Subdistrict and tailings pond, Irondale Subdistrict, and Viburnum No. 29 Mine in the Viburnum Trend Subdistrict in the Southeast Missouri Lead District and the Pea Ridge Iron Mine tailings pond.

Smelting of the lead ore to elemental lead was first done using a log hearth, also called a log furnace, which was described by Schoolcraft (1819) and Winslow (1894) and is shown in figure 9. The log furnace was an inclined hearth on a sloped hill with stone walls on the front and the sides. Logs were placed in the furnace, a charge of lead ore consisting of about 5,000 lb of galena in pieces averaging 15 lb in weight was placed on the logs, more logs were placed over the ore, and a fire was started. The ore was roasted at a low temperature for several hours to remove the sulfur by oxidizing the galena to lead oxide, and then the temperature was raised for several hours to reduce the lead oxide to elemental lead in a molten state. The molten lead fell through the wood and ashes to a groove in the floor of the hearth, through which it flowed downslope to an iron mold where the lead was formed into pigs. The entire process took 24 hours or more. After smelting the ore, the furnace was cooled, the ashes removed, and the furnace was charged again. A log furnace was inexpensive to build and could be built almost anywhere; this was the only type of furnace used until 1798 (Winslow, 1894). Log furnaces do not seem to have been permanent structures like the Scotch hearths and air furnaces that would later be built, so they were probably built wherever there was mining and replaced as they wore out. For this reason, and the fact that these were used during the early years of mining when records generally were not kept, the numbers and locations of these furnaces are not known and a map showing the locations of these furnaces is not given in this report. Considering that mining locations were widespread and that mining had been ongoing since about 1720, there probably were many log furnaces in the Southeast Missouri Barite District and the Valles Mines.

Log furnaces were inefficient. Robertson (1894b, p. 199) described them as an "improved form of campfire" and estimated that only about 50 percent of the lead was recovered and the remainder was lost to the ashes (slags) and to volatilization. Given that galena is about 87 percent lead (table 1), that equates to about 43 lb of lead recovered per 100 lb of galena smelted. Using percentage recovery in a different way, Park (2006) stated that recovery was 35 percent, which means that 35 lb of lead was recovered per 100 lb of galena ore. Ingalls (1908) estimates that the grade of ore fed to the log furnaces was about 80 percent lead, or 1,600 lb of lead per ton of ore, and that the yield of the log furnace was only 700 to 800 lb of lead (less than 50 percent).

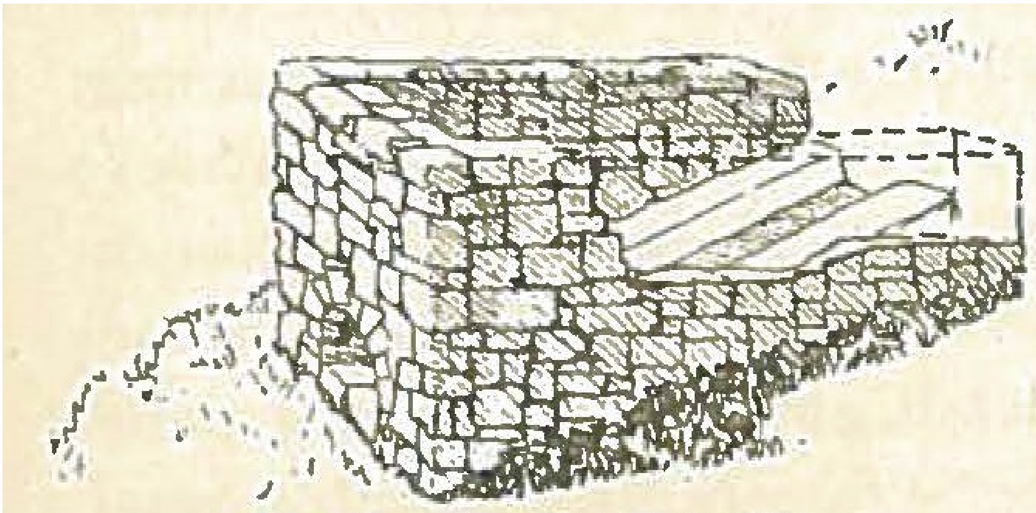
About 20 log furnaces were in operation near Potosi when Moses Austin arrived in 1798 (Burford, 1978). Austin was attracted to the area not only because of the richness of the ore but also because of the abundance of ashes from the log furnaces that the French had been using, which contained lead and could be smelted for a profit. Austin built two more-efficient reverbatory furnaces, one for smelting primary ore and the other for smelting ashes (called an ash furnace; Park, 2006; fig. 9). The ashes from the log furnace, which contained lead already in an oxidized form, were crushed, washed, and placed in layers alternating with crushed sand or chert (Robertson, 1894a). A wood fire was started, and after about 2 hours the slag was tapped and the molten lead was recovered, which was about 15 percent of the original concentration of the ore (Schoolcraft, 1819), bringing the recovery up to about 65 percent (65 lb of lead per 100 lb of galena; Park, 2006). An ash furnace thus supplemented the log furnace (Ingalls, 1908) and could be operated continuously for about 15 to 20 days, but wore out rapidly and needed to be rebuilt. By 1802 all but one of the log furnaces at Potosi had been closed, and Austin was smelting almost all the ore produced in the area. Just how much of the ashes were processed by Austin is unknown because one of his partners may have removed much of the ash prior to Austin's arrival (Park, 2006).

Log furnaces and ash furnaces, sometimes collectively termed a log and ash furnace when they worked in tandem, were used in Missouri for many years but were gradually replaced by other furnaces. The locations of most of the later furnaces described in this report are shown in figure 8, but many locations are imprecise. The furnaces identified by number in figure 8 are listed in table 3, which shows principal references. Furnaces in the IMOP database are also shown on figure 8; many of these correspond to furnaces described in this report and are identified by number in figure 8 and listed in table 3.

Litton (1855) stated that the log and ash furnaces were replaced by the Scotch hearth or by the reverbatory furnace; Robertson (1894a) classified the ash furnace as a type of reverbatory furnace, and Garlichs (1918) called the ash furnace a crude type of reverbatory furnace, so Litton (1855) may have been referring to the ash furnace being replaced by another type of reverbatory furnace such as an air furnace. Without stating the type of furnace, Park (2006) stated that there were 38 lead furnaces in Washington County in 1819. The Scotch hearth may have been in use in Washington County before 1819, but the first known Scotch hearth in Missouri was Manning's furnace at Webster (the name of this town was later changed to Palmer), which was built in 1836 (fig. 8 and table 3). Three log and ash furnaces operated at Webster previous to 1837 (Litton, 1855; Ingalls, 1908). Litton (1855) stated that there was only one log and ash furnace in southeastern Missouri in 1855 (Higginbotham's Furnace; fig. 8 and table 3), although Robertson (1894b) reported that a log and ash furnace was still in use at Cadet in Washington County in 1864 (fig. 2).

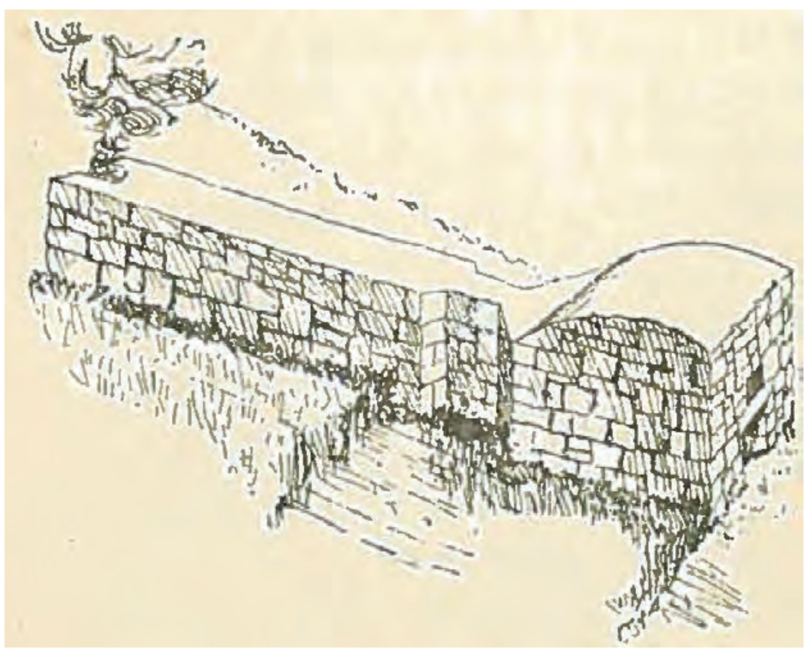
The Scotch hearth, more properly called the American-Scotch hearth (Ingalls, 1908) and sometimes called a blast furnace, used a blast of hot air, which was powered either by water, steam, or horse power (Litton, 1855). The roasting and reduction of the ore was simultaneous rather than in two steps, as with the log furnace (Robertson, 1894a). Robertson (1894a) estimated that the recovery of lead by a Scotch hearth was 80–90 percent with 10–20 percent loss to slag and volatilization, but Winslow (1894) quoted estimates of 67- and 70-percent recovery. Ingalls (1908) stated that the Scotch hearth did not immediately replace the log and ash furnace and suggested that the reason is that they did not provide a large advantage. Slag was at least sometimes re-smelted in a slag furnace. This type of furnace is not described; it may have been a Scotch hearth (or later, an air furnace) that was dedicated to smelting slag.

A. **Log furnace**



Robertson, Missouri Geological Survey, (1894a)

B. **Ash furnace**



Robertson, Missouri Geological Survey, (1894a)

Figure 9. Log and ash furnaces.

Table 3. Furnace name, commodity smelted, type of furnace, and furnace references (described or mentioned in this report).

[Furnace references are for furnace information or location; most furnaces are only approximately located; unless noted, log and ash furnaces are not shown; iron furnaces not shown unless lead also was smelted; IMOP, Inventory of Mines, Occurrences, and Prospects (Missouri Department of Natural Resources, 2015a)]

Furnace number (fig. 8)	Furnace name	Resource smelted	Type of furnace	Furnace reference
1	Abbyville Mining Company Furnace	Iron, Lead	Unspecified	Robertson (1894b); IMOP
2	Bisch's Mine Furnace	Lead	Scotch hearth ?	Park (2006); Litton (1855); Winslow (1894); IMOP
3	C. White's Furnace	Lead	Scotch hearth	Litton (1855)
4	Casey and Clasey's Furnace	Lead	Scotch hearth	Litton (1855); IMOP
5	Charles Moran Furnace	Lead	Air furnace	Robertson (1894b)
6	Cresswell's Furnace	Lead	Scotch hearth	Litton (1855); Park (2006); IMOP
7	Deane's Furnace	Lead	Scotch hearth	Litton (1855)
8	Deggendorf Zinc Works	Zinc	Unspecified	Winslow (1894)
9	Edmonds and Wilcox Furnace and Mill	Unspecified	Unspecified	Park (2006)
10	Flynn's Furnace	Lead	Air furnace	Robertson (1894b)
11	Frumet Mine Furnace	Lead	Flintshire furnace	Robertson (1894b)
12	Herculaneum Smelter	Lead	Unspecified	Park (2006)
13	Hesselmeyer Furnace	Zinc	Unspecified	Ingalls (1908); Winslow (1894)
14	Higgenbotham's Furnace	Lead	Log furnace/Scotch hearth/Air furnace	Litton (1855); Robertson (1894b); Park (2006); IMOP
15	Hopewell Furnace	Lead	Scotch hearth	Litton (1855); Park (2006);
16	J.P. and R.M. Bugg Furnace	Lead	Scotch hearth	Robertson (1894b); IMOP
17	James Long Furnace	Lead (and zinc?)	Air furnace	Robertson (1894b)
18	Kennett's Furnace	Lead	Scotch hearth (probably)	Litton (1855); Park (2006)
19	L.J. White Furnace	Lead	Air furnace	Robertson (1894b)
20	Long's Furnace	Lead	Scotch hearth	Litton (1855)
21	M. and S. Union Company Furnace	Lead	Air furnace	Robertson (1894b)
22	Mammoth Mines Furnace	Lead	Scotch hearth	Litton (1855); IMOP
23	Manning's Furnace	Lead	Scotch hearth	Litton (1855); Park (2006)
24	McIlvaine's (Dunklin) Furnace	Lead	Scotch hearth	Litton (1855); IMOP
25	P.E. Blow Furnace	Lead	Scotch hearth	Litton (1855)
26	Palmer Lead Company Furnace	Lead	Air furnace	Robertson (1894b); Park (2006); IMOP
27	Perry's Mine Furnace	Lead	Scotch hearth	Park (2006); Litton (1855); Winslow (1894); IMOP
28	Prairie Diggings Furnace	Lead	Unspecified	IMOP
29	Renault Lead Company Furnace	Lead	Unspecified	Park (2006); IMOP
30	Roussin Furnace	Lead	Scotch hearth	Litton (1855)
31	Sandy Mines Furnace	Lead	Scotch hearth	Litton (1855)
32	Shibboleth Lead Company Furnace	Lead	Air furnace	Robertson (1894b)
33	Smith Furnace	Zinc	Unspecified	IMOP
34	T & W Murphey's Furnace	Lead	Scotch hearth	Litton (1855); Park (2006); IMOP
35	Unknown	Lead	Air furnace	Park (2006)
36	Unknown	Lead	Air furnace	Park (2006)
37	Valles Mines Furnace	Lead	Scotch hearth	Valles Mines, Missouri, USA (2014); Missouri Department of Health and Senior Services (2005); Litton (1855); Robertson (1894b); Park (2006)
38	Walton's Furnace	Lead	Scotch hearth (probably)	Litton (1855); Park (2006)
39	Washington County Zinc Works	Zinc	Sorting plant for Hopewell Furnace	IMOP
40	Willian Long Furnace	Lead	Air furnace	Robertson (1894b)

Litton (1855) listed 3 furnaces in Jefferson County, 2 furnaces in St. Francois County, and 14 furnaces in Washington County that were operating in 1855. Most were specified as Scotch hearths, one a log and ash furnace, and a few were unspecified, but most of these likely were Scotch hearths. The furnaces in Jefferson County were a Scotch hearth and slag furnace that smelted ore from the Valles Mines (proper?) in nearby St. Francois County (Litton [1855] did not give a precise location of the furnace; Valles Mines, Missouri, USA, 2014; Missouri Department of Health and Senior Services, 2005; Robertson, 1894b), a Scotch hearth at the Mammoth Mine, and a furnace (probably a Scotch hearth) at the Sandy Mines (fig. 8 and table 3). The furnaces in St. Fancois County were the Perry's Mine Furnace (a Scotch hearth) and the Bisch's Mine Furnace (Litton [1855] stated that this was a reverbatory furnace, which could mean an ash furnace or an early air furnace; Park [2006] stated that this was a Scotch hearth; fig. 8 and table 3). These two plus the Valles Mines (proper?) furnace in Jefferson County make three furnaces at the Valles Mines. The furnaces in Washington County (located approximately on fig. 8 and listed in table 3) were Higginbotham's Furnace at Fertile (Litton [1855] and Park [2006] stated that this was a log and ash furnace, and Park [2006] also stated that a Scotch hearth was built there in 1837); T&W Murphey's Furnace, a Scotch hearth; Long's Furnace at Old Mines, a Scotch hearth; C. White's Furnace at Old Mines, a double Scotch hearth; McIlvaine's Furnace (previously known as Dunkiln's furnace), a Scotch hearth; Deane's Furnace near of Potosi, a Scotch hearth; Kennett's Furnace at Shibboleth (probably a Scotch hearth but this could have been the log and ash furnace that Robertson [1894b] stated was operating at nearby Cadet in 1864); Boase's Furnace on Mill Creek (not located on fig. 8 because of the unspecific location, and not listed in table 3), a Scotch hearth which replaced an earlier furnace; Hopewell Furnace, also known as Evan's Furnace (Park, 2006), a Scotch hearth and slag furnace; Manning's Furnace, a Scotch hearth at Webster (Palmer) that smelted ore from Fourche a Courtois (Palmer) mines beginning in 1837; Walton's Furnace, unspecified but probably a Scotch hearth, which smelted ore and slag from the Fourche a Courtois (Palmer) mines beginning in 1841; Cresswell's Furnace, a Scotch hearth; Casey and Clancey's Furnace, a Scotch hearth; and two furnaces at Richwoods, both probably Scotch hearths—one operated at that time by Mr. P.E. Blow, and one formerly belonging to Mr. Roussin (unclear if it was still operating in 1855). Annual production statistics dating back a few years to as far back as 1837 were given for most of the furnaces Litton (1855) listed, and further descriptions of these furnaces indicate that smelting had been active at some of these locations for a longer period (for example, one furnace had been active since 1819). The descriptions of the furnaces listed several mines that supplied ore to each furnace, indicating that these were larger and more permanent structures than the earlier log and ash furnaces. Litton (1855) stated that log and ash furnaces previously had been used at the location of one of the Scotch hearth furnaces; log and ash furnaces may have been used earlier at two other locations where smelting is recorded as having been active before 1836, which is the first year the Scotch furnace is known to have been used in Washington County. Although Litton (1855) described the location of Walton's Furnace only by saying that ore from Forche a Cortois Mines (a large area) was smelted, Park (2006) implied that it was near Manning's Furnace, and Robertson (1894b) listed two probable Scotch hearths at Webster (Palmer).

At least three types of reverbatory furnaces were used in Missouri: the previously described ash furnace; the Drummond furnace, also called the air furnace (Robertson, 1894b); and the Flintshire furnace, which was described by Ingalls (1908) as a more developed form of reverbatory furnace. The ore charge and fuel are not in contact in a reverbatory furnace, and a blast of air is not required. The ore is smelted by the heat that reflects, or reverberates, off the walls of the furnace. The reverbatory furnace ran continuously rather than intermittently, as was the case of the Scotch hearth, was more economical, and produced more lead than the Scotch hearth (Park, 2006), although the recovery of lead by an air furnace was estimated by Robertson (1894a) and Ingalls (1908) to have been 80–90 percent, similar to that of the Scotch hearth. Winslow (1894) quoted an estimate of 63 percent. Although the amount of slag produced was small (Robertson, 1894a), Ingalls (1908) estimated that the slag, which was generally thrown away, contained from 40 to 55 percent lead; Robertson (1894a) stated that the loss of lead to the slag and by volatilization was 10 to 20 percent.

The Scotch hearths were replaced by (or converted to) air furnaces in Missouri starting about 1874 (Park, 2006), although Litton's (1855) mention of a reverbatory furnace at Bisch's Mine may indicate that this was an early air furnace. Robertson (1894b) stated that there were two Scotch hearths and a slag furnace at the Valles Mines (for the Valles Mines [proper]?) at that time, indicating that some Scotch hearths were still operating in 1894. Several air furnaces were in operation in Missouri by 1876, particularly in central Missouri (Robertson, 1894b), but apparently not yet in Washington County. Without giving locations, Winslow (1894) quoted an estimate of no air furnaces and two Scotch hearths operating in Washington County in 1876, one air furnace and two Scotch hearths in Jefferson County in 1876, and nine air furnaces and zero Scotch hearths in St. Francois County in 1876 (it is unclear if any of the air furnaces in St. Francois County were at the Valles Mines). Robertson (1894b) listed, with only approximate locations, eight air furnaces operating in 1894 in Washington County and one in St Francois County (with no specific location information, it is unclear if this furnace was at the Valles Mines). The air furnaces in Washington County were Higgenbotham's Furnace at Fertile, which replaced a previous furnace at that location; James Long Furnace at Potosi; William Long Furnace at Potosi; Charles Moran Furnace at Richwoods; Palmer Lead Company Furnace (the Palmer furnace, or Hazel Creek Furnace; Park [2006]) at Palmer; Shibboleth Lead Company Furnace at Cadet; M. and S. Union Company Furnace at Old Mines; and L.J. White

Furnace at Old Mines (fig. 8 and table 3). These eight furnaces are located only approximately on figure 8 using information from Robertson (1894b).

In addition to the mostly Scotch hearth furnaces listed by Litton (1855) and the air furnaces listed by Robertson (1894b), a few other furnaces are mentioned in various sources. Some of these sources provide good location data, others are ambiguous, and a few furnace locations in the IMOP database (Missouri Department of Natural Resources, 2015a) are at different locations than what was given in cited references or were not found in references. Winslow (1894) and Litton (1855) stated that furnaces were operated by George Cresswell beginning in 1828 at two other locations prior to his construction of a Scotch hearth on Mineral Fork in 1838 (Cresswell's Furnace; fig. 8 and table 3); the locations of these two other locations were not given accurately enough to show on figure 8, but given the early period of operation, these early furnaces were probably log and ash furnaces. Robertson (1894b) provided a cumulative lead production figure through early 1874 for two furnaces at or near Webster (Palmer). Given that air furnaces were probably not being operated in Washington County until 1876, these may be Scotch hearths at Manning's Furnace, and Walton's Furnace (Litton, 1855; fig. 8 and table 3). Park (2006) stated that three air furnaces were operating at Palmer by 1887. One of these likely is the Palmer Lead Company Furnace listed by Robertson (1894b), the location of which is well established (fig. 8 and table 3); the locations of the other two are not known and are shown on figure 8 and listed in table 3 as having unknown furnace names near the town of Palmer. Robertson (1894b) provided some late 1870's lead production figures for Flynn's Furnace at Richwoods, an air furnace (fig. 8 and table 3). Robertson (1894b) mentioned and provided a late 1870's lead-production figure for a Scotch hearth owned by J.P. and R.M. Bugg at Potosi (fig. 8 and table 3). Winslow (1894) provided data for a small amount of cumulative lead production from 1872 to 1891 from the Abbyville Mining Company Furnace in northwestern Washington County (fig. 8 and table 3; the IMOP database shows this as primarily an iron furnace but the type of furnace is unspecified). Winslow (1894) also provided data for a small amount of cumulative lead production from 1872 to 1891 from the Kingston Furnace in Washington County but did not describe the type of furnace or its location (because the IMOP database shows two furnaces called the Kingston Furnace at different locations, this furnace is not shown in figure 8 or listed in table 3). Park (2006) mentioned and located on a map the Edmonds and Wilcox Furnace and Mill near Richwoods (fig. 8 and table 3), but it is not clear if this was a lead furnace, and no dates of operation are given. Park (2006) mentioned a Cannon Creek Mine Furnace but provided no other information except that it may be the same as Murphey's Furnace (probably T & W Murphey's Furnace; fig. 8 and table 3). A Flintshire furnace was operated for several years at the Frumet Mine in Jefferson County beginning in 1870 (Robertson, 1894b; fig. 8 and table 3). The IMOP database lists a furnace at the Prairie Diggings (fig. 8 and table 3), but the type of furnace is not given. The IMOP database lists a furnace of the Renault Lead Company and locates it about 3 mi northeast of the Palmer Lead Company furnace (fig. 8 and table 3). The only other available reference to this company is Park (2006) who stated that the company operated in the Palmer area from 1898 until about 1907 but did not mention a furnace. The IMOP database also lists another possible furnace near the Renault Lead Company Furnace. The IMOP database shows a log furnace at Gray's Mines (fig. 7 and table 2) and what is probably a log furnace at Forche a Renault Mine (Mine Renault).

Winslow (1894) is the most recent report that discussed lead mining in the Southeast Missouri Barite District and the Valles Mines in a comprehensive manner, and information regarding the smelting of lead ores since then is not available. Air furnaces were being used in 1894, but it is not known if any other type of furnace was used in the district later. Winslow (1894) described the Cupola, or stack furnace, which Ingalls (1908) described as a blast furnace, but no mention is made of its use in the Southeast Missouri Barite District or at the Valles Mines. The Cupola furnace, which required large and constant supplies of ore and could smelt lower grade ore economically (Robertson, 1894a), was used to smelt ore from Mine La Motte and the Old Lead Belt. Beginning in 1892, a large lead smelter operated for more than 100 years at Herculaneum, Jefferson County (fig. 8 and table 3), smelting lead concentrate from the Old Lead Belt, Mine La Motte, and later, the Viburnum Trend Subdistricts of the Southeast Missouri Lead District.

The first zinc furnace in Missouri was the Hesselmeyer furnace built in Potosi in 1867 to smelt ore from the Valles Mines (Winslow, 1894; Ingalls, 1908; Park, 2006; fig. 8 and table 3). Zinc was more profitable than lead at the Valles Mines, but the furnace did not operate for very long (Ingalls, 1908). Much of the zinc ore was shipped out of the area, either to a smelter in St. Louis (Park, 2006; Winslow, 1894) or to other smelters; Robertson (1894b) listed several in Illinois, southwestern Missouri, and Kansas. Processing of zinc to zinc white (a paint pigment) was done at the Hopewell Furnace (fig. 8 and table 3), Washington County, beginning in the mid-1870's, where lead was already being smelted in a Scotch hearth (Winslow, 1894). The IMOP database shows a furnace at the Washington County Zinc Works and also describes it as a sorting plant near Hopewell. The IMOP database identifies Smith's Furnace (fig. 8 and table 3) at Evans Mine about 2 miles to the south of the Hopewell Furnace and shows it as a zinc smelter. Winslow (1894) mentioned surface diggings near Irondale and stated that the Deggendorf Zinc Works (fig. 8 and table 3) was built in 1870 about 2 miles north of Irondale; this is shown on figure 8 at the IMOP location of the Deggendorf and Wills Mine (not identified on fig. 7). In 1915–16, 15 carloads of zinc carbonate ore were shipped from the Strawberry Diggings in the Palmer Mines area (Park, 2006; Kiilsgaard and others, 1967; fig. 7 and table 2), but it is not stated where the ore was smelted.

For many years lead was transported by pack horses or wagons to ports on the Mississippi River for shipment to various markets. These ports were Ste. Genevieve in the early years (fig. 1), Herculaneum beginning in about 1808, and Selma (fig. 2) also in the early 1800's, for which the Selma Road was built (not shown on figures). The road ran from the Shibboleth Mines at first, then was extended through Old Mines to Cresswell's Furnace, and connecting roads were built to Potosi, Cadet, Hopewell Furnace at Hopewell, Higgenbotham's Furance at Fertile, and to the Palmer, Frumet, and Valles Mines (Park, 2006; figs. 2, 7 and 8; tables 2 and 3). Shipment of lead by wagon on the Selma Road and other roads continued for decades, and by the late 1840's there were several other shipping ports on the Mississippi River (Winslow, 1894). Shipment of lead by railroad began in the 1850's with the construction of the Iron Mountain Railroad from St. Louis to the Pilot Knob iron mine in Iron County, south of the Southeast Missouri Barite District (Winslow, 1894). Other railroads were built beginning in the late 1870's to ship lead concentrate from the mines of the Old Lead Belt, but may also have shipped some lead from the Southeast Missouri Barite District and the Valles Mines. A rail spur was built in 1969 from Cadet to the Indian Creek Mine and later the Pea Ridge iron mine in northwestern Washington County (fig. 2).

Underground room and pillar mining methods were employed at lead mines in Washington County at the Indian Creek Subdistrict, the Viburnum No. 29 Mine of the Viburnum Trend Subdistrict, and probably the Irondale Subdistrict of the Southeast Missouri Lead District (fig. 7 and table 2). The Indian Creek Subdistrict consisted of two mines (Indian Creek Mine and Goose Creek Mine), which operated from 1953 to 1982, with a shared lead concentrating mill and tailings pond but not a smelter. The Viburnum No. 29 Mine in southwestern Washington County began operations in 1964. It is one of three mines centered on the city of Viburnum in Iron County (fig. 1) with a central concentration mill but not a smelter. The mill's tailings pond is outside the study area in Iron County on Indian Creek, a tributary of Courtois Creek that flows northward through southwestern Washington County. The Viburnum No 29 Mine is located along Indian Creek downstream from the tailings pond. The IMOP database shows that there was a blast furnace at the Irondale Mine in the Irondale Subdistrict.

Lead and Zinc Production and Losses During Processing

Lead and zinc production from the Southeast Missouri Barite District and the Valles Mines is poorly documented but some data and estimates are available. Most production figures in the literature are for specific mines, mining areas, or furnaces at various points in time (rather than for the entire history of a mine or furnace, though some data of this type are available); are different types of production (mine ore production or furnace metal production); and are of variable quality depending on the age of the mine or furnace and the type of source (recorded, or reported by a mine owner or another person). There are many mines for which no production data or estimates are available.

The most comprehensive estimates of lead and zinc production through the late 1800's are in Winslow (1894); Wharton (1975) provided more recent production estimates that capture the entire period of mining. Winslow (1894) has tabulated estimates of tons of lead produced and tons of lead in the ore that was fed to the furnaces, and the same for zinc and zinc ore, by decade or longer period of time and with cumulative production through 1893 for Washington, Jefferson, and St. Francois Counties. In most cases, Winslow (1894) first estimated lead or zinc metal production and then applied an estimated furnace recovery rate to calculate the tons of lead or zinc in ore that was fed to the furnaces. In some cases he started with tons of metal in the ore and applied the furnace recovery rate to calculate metal production. The Valles Mines are in both Jefferson and St. Francois Counties, so it was not possible for Winslow (1894) to differentiate production from these mines by county; Winslow (1894) arbitrarily credited St. Francois County with all the Valles Mines production through 1879 and credited Jefferson County with all the Valles Mines production after that (table 4). Also, Winslow's (1894) tabulated production estimates for St. Francois County include production from early diggings in areas that would become the Old Lead Belt, and beginning in the 1860's, production from larger scale mines of the Old Lead Belt. Because Winslow (1894) also included some details of production from specific mines in St. Francois County, it was possible to estimate for this report approximately how much of the St. Francois County lead production was from the Valles Mines. Winslow's (1894) estimates were used to construct table 4, which shows estimated lead content of the ore (tons of lead in the ore that was fed to the furnaces), tons of lead produced, zinc content of the ore (tons of zinc in the ore that was fed to the furnaces), and tons of zinc produced, by decade or longer period of time and with cumulative production through 1893 for the combined Southeast Missouri Barite District and Valles Mines, by county. The production estimates for Washington County probably include the Irondale Subdistrict of the Southeast Missouri Lead District (fig. 1); Winslow (1894) described these mines as surface diggings, so production through 1893 would not have been large and any larger-scale underground mine production from the Irondale Subdistrict would have been after 1894. Buckley (1908) showed that 790 tons of lead concentrate were produced by the Irondale Lead Company in 1902, after which the company was purchased by the Federal Lead Company, which operated mines in the Old Lead Belt; it is not possible to determine how much of the production of the Federal Lead Company in subsequent years came from the Irondale Subdistrict. Production data for the Indian Creek Subdistrict and the Viburnum No. 29 Mine of the Viburnum Trend Subdistrict are not included for Washington County, as these mines came into production much later than 1893.

Table 4. Estimates of combined lead and zinc production from the Southeast Missouri Barite District and Valles Mines, and the Southeast Missouri Lead District.

[Lead or zinc content of ore is the tons of lead or zinc in the ore fed to the furnaces; lead or zinc produced is the tons of lead or zinc produced from the furnaces; these estimates do not include lead recovered during barite mining since 1948, the amount of which is unknown; --, no production or no production figure available]

Southeast Missouri Barite District and Valles Mines	Washington County[a]				Jefferson County[a]				St. Francois County[b]				Southeast Missouri Barite District			
	Lead content of ore (tons)	Lead produced (tons)	Zinc content of ore (tons)	Zinc produced (tons)	Lead content of ore (tons)	Lead produced (tons)	Zinc content of ore (tons)	Zinc produced (tons)	Lead content of ore[c] (tons)	Lead produced (tons)	Zinc content of ore (tons)	Zinc produced (tons)	Lead content of ore (tons)	Lead produced (tons)	Zinc content of ore (tons)	Zinc produced (tons)
Winslow[a,b] (1894), modified																
to 1799	19,000	9,500	--	--	--	--	--	--	0	0	--	--	19,000	9,500	--	--
1800–19	28,500	17,100	--	--	333	200	--	--	0	0	--	--	28,833	17,300	--	--
1820–29	16,130	10,000	--	--	2,420	1,500	--	--	4,842	3,000	--	--	23,392	14,500	--	--
1830–49	38,460	25,000	--	--	7,200	4,680	--	--	26,154	17,000	--	--	71,814	46,680	--	--
1850–59	18,555	13,000	--	--	4,500	3,150	--	--	11,428	8,000	--	--	34,483	24,150	--	--
1860–69	4,285	3,000	--	--	2,000	1,400	--	--	5,286	3,700	200	67	11,571	8,100	200	67
1870–79	13,000	9,100	10,000	3,333	4,000	2,800	3,000	1,000	4,286	3,000	26,512	8,837	21,286	14,900	39,512	13,170
1880–[d]93	23,000	16,100	4,000	1,333	6,210	4,347	31,561	10,520	1,820	1,274	--	--	31,030	21,721	35,561	11,853
Total for Southeast Missouri Barite District and Valles Mines through 1893[e]	161,000	103,000	14,000	4,700	27,000	18,000	35,000	12,000	54,000	36,000	27,000	8,900	241,000	157,000	75,000	25,000
Wharton (1975)																
Total for Southeast Missouri Barite District and Valles Mines through 1948														180,000		54,000
Wharton (1975), modified[f]																
Total for Southeast Missouri Barite District and Valles Mines through 1948														180,000		60,000
Total for history of Southeast Missouri Barite District and Valles Mines													**[g]277,000**	**180,000**	**[g]180,000**	**60,000**

Table 4. Estimates of combined lead and zinc production from the Southeast Missouri Barite District and Valles Mines, and the Southeast Missouri Lead District.—Continued

[Lead or zinc content of ore is the tons of lead or zinc in the ore fed to the furnaces; lead or zinc produced is the tons of lead or zinc produced from the furnaces; these estimates do not include lead recovered during barite mining, the amount of which is unknown; --, no production or no production figure available]

Southeast Missouri Lead District (through 2011)[h]	Period of production	Tons of ore	Percent lead	Lead content of ore (tons)	Percent zinc	Zinc content of ore (tons)
Old Lead Belt Subdistrict	1864–1972	263,000,000	2.9	7,600,000	0.3	800,000
Viburnum Trend Subdistrict[i]	1960–[i]2011	300,000,000	5.8	17,400,000	1.1	3,300,000
Mine La Motte Subdistrict	1720–1961	15,000,000	3.9	600,000	--	--
Indian Creek Subdistrict	1954–85	32,000,000	3.6	1,200,000	0.4	100,000
Annapolis Subdistrict	1915–31	1,200,000	2.3	30,000	--	--
Total production from Southeast Missouri Lead District (through 2011)[h]		**611,200,000**	**4.4**	**26,830,000**	**0.7**	**4,200,000**

[a]Data for Washington and Jefferson Counties are from Winslow (1894).

[b]Data for St. Francois County through 1893 are modified from Winslow (1894) by removing estimated production from the Old Lead Belt.

[c]The lead content of the ore for St. Francois County was estimated by applying the lead recovery percentage in Winslow (1894) for all of St. Francois County to the estimated lead produced in St. Francois County after removing estimated lead production from the Old Lead Belt.

[d]1892 for Jefferson County.

[e]Total production data are rounded.

[f]Adds 6,000 tons of zinc production to Wharton's (1975) zinc production; Winslow (1894) estimated 5,666 tons of zinc production that was not included in Wharton's (1975) estimate from the Valles Mines.

[g]Metal content of furnace feed was calculated by applying Winslow's (1894) percentage of metal recovered by furnaces (65 percent for lead, 33 percent for zinc) to the tons of metal produced.

[h]Data from Schott (2012); production from the Irondale Subdistrict is not included.

[i]Data are through 2011; production from the Viburnum Trend continues to the current time (2016).

Estimated lead and zinc production from the combined Southeast Missouri Barite District and Valles Mines are shown on table 4, by county, through 1893 (1892 for Jefferson County), modified from Winslow (1894). Most of the lead produced through 1893 came from Washington County, but there was more zinc produced in each of Jefferson and St. Francois Counties than Washington County. Table 4 shows that an estimated 103,000 tons of lead and 4,700 tons of zinc were produced in Washington County through 1893; 18,000 tons of lead and 12,000 tons of zinc were produced in Jefferson County through 1892; and 36,000 tons of lead and 8,900 tons of zinc were produced in St. Francois County through 1893, for a total of 157,000 tons of lead and 25,000 tons of zinc through 1893 (but not including production from Jefferson County in 1893; also, in addition to being just estimates, the figures for Jefferson and St. Francois Counties are inaccurate to the extent that Winslow [1894] was unable to split production from the Valles Mines by county and allocated all the production to one or the other county for different periods of time).

Lead and zinc mining continued after 1893, so Winslow's (1894) estimates do not show total production from the Southeast Missouri Barite District and Valles Mines but capture most of the lead production; mining in the Southeast Missouri Barite District was declining as larger-scale underground mining in the Old Lead Belt increased. Ball (1916, p. 807) described lead mining in 1916 by stating that "mining methods of a century ago prevail," so at least some lead mining continued into the 1900's, and lead was sometimes recovered as a byproduct of barite mining (which continued into the 1980's). Also, there was substantial zinc production after 1893, particularly from the Valles Mines in St. Francois and Jefferson Counties. Wharton (1975) used Winslow's (1894) data and other data to provide estimates of cumulative lead and zinc production through 1948 from Potosi-Eminence Mineralization in what he called the "Potosi-Palmer-Richwoods Subdistrict," which includes parts of Washington, Jefferson, and St. Francois Counties (exclusive of the Valles Mines), and, separately, from the Valles Mines. Although there may be some production from outlier mines that is not included, production from the "Potosi-Palmer-Richwoods Subdistrict" and the Valles Mines essentially is production from the Southeast Missouri Barite District and the Valles Mines. Wharton (1975) estimated that 150,000 tons of lead were produced from the "Potosi-Palmer-Richwoods Subdistrict" through 1945, and 30,000 tons of lead and 54,000 tons of zinc were produced from the Valles Mines through 1948. Combining these two, Wharton's (1975) estimate of total production from the Southeast Missouri Barite District and Valles Mines through 1948 is 180,000 tons of lead and 54,000 tons of zinc (table 4), 23,000 tons more lead and 29,000 tons more zinc than the estimate of 157,000 tons of lead and 25,000 tons of zinc produced through 1893 (table 4). Wharton (1975) included zinc production only for the Valles Mines; Winslow (1894) estimated 5,666 tons of zinc production that was not from the Valles Mines. These 5,666 tons of zinc are probably a minimum amount not included by Wharton (1975), so if 6,000 tons are added to his 54,000 tons of zinc, then the estimated zinc production from the Southeast Missouri Barite District and Valles Mines through 1948 is 60,000 tons (table 4). Except for some lead recovered during barite mining since 1948 (for which no estimate is available), the production of lead and zinc through 1948 is essentially all of the lead and zinc produced during the history of the Southeast Missouri Barite District and Valles Mines (table 4). Although most of the lead was produced before 1893, there was more zinc produced after 1893 than before 1893. These figures are only rough estimates, but give an approximation of the lead and zinc production from the Southeast Missouri Barite District and Valles Mines.

Although the mines of the Southeast Missouri Barite District and Valles Mines were small compared to the mines of the Old Lead Belt and the Viburnum Trend, they were widespread, and mining throughout the district lasted for many years, from the early 1700's to at least the early 1900's (and later, if lead as a byproduct of barite mining is considered). Production was not evenly distributed throughout the area; Ball (1916) estimated that about 55 percent of the lead production in Washington County was from mines around Potosi, and about 35 percent was from mines around Palmer (without defining these areas any further).

Using a density of lead of 709 pounds per cubic foot (lb/ft^3), the volumetric equivalent of the estimated 180,000 tons of lead produced in the Southeast Missouri Barite District and Valles Mines through 1948 is a cube of lead about 80 ft on a side, or a football field covered with lead to a height of 10.6 ft. Using a density of zinc of 445 lb/ft^3, the volumetric equivalent of the estimated 60,000 tons of zinc produced in the Southeast Missouri Barite District and Valles Mines is a cube of zinc about 65 ft on a side, or a football field covered with zinc to a height of 5.7 ft.

Considerable amounts of lead were lost during smelting. The difference between the estimated total tons of lead in the furnace feed (241,000 tons) and the total tons of lead produced (157,000 tons) through 1893 (table 4) is 84,000 tons of lead lost to ashes, volatilization, or some other process; 65 percent of the lead in the furnace feed was recovered and 35 percent was lost. These percentages applied to the estimated 180,000 tons of lead produced through 1948 yield 277,000 tons of lead in the furnace feed (table 4) and 97,000 tons of lead lost. The unrecovered lead has a volumetric equivalent of a cube of lead about 65 ft on a side, or a football field covered with lead to a height of 5.7 ft.

Considerable amounts of zinc were also lost during processing. The difference between the estimated total tons of zinc in the furnace feed (75,000 tons) and the total tons of zinc produced (25,000 tons) through 1893 (table 4) is 50,000 tons of zinc; 33 percent of the zinc in the furnace feed was recovered and 67 percent was lost, about twice as large a loss percentage as for lead. These percentages applied to the estimated 60,000 tons of zinc produced through 1948 yield 180,000 tons of zinc in the furnace feed (table 4) and 120,000 tons of zinc lost. The unrecovered zinc has a volumetric equivalent of a cube of zinc about 81 ft on a side, or a football field covered with zinc to a height of about 11 ft. It is interesting to note that although the estimated lead produced (180,000 tons) exceeded the estimated zinc produced (60,000 tons) by a factor of 3, the estimated zinc lost (120,000 tons) exceeded the estimated lead lost (97,000 tons) by a factor of about 1.2 because of the larger percentage loss of zinc than lead. Also, the volumetric equivalent of zinc lost was larger than the volumetric equivalent of lead lost by a factor of about 2 because the density of lead is greater than that of zinc. The loss of zinc during smelting was likely not as widespread in the study area as that of lead. There were fewer zinc furnaces than lead furnaces, and most of the zinc smelting seems to have been outside the study area (Park, 2006; Robertson,1894b).

The estimated lead and zinc losses presented above are losses during smelting, based on Winslow's (1894) estimates of the metal content of the feed to furnaces and the metal produced through 1893, and assuming that the percentage of metal lost, particularly zinc, was the same after 1893 as before 1893. The estimated losses do not include losses at the mine site during mining and preparation for smelting, such as the loss of fine-grained galena during hand cleaning or the discarding of zinc ore before its value was known, for which no estimates are available.

The amount of rock and residuum that was mined for lead and zinc from the Southeast Missouri Barite District and Valles Mines is not known but is more than the amount of ore that was fed to the furnaces. The mined material that was brought to the surface consisted of ore and gangue minerals, dolomite, and clay, and was hand cleaned to provide as pure a feed for the furnaces as possible. The estimated lead and zinc content of the ore fed to the furnaces through 1893 (not the amount of ore fed to the furnaces), by county, modified from Winslow (1894), is shown in table 4. Ingalls (1908) estimated that the grade of ore fed to the log furnaces was about 80 percent lead; pure galena is about 87 percent lead (table 1). This contrasts with larger-scale underground disseminated-lead mines of, for example, the Viburnum Trend, where most of the material that goes to the mills is dolomite, which contains only a small percent of lead and zinc.

The estimated production from the Southeast Missouri Lead District also is shown in table 4 for comparison with the combined production from the Southeast Missouri Barite District and Valles Mines. Schott (2012) estimated that 263 million tons of ore containing 2.9 percent lead (7.6 million tons of lead) and 0.3 percent zinc (800,000 tons of zinc) were mined from the Old Lead Belt, and 300 million tons of 5.8 percent lead (17.4 million tons of lead) and 1.1 percent zinc (3,300,000 tons of zinc) were mined from the Viburnum Trend through 2011 (table 4). Production from other subdistricts also is shown in table 4, and the total of these subdistricts (but not including what was a small amount of production from the Irondale Subdistrict) is 611,200,000 tons of ore containing 26,830,000 tons of lead and 4,200,000 tons of zinc. The estimated 180,000 tons of lead produced from the Southeast Missouri Barite District and Valles Mines is small compared with the Southeast Missouri Lead District. The lead content of the Southeast Missouri Barite District and Valles Mines furnace feed (277,000 tons) was only about 1 percent of the lead content of the Southeast Missouri Lead District ore through 2011 (26,830,000 tons), but was still substantial. The estimated 180,000 tons of lead produced in the Southeast Missouri Barite District and Valles Mines is about 1.5 times the estimated 118,000 tons of lead produced in 2013 by the Doe Run Resources Corporation Herculaneum, Mo., lead smelter, which was supplied by six mines in the Viburnum Trend (Guberman, 2014). In earlier years, when richer ore was being mined in the Viburnum Trend and when mine production was greater, a single, large mine might produce about 1,800,000 tons of ore containing about 10 percent lead in one year, with a lead content roughly equivalent to the estimated 180,000 tons of lead produced in all years from the Southeast Missouri Barite District and Valles Mines.

Barite Mining

Although barite was produced from the Valles Mines, its production was small compared to the Southeast Missouri Barite District, and barite mining at the Valles Mines was not as important as zinc or lead. For this reason, this section focuses mostly on barite mining in the Southeast Missouri Barite District.

Early barite hand mining was widespread but the locations of barite diggings are not well documented. Areas of later, mechanized open-pit mining (fig. 10) and barite tailings ponds (fig. 11) are better documented; both are from the Missouri Geological Survey Mined Land Coverage (Cheryl Seeger, Missouri Geological Survey, written commun., October 27, 2015). It is possible that some of the tailing ponds are also sites of barite mining before mine tailings were placed there. The locations of barite mines (with or without lead or zinc) in the IMOP database are also shown on figure 10. The locations of barite tailings ponds and processing plants in the IMOP database, and the locations of processing plants in Washington County given in Park (2006), are also shown on figure 11. Although not capturing all barite mines, particularly the early diggings, figures 10 and 11 illustrate how widespread barite mining was in the Southeast Missouri Barite District. All barite occurrences in the study area included in the IMOP database (prospects and occurrences in addition to mines) are shown on figure 6.

Development of Barite Mining

Schoolcraft's (1819, p. 70) description of the early lead mines in Missouri included the observation that barite "may be considered the proper matrix of the lead ore, as it is found imbedded in, and often completely enveloped by it." Although Schoolcraft (1819) stated that barite was used as a chemical reagent and a flux for iron-ore smelting, it had no value to the early lead miners. The barite, or tiff as the miners called it,

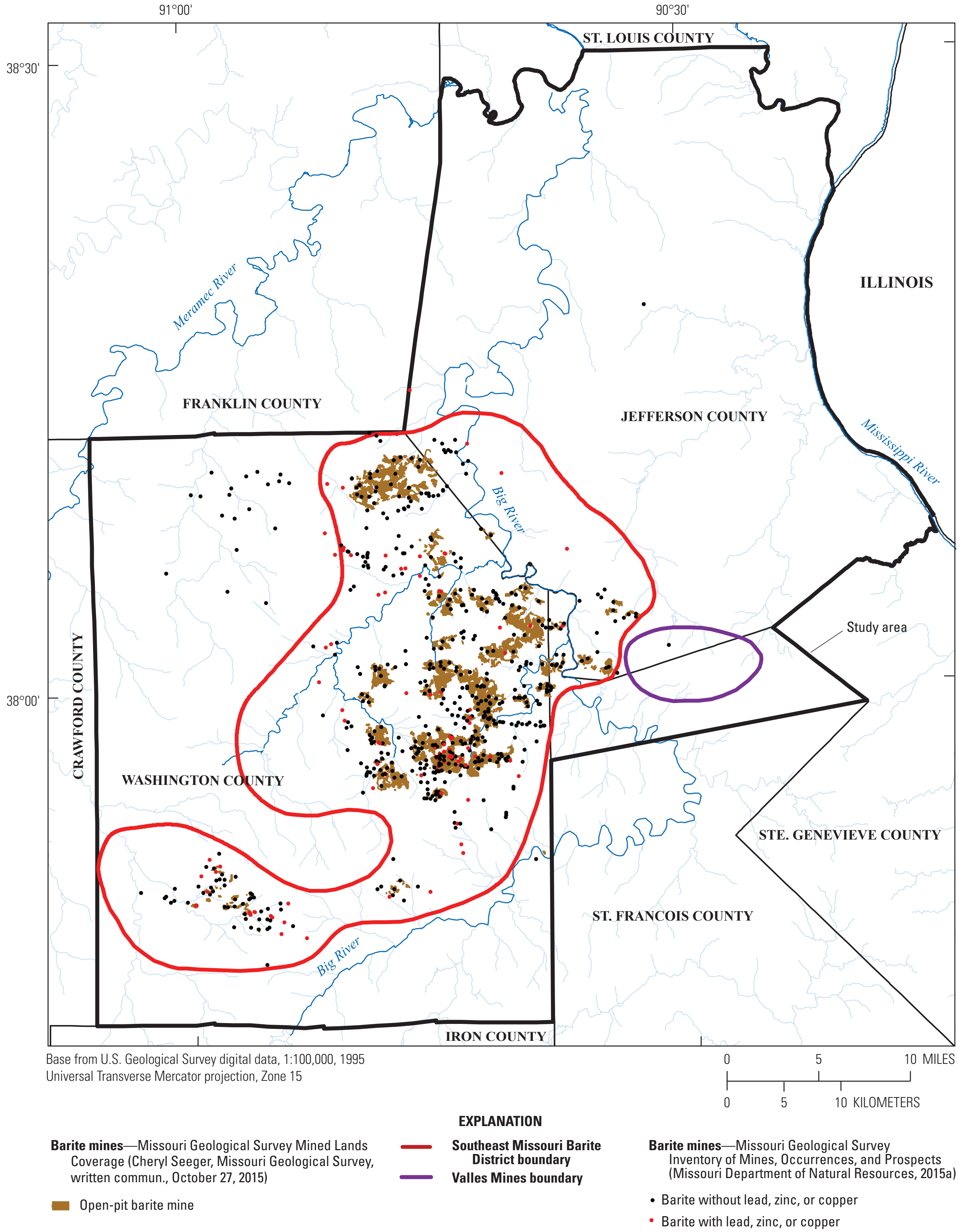


Figure 10. Locations and types of mineralization of Southeast Missouri Barite District and Valles Mines barite mines.

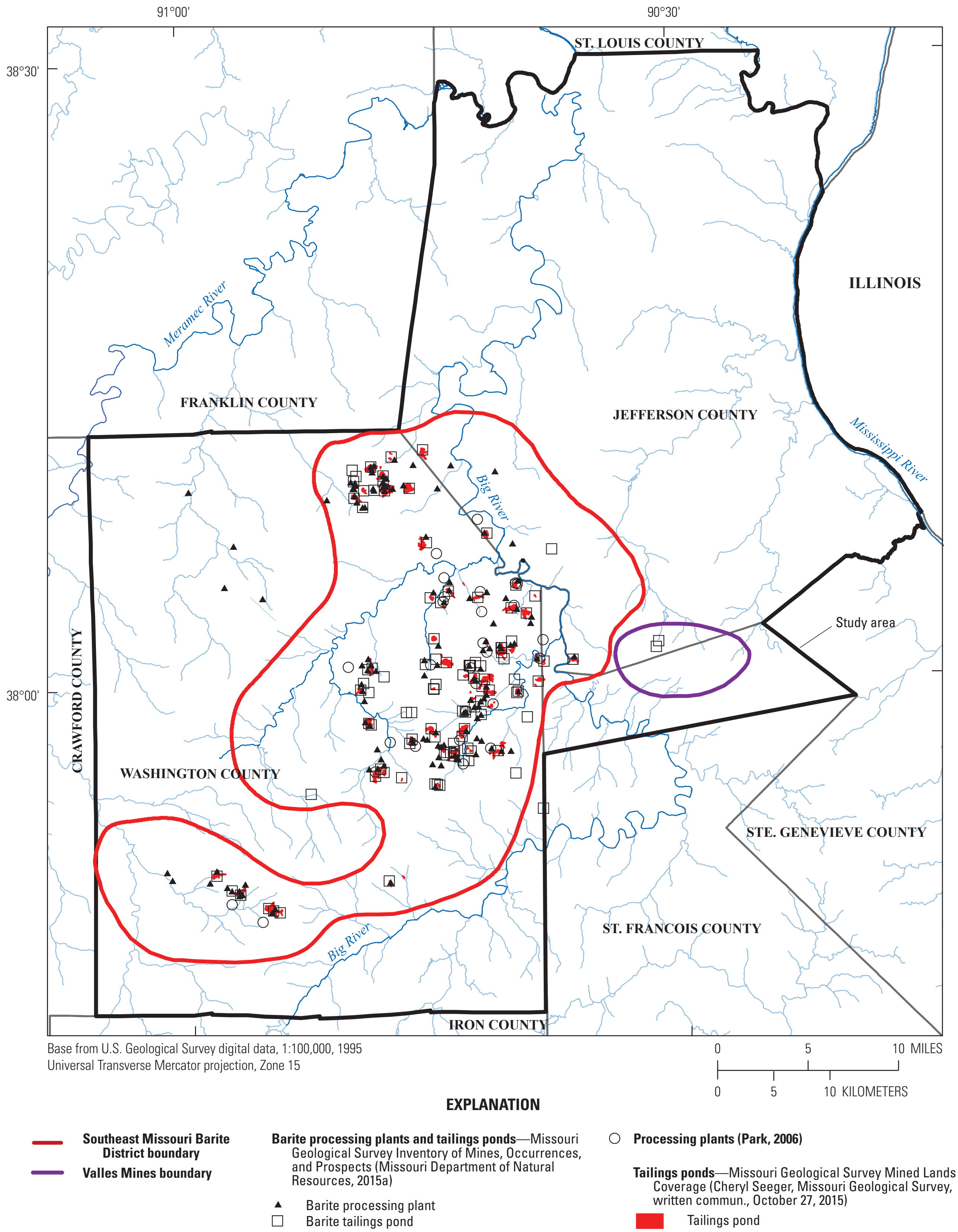


Figure 11. Locations of Southeast Missouri Barite District and Valles Mines barite processing plants and tailings ponds.

was extracted from the residuum during lead mining and for many years was tossed aside or back in the pit (Tarr, 1918). Mining for barite in the United States began in Virginia and Connecticut in about 1845 (Brobst and Wagner, 1967), as barite was by then being used as a paint pigment. Mining for barite in Missouri may have started in about 1850 (Brobst and Wagner, 1967), but Litton (1855) did not describe barite as an economically important resource in southeastern Missouri, so the barite mining referred to by Brobst and Wagner (1967) may have been in central Missouri, where a barite mill reportedly was operating by 1866 (Tar, 1919). Barite mining in southeastern Missouri was active by at least the 1860’s, as Showalter (1963) states that barite mining near Potosi began near the end of the Civil War. Without saying where in Missouri, Tarr (1918) suggested that barite mining was well established in Missouri by the 1870’s. Showalter (1963) describes barite mining from the 1860’s to about 1905 as carried out on a small scale because there were few buyers. Mining was by hand; production increased after 1905 as more uses for barite were developed. Tarr (1918) listed 39 uses of barite, including paint pigment, lithopone (a white pigment made from barite and zinc sulfide), putty, rubber (for added weight), and linoleum (also for added weight). The peak of hand mining was from 1905 to the 1930’s, when several thousand people were engaged in barite mining (Showalter, 1963).

Because barite and lead commonly are present together, the existence of large amounts of barite was known by the lead miners. For this reason, many of the barite diggings were on land previously mined for lead, and waste from lead diggings was picked through to recover barite that had been left behind. New areas of barite were found when barite float was turned up by plowing (Harness and Barsigian, 1946) and from prospecting. A common prospecting practice was to drive a steel bar into the ground, withdraw it, and inspect the tip of the bar for white barite residue, which would indicate the presence of barite in the subsurface (Park, 2006; Showalter, 1963). Barite was hand mined over a large area, especially in Washington County. Tarr (1918) estimated that the area of the barite-lead district as of 1918 was about 250 mi^2, mostly in Washington County but also in Jefferson County. Buckley (1908) described and showed on a map 33 areas of barite diggings within a few miles of Mineral Point in Washington County. It was estimated that good productive land produced 2,000–6,000 or more tons of barite per acre, that the ore (barite) grade was 4–7 percent and as much as 25 percent in pockets, and that clay containing 125 lb of barite per cubic yard (yd^3) could be mined profitably (Park, 2006).

An important development happened around 1926 when barite began to be used as a weighting agent (drilling mud) for oil well drilling, leading to increased demand for barite; eventually 80–85 percent of the barite produced in Missouri was marketed as drilling mud, the remainder going to the chemical grade market (Wharton and others, 1969). Burford (1978, p. 29) stated that when the drilling mud market was realized, “Outsiders pushed in, corporations were formed, residents and speculators alike bought up thousands of acres of barite-bearing land in hopes of getting a quick profit. Farmers marked off sections to be mined.” Mechanized open-pit mining of old barite diggings began at Mineral Point in 1924 (fig. 2; Dake, 1930) to recover barite left behind by hand mining, and large-scale washing plants were used to clean the clay from the barite. Hand mining, however, continued to thrive; Weigel (1929), describing mining practices in 1929, stated that hand mining still accounted for well over one-half of the barite production. Washer plants closed beginning in 1931 (Showalter, 1963), unable to compete with the cheap labor of hand digging during the Great Depression (Park, 2006). Muilenburg (1954) stated that nearly all of the barite produced before 1937 was by hand mining. Mechanized mining and washing returned in the 1940’s, in large part because of a 1939 Federal court affirmation of a National Labor Relations Board’s decision that hand miners were employees of the landowner rather than independent contractors (Harness and Barsigian, 1946). Miners had been permitted to live in cabins on the land and pay the landowner a mining royalty, but following this decision landowners became reluctant to continue this practice, fearing higher labor costs, already high because nearby war industries were employing some workers. By the late 1960’s there were 25–30 washer plants in Washington County owned by 10 companies, and most of the concentrates were processed at 4 grinding plants near Mineral Point (Wharton and others, 1969). Park (2006) provided the locations of 30 processing plants (washer plants and grinding plants) in operation in the late 1960’s (fig. 11). Wharton (1972) stated that 8 companies operated 15 mines and washer plants in Washington County in 1971, a smaller number of plants than just a few years earlier. Muilenburg (1954) estimated that the barite-mining areas of Washington and adjacent counties constitute about 75 mi^2 (of which he forecast 15,000 acres [23.4 mi^2] would be productive and available for mining), an area smaller than the 250 mi^2 estimated by Tarr (1918), probably indicating that mechanized mining, although concentrated where it did take place, was not as widespread as hand mining. The mechanized surface-mined areas shown in figure 10 have a combined area of about 26.3 mi^2. The area of mechanized mining is actually somewhat larger because at least some of what is shown on figure 11 as tailings ponds (about 4.7 mi^2) had been mined and later used to store tailings; the combined area of mechanized surface mining and tailings ponds is about 31 mi^2.

Barite was last mined in Missouri in 1998 (Missouri Department of Natural Resources, 2012). Searls (2000) stated that a grinding plant operated in Missouri in 2000 using stockpile from an idle mine, and Rueff (2003) showed a barite grinding plant in Washington County. This may be the same grinding plant that operated in 2009 in Washington County (Miller, 2011).

Barite Mining and Processing Methods

Most of the barite that was mined in the Southeast Missouri Barite District was from the residuum, and for many years the mining method was hand digging in the same way as earlier lead mining. Landowners leased their property to miners, or tiff diggers as they were known (Chaney, 1949), who paid a royalty to the landowner for the barite they mined. Miners commonly lived with their families on the land they were mining, living rent free in small houses built by the landowner (Weigel, 1929).

A small pit, or shaft, was dug with pick and shovel from 4 to about 30 ft deep (Tarr, 1918), often going to bedrock. The shafts were 3 to 5 ft in diameter but were square on top if cribbing was used (Weigel, 1929); cribbing seems to generally have not been necessary because the pits remained open for years despite rains (Steel, 1910). The shafts were widened out at depth, undercutting the upper few feet of residuum, such that the shafts resembled an inverted mushroom (fig. 12*A*). Instead of widening the bottom of the shaft in all directions, drifts were sometimes dug in the directions of the richest ore as far as the miner felt was safe, usually 4 to 8 ft. (Steel, 1910). Three drifts might be dug and intersect drifts from adjacent shafts to create pillars and aid in ventilation. Ventilation could be improved by starting a fire or placing heated rocks in one shaft, causing an updraft in that shaft and a downdraft in an intersecting shaft (Tarr, 1918). Once the upper ore had been mined to the extent possible the shaft would be deepened; alternately, sometimes the shaft would be dug to its total depth at first and then the upper ore would be mined by stoping a drift upward, allowing the roof of the drift to collapse (Steel, 1910).

When one shaft was completed, a second was started in the most favorable direction, and then a third and so on. Eventually the shafts would be spread out over the field as a series of holes with accompanying mounds of red clay (McQueen and Grohskopf, 1933; fig. 12*B*) and might have a regular pattern like a checkerboard (Steel, 1910). Each miner was generally allotted an area 60 ft square (Tarr, 1918) in which they tried to maximize the amount of ore removed. A large part of the ground was necessarily left behind as pillars and was not mined; Steel (1910) estimated that only about one-half of the barite was recovered.

Barite mining sometimes extended into the bedrock, but this required explosives and was more expensive, and the bedrock was mined only when enough lead ore was present to justify the added expense (Steel, 1910). Shafts followed a vertical fissure until a “cave” containing ore was reached, and drifts were mined following horizontal stringers of barite and galena, which sometimes led to more ore.

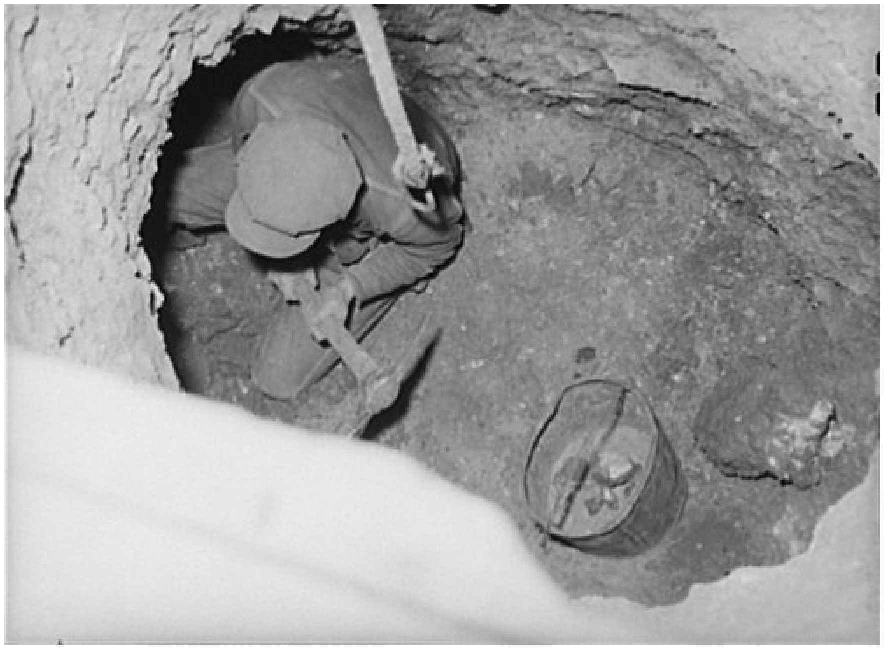
Miners commonly worked with one or more partners, including family members (Chaney, 1949). The miner dug for barite while their partner operated the windlass to hoist ore and waste material to the surface in a bucket, and processed the raw ore (figs. 12 and 13). Generally, all of the excavated material was removed from the shaft, but sometimes the material was sorted in the shaft and the waste was left behind in an abandoned drift, and only the sorted ore was removed from the shaft. The barite was spread out on the ground or on boards to dry, or dried over an open fire (Showalter, 1963). Once dried, the barite was cleaned by cobbing to remove clay and other impurities (Tarr, 1918; fig. 13*B*) in much the same way as clay was separated from galena during lead mining. The barite was then placed in a rattle box shaped somewhat like a baby’s cradle, which, when rocked back and forth, forced the barite against metal spikes inside the rattle box, further cleaning the barite (fig. 14*A*). Fine-grained material, consisting of waste such as clay and iron oxides (Harness and Barsigian, 1946) and other materials but also fine-grained barite, passed through holes in the bottom of the rattle box. Although galena was sometimes recovered as a byproduct, fine-grained galena also would have passed through the rattle box onto the ground (Missouri Department of Natural Resources, 2013).

The cleaned barite passed through several hands after processing. The barite was hauled by a mule-drawn wagon or cart to merchants such as country stores where the barite was weighed and sold in exchange for other commodities (Tarr, 1918). The barite was stockpiled there and sold to a buyer with access to the railroad (fig. 14*B*), who then sold it to a customer or to a larger selling company (Hill, 1917). Hill (1917) lists 16 individuals or companies with offices in Washington, Jefferson, or St. Francois Counties or in St. Louis that sold barite. One of these was the Point Milling and Manufacturing Company that, beginning in 1904 (Steel, 1910), operated a mill in Mineral Point (fig. 2) for manufacturing ground barite. The barite was crushed and ground to minus 200 mesh, washed to remove clay, treated in lead-lined tanks with sulfuric acid to remove iron oxide (bleaching process), washed again to remove the acid, dried, and packed in barrels and sacks (Steel, 1910; Tarr, 1918). Additional details of the operation of this mill and the bleaching process, using lead-lined tanks, lead pipes, lead-lined tank cars, and sulfuric acid, are given in Steel (1910). This may be the same company, called the Point Mining and Milling Co. by Wharton (1972), that experimented with steam shovels at Mineral Point in 1904. This experiment was apparently short-lived, and it was not until about 1924 that mechanized mining became important.

Early mechanized mining techniques are described by Weigel (1929). Shovels with ¾ to 1½ yd^3 dippers and powered by steam, gasoline, or electricity were used to mine the residuum to a depth of 12 to 15 ft (fig. 15). The entire thickness of residuum was processed without setting aside any nonbarite-bearing overburden that might be present. Because the ground was relatively soft, blasting was not necessary. The shovels were not able to mine cleanly to the bedrock because of its uneven surface, so any barite remaining in the low spots between bedrock pinnacles was mined by hand. Shovels loaded ore onto 5 yd^3 rail cars, which were hauled as far as 2,500 ft to washer plants by gasoline-powered locomotives on rail lines that were extended into the mine pit as mining progressed.

The processing (milling) of barite ore was a matter of washing the barite to remove the clay, breaking the pieces of ore to reduce their size and remove coarse waste material, and then concentrating the barite. Weigel (1929) described small, combined hand and mechanical washers that were portable and could be operated by two men. Ore was fed by

A. **Miner digging laterally at bottom of shaft**



Rothstein (1939a), Library of Congress

B. **Miner using windlass to hoist ore from shaft; abandoned shaft and waste piles nearby**

Werner (1937), National Archives Catalog

Figure 12. Barite diggings.

A. **Miner operating windlass to hoist barite ore to the surface**

U.S. Department of Agriculture (1937), National Archives Catalog

B. **Miner sorting and cleaning barite ore next to shaft and windlass**

Rothstein (1939b), Library of Congress

Figure 13. Hoisting barite ore to the surface, and cleaning and sorting the barite.

A. **Cleaned barite stockpiled at mine site, rattle box in lower right**

Buckley (1908), Missouri Geological Survey

B. **Barite stockpiled along rail line**

Buckley (1908), Missouri Geological Survey

Figure 14. Stockpiles of cleaned barite.

A. **Mining barite with a power shovel**

Dake (1930), Missouri Geological Survey

B. **Open-pit barite mine**

Dake (1930), Missouri Geological Survey

Figure 15. Mechanized surface barite mining.

hand from a barrow or wagon to a single gasoline-powered log washer where clay was removed, and a jig was then used to concentrate the barite. These washers could be moved from site to site as mining operations moved. Larger, more elaborate permanent washer plants were located at Mineral Point, Old Mines, Cadet (figs. 2 and 16), and Fountain Farm (not shown on fig. 2) during these early years of mechanized mining (Weigel, 1929). Weigel (1929) described two plants near Cadet where ore was dumped from elevated rail cars through grizzlies (which retained oversized boulders) into 30-ft-long double log washers. Log washers consisted of paddles rotating around an axis (log) that, with the addition of water, removed clay from the ore. Overflow from the log washers went to a mud (tailings) pond. The washed ore was crushed to about ¾ in., and the barite was concentrated in jigs. The coarse jig tailings went to tailings piles or were used as railroad ballast, and the jig fines (middlings) went to gravity tables for further concentration (Weigel, 1929; Dake, 1930). The table concentrates typically had a higher grade (about 98 percent barite) than the jig concentrates. Weigel (1929) also described the operations at another plant at Cadet where a somewhat different process was used, including the use of trommels for concentration before the ore went to jigs, a drag dewaterer, and other processes. Limonite, which can coat the barite, presented a problem because even after crushing its specific gravity is similar to that of barite, and much of the barite shipped from the district contained limonite. The limonite did not affect oil-well drilling applications but was a problem for some other applications.

This period of early mechanized barite mining was short-lived, and some hand mining continued during this time. By the early 1930's, the washer plants had closed and all barite mining was done again by hand. This situation lasted only a few years and by the 1940's barite mining and processing were again mechanized, this time at a larger scale, and hand mining accounted for only a small percentage of the barite production from the district. In describing mining practices at the time, Chaney (1949) stated that power shovels removed the ore, which now was loaded onto trucks rather than rail cars. Barite-free overburden was sometimes stripped. Trucks hauled the ore to washer plants that were normally located within about 2 mi of the mine. These washer plants were temporary and were moved as necessary to remain within a reasonable distance of the mine site. Chaney (1949) stated that the ore was fed from hoppers to a primary crusher before going to the washer, or breaker, a step not described for earlier washer plants (Weigel, 1929; Dake, 1930), where a strong jet of water was used to remove clay from the barite. Most of the breakers were a rotating grizzly, or squirrel cage, of rails into which the ore was fed. The relatively soft barite (table 1) would break into smaller pieces and fall through the spaces between the rails, leaving behind the harder silica minerals, which went to waste dumps. The ore then went to double log washers where, as in earlier washer plants, any remaining clay was removed and sent to tailings ponds. Next, a trammel screen was used to grind and further concentrate the barite. The ore then went to jigs for more concentration and then to a rake classifier. Overflow material went to the tailings pond. Chaney (1949) stated that there were more than 20 washer plants in the district, in addition to several grinding plants. Apparently, only some barite was ground, depending on its final use.

Harness and Barsigian (1946) described the grinding and bleaching process used in the barite industry in the United States, with some reference to practices in Missouri. Barite that was not going to be bleached (which was not necessary for well drilling and some other applications) was ground dry, and barite that was to be bleached was ground wet. Wet grinding consisted of grinding 5/8-in. jigged barite in a tube mill, and the ground barite was then thickened, bleached, vacuum-filtered, dried in a kiln, and bagged. Bleaching was accomplished using a hot solution of sulfuric acid, which removed impurities such as iron minerals and lead sulfide (galena). The type of vessel used during this process is not specified; an earlier bleaching process used lead-lined tanks (Steel, 1910; Tarr, 1918). Magnetic separators were later used to remove iron oxides (Wharton and others, 1969).

Mining methods did not change much through 1957. Muilenburg (1957) stated that exploration generally was unnecessary, as old barite shafts served as guides for mining. Some exploration was probably done, though, as Wharton (1986) mentioned prospecting using backhoes and power augers in a grid pattern. Barite was found at the surface in most places, so stripping of overburden generally was unnecessary. In addition to diesel- or gasoline-powered shovels, draglines were employed (Muilenburg, 1957). Excavation depth averaged 10 or 15 ft and in some locations extended to 30 ft or more. Ore in low spots between bedrock pinnacles had been hand mined earlier (Weigel, 1929), but now (Muilenburg, 1957), this ore

Dake (1930), Missouri Geological Survey

Figure 16. A barite mill.

was generally not recovered and was lost to future mining because it was covered by jig tailings used for building and maintaining roads in the mine pit. Ore continued to be hauled by trucks, and trucks commonly returned from the washer plant with a load of jig tailings. A new road was built each time the shovel or dragline was moved (fig. 17*A*).

Muilenburg's (1957) description of the milling processes provides some additional details, but basic methods do not seem to have changed much from the time of Chaney's (1949) description. A rotating breaker screen (perhaps similar to the trommel screen mentioned by Chaney [1949]), was used to break the barite into pieces that would pass through the screen, thus continuing the process of separating the barite from the harder gangue material before going to the jigs. A jaw crusher was sometimes used in place of the rotating breaker screen.

Large quantities of water were required for milling the barite. A plant processing 800–1,000 yd^3 of ore to produce about 100 tons of barite concentrate in 24 hours required 1,000–1,200 gallons per minute (gal/min) of water (Muilenburg, 1957). About 800–900 gallons would be recirculated water, with the remainder coming from dammed streams or wells. Tailings and wastewater were impounded behind dikes, a method employed since washer plants had been used. Dikes were built across small valleys and were increased in height as necessary using washer waste and any overburden that had been stripped. In some cases, dikes were built across valleys that had already been mined for barite (Harness and Barsigian, 1946). Ponds could be many acres in size, particularly where the land was relatively flat, and took many years to dry (fig. 17*B*). Harness and Barsigian (1946) stated that older ponds had not completely dried but had a strong enough crust to support a plow team for cultivation. Waste material not placed in tailings ponds was placed in mine pits (Missouri Department of Natural Resources, 2013)

By 1972, front end loaders were being used in addition to power shovels and, less commonly, dragline excavators (Wharton, 1972). Ore left in low spots in the bedrock surface was sometimes recovered using draglines, a practice previously done by hand (Weigel, 1929) but which later had been discontinued (Muilenburg, 1957). Abandoned pits were sometimes re-mined to recover lower-grade ore when market conditions allowed it. Ore was generally milled using the methods described by Muilenburg (1957). Rotary breakers, log washers, and breaker screens continued to be used; crushers were no longer used (Wharton, 1972). A typical washer plant could process 70–120 yd^3 of ore per hour to produce 100–200 lb of barite per cubic yard of ore, using up to 5,000 gal/min of water. It is not stated by Wharton (1972), but most of this water probably would have been recirculated, as described by Muilenburg (1957). Wharton (1986) stated that froth flotation was attempted with the goal of recovering barite from the washer wastewater that went to the tailings ponds. It was unclear in 1986 whether froth flotation would be economical, but mining of barite did not last for many years after 1986, so this process could not have been common, if practiced at all.

Although lead was sometimes recovered while processing the barite, the amount of lead recovered is unknown. Weigel (1977), describing washers at Valles Mines, stated that it was common practice to place the log washer oversize on a picking belt where galena "nuggets" could be removed. Weigel (1977) also stated that galena was recovered from the first jig cell at the old plants.

Barite Production, Losses During Mining and Processing, and Potential Reserves

Cumulative production of barite in Missouri, starting in 1872 when some recordkeeping began, is estimated at 13.4 million tons (Missouri Department of Natural Resources, 2012). Allowing for 5,000–10,000 tons per year from the 1860's through 1871 (Park, 2006) increases the estimate to 13.5 million tons. The total barite production from the Central Missouri Barite District (fig. 1), where production ended in the 1950's, is estimated at 400,000 tons (Wharton and others, 1969), so the total production of barite from the Southeast Missouri Barite District and the Valles Mines can be estimated to have been about 13.1 million tons.

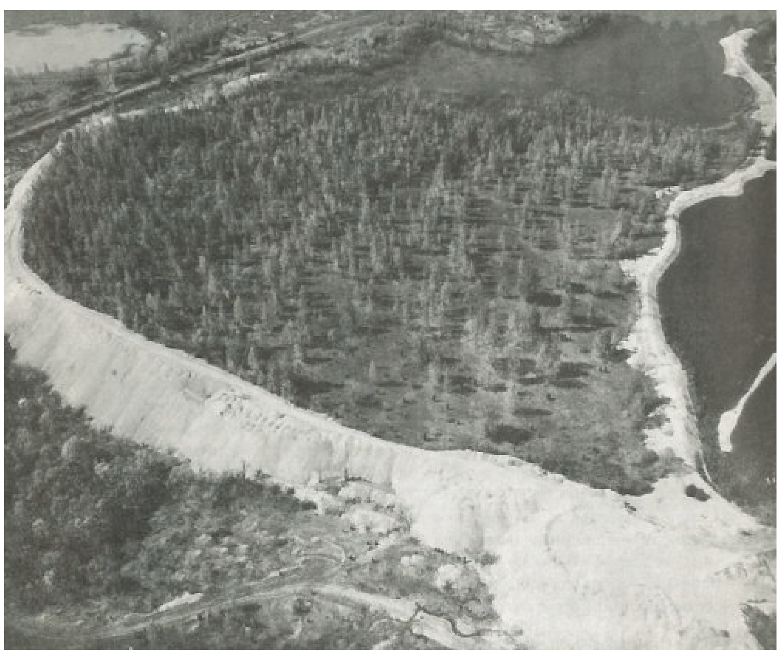
Most of the barite production from the Southeast Missouri Barite District was from Washington County. For this reason, most authors, when referring to district production, refer only to production from Washington County, from the "Washington County Barite District," or use the term "Washington County barite" or similar terminology without referencing production from Jefferson or St. Francois Counties (also, there was minor barite production from adjacent Franklin and Crawford Counties, which are not part of the Southeast Missouri Barite District). Wharton (1975) estimated that the barite production from the Valles Mines through 1974 was about 3,200 tons, just 0.03 percent of the estimated 11.828 million tons of combined barite production for the Southeast Missouri Barite District and the Valles Mines through 1974.

Because most of the barite production in Missouri was from the Southeast Missouri Barite District, statistics for Missouri barite production serve as a proxy for production from the district. A graph of Missouri barite production from 1872 to 1998 (fig. 18) shows a general increase, with some brief downturns, from the early 1900's to 1957 when production peaked at 382,000 tons per year. Production was strong for the next few years before dropping in the 1970's and 1980's. Barite mining in Missouri ceased in 1998 (Missouri Department of Natural Resources, 2012). Although a grinding plant was operating in Washington County in 2000 (Searls, 2000) and in 2009 (Miller, 2011), and Rueff (2003) shows a grinding plant in Washington County, the Missouri Department of Natural Resources (2012) does not show any barite production after 1998 (fig. 18). Missouri led the United States in barite production in most years from 1885 to 1971, after which Nevada was the major producer (Missouri Department of Natural Resources, 2012).

A. **Open-pit barite mine, showing network of roads in the mine**

Wharton (1972), Missouri Geological Survey

B. **Barite tailings pond, partially vegetated**



Wharton (1972), Missouri Geological Survey

Figure 17. An open-pit barite mine and tailings pond.

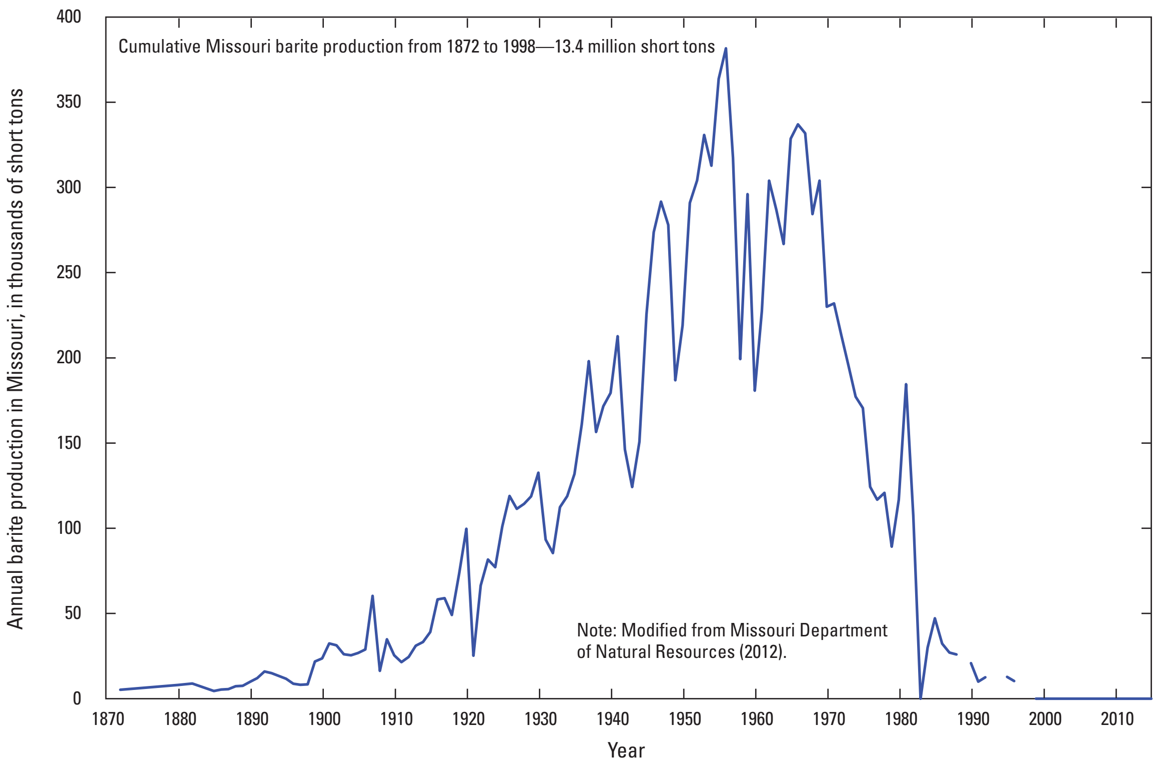


Figure 18. Cumulative Missouri barite production, 1872–1998.

Hand mining and processing of barite was inefficient. Estimates of barite recovery range from less than one-fourth (Muilenburg, 1954) to about one-half (Steel, 1910) because the pillars between the shafts in the residuum needed to be left unmined for stability. The hand cobbing of the barite at the surface was probably also inefficient because it would have been difficult to recover small pieces of barite bound to drusy quartz or other gangue minerals. Wharton (1972) stated that the fine-grained barite was either discarded or lost; the rattle box was used to concentrate the barite by removing clay, but some barite, being relatively soft at 3 to 3.5 on the Mohs 1 to 10 scale of hardness (table 1; Hurlbut, 1971) would have broken into smaller pieces and passed through the slots in the bottom of the rattle box and onto the ground. Some galena, a soft mineral at 2.5 on the Mohs hardness scale (table 1), also would have broken into small pieces; the galena fines would have remained with the clay (Missouri Department of Natural Resources, 2013) and would have passed through the slots onto the ground. Although mechanized mining did not leave pillars and was therefore more efficient than hand mining, ore was sometimes left behind, particularly in low areas between bedrock highs. Pits were sometimes re-worked to recover additional barite (Wharton, 1972).

Wharton (1986) estimated that about 30 percent of the barite was lost during the milling process. Wharton (1972) estimated that about two-thirds of the lost barite was fine-grained and was discharged to the tailings ponds. Most of this fine-grained barite loss was overflow from the log washers (Wharton, 1972), but some was also lost during the jigging process (Muilenburg, 1957). Some galena was lost to the tailings ponds (Missouri Department of Natural Resources, 2013), but this has not been quantified.

Recognizing that the tailings ponds contained a large amount of barite and might be considered a barite resource, the Missouri Geological Survey investigated them to determine the tonnage, grade, and distribution of barite in representative ponds, and to provide information that could be used to develop barite recovery methods (Wharton, 1972). A 1972 inventory of tailings ponds by the Missouri Geological Survey identified 67 ponds in the Southeast Missouri Barite District, 40 of which were considered large (more than 500,000 yd^3 or 500,000 tons of tailings, with 1 yd^3 weighing roughly 1 ton dry weight). Four ponds were drilled, and samples were scanned using x-ray fluorescence spectrometry to determine barium concentrations, from which barite concentrations were calculated. Wet chemistry was used for control assays. Results from the 4 ponds were used to estimate that the 67 ponds contained almost 39 million tons (or cubic yards) of tailings averaging about 5 percent barite, for a reserve of 1.935 million tons of barite. This is about 17 percent of the estimated 11.5 million tons of barite produced in the district through 1971, and represented about 10 years of supply at the rate of production in the 1960's. Metallurgical tests determined that about 50 percent of the barite is a minus 400-mesh size. A map showing the location of the 67 tailings ponds, and a detailed map and cross section of each of the four ponds showing locations of drill holes, barite grade, and thickness at each drill location and areas of different grades of barite in each pond are given by Wharton

(1972). The barite concentrations were the highest near the points of mill discharge because of the relatively large specific gravity of barite (table 1). For example, a 15-ft interval of tailings near an old mill site contained about 26 percent barite, whereas the tailings most distal from the point of discharge ranged from 1.5 to 2.5 percent barite. The 67 tailings ponds inventoried in 1972 are fewer than the 93 tailings ponds in the study area listed in the IMOP database. Although lead was not reported by Wharton (1972), its distribution in the tailings ponds would probably be similar because of the large specific gravity of lead minerals (table 1).

The barite deposits generally contained lead (and zinc) minerals as well as barite. It is not known how much lead was removed during barite mining, how much lead was recovered, or how much lead went to the tailing ponds or was used for mine roads or was otherwise lost.

Summary

The Southeast Missouri Barite District and the Valles Mines are located in Washington, Jefferson, and St. Francois Counties, Missouri, where barite and lead ore are present together in surficial and near-surface deposits. Lead mining began in the early 1700's and extended into the early 1900's. Lead minerals were recovered by hand and although hand mining was carried out on a small scale compared to modern mining, the Southeast Missouri Barite District was the most important lead-producing district in the United States for a number of years. Although lead and barite were recovered, the Valles Mines was better known for zinc production. Lead mining in residuum (residual soil) resulted in widespread pits (also called shafts or diggings), and there was some underground mining of lead in bedrock.

For many years, barite was recovered from the residuum by hand mining, which also resulted in widespread diggings but generally not underground mines in bedrock. Mechanized open-pit mining of the residuum for barite began in the 1920's, and by the 1940's all barite mining was mechanized. Barite continued to be mined after lead mining had ceased, and more barite was produced than lead. Barite production slowed by the 1980's, and there has not been any barite mining since 1998. Missouri led the United States in barite production in most years from 1885 to 1971. Mechanized barite mining resulted in large mined areas and tailings ponds containing waste from barite mills.

The U.S. Environmental Protection Agency (EPA) has determined that lead is present in surface soils in Washington and Jefferson Counties at concentrations exceeding health-based screening levels. Also, elevated concentrations of barium, arsenic, and cadmium have been identified in surface soils, and lead concentrations exceeding the Federal drinking-water standard of 15 micrograms per liter (μg/L) have been identified in private drinking-water wells. Potential sources of these contaminants are wastes associated with barite mining, wastes associated with lead mining, or unmined natural deposits of barium, lead, and other metals. As a first step in helping EPA determine the source of soil and groundwater contamination, the U.S. Geological Survey (USGS), in cooperation with the EPA, investigated the geology and mining history of the Southeast Missouri Barite District and the Valles Mines.

The Southeast Missouri Barite District and the Valles Mines have some similarities but they are different primarily in two ways: (1) most of the mining at the Valles Mines was in bedrock, which in contrast to the Southeast Missouri Barite District where most of the mining was in the residuum; and (2) the Valles Mines was an important zinc-producing area, and barite was not as important of a product as in the Southeast Missouri Barite District. Zinc was not recovered during the early years of lead mining because it was not a valuable commodity at that time.

The Cambrian Potosi Dolomite is the most important formation in the Southeast Missouri Barite District and the Valles Mines because the residuum derived from it hosts most of the barite and lead in the Southeast Missouri Barite District, and ore also is found in the formation. The Cambrian Eminence Dolomite conformably overlies the Potosi Dolomite and is the second most important ore-bearing formation. Clayey residuum overlies the Cambrian and Ordovician formations in the study area and is mostly clay, but also contains chert, sand and sandstone, and drusy quartz and chalcedony, particularly where the residuum is developed from the Potosi Dolomite.

Barite (barium sulfate) is a primary ore mineral. The primary, and most important lead-ore mineral, is galena (lead sulfide). Secondary lead minerals are cerussite (lead carbonate; also called dry bone by the early miners) and anglesite (lead sulfate). These secondary lead minerals commonly are present as alteration products of galena and were locally important ore minerals. The primary zinc ore mineral is sphalerite (zinc sulfide); smithsonite (zinc carbonate) is a secondary mineral that also was mined as an ore mineral and was more important than sphalerite in some deposits, including the Valles Mines. Chalcopyrite (copper-iron sulfide) also is present in the ore deposits as a primary mineral and was recovered in a few mines.

Most of the ore that is present in bedrock is of one of two types: (1) runs or channels, also called pipes and pipe veins, are deposits with a larger horizontal than vertical extent with the vertical extent ranging from 1 to 6 feet (ft), and sometimes present in different levels; or (2) vertical crevice ore, also called fissures and veins, are vertical, tabular deposits that pinch out with depth and form along joints, with a greater vertical than horizontal extent, and which also are present as cross-veinlets. Breccia-filling ore also is present as vertical tabular masses cementing either fault or solution breccia. Ore in bedrock is characterized by open-space filling and less commonly replacement of the host dolomite.

Because galena, sphalerite, and barite are less soluble than dolomite, chemical weathering of the dolomite bedrock resulted in the concentration of ore minerals in the residuum, and most of the barite and lead mining was in the residuum, which averages 10 to 15 ft thick. Barite and lead concentration can be randomly distributed in the residuum or evenly distributed from top to bottom, but usually the richest ore was found at the bottom of the residuum near the bedrock surface.

Barite, known as tiff to the miners, varies in size from minute grains to large masses (as much as several hundred pounds), but is more commonly in pieces from about 1 to about 10 inches in size. Galena usually is present as small cubes but was sometimes found in masses as large as several hundred pounds. Sphalerite is present as layers and isolated clusters of black, greenish-black, light red, and tan crystals.

Barite textural zoning and mineralogic zoning are present in large, linear ore runs from about 1 to at least 6 miles long and from about 200 yards to about 2.5 miles wide in the Southeast Missouri Barite District. Barite textural zoning consists of a central zone of coarsely crystalline barite that grades (or sometimes more abruptly changes) outward to a zone of finely crystalline barite. Mineralogic zoning coincides spatially with the barite-textural zoning, with sulfides concentrated mostly in the center of runs.

Lead mining by French explorers may have begun in 1719 along Old Mines Creek at Cabanage de Renaudiere. This was followed shortly by the discovery of lead and the development of lead mines by Philippe Francois Renault at Mine Renault (also called Forche a Renault Mine), Old Mines, and at other places along the Big River, Mineral Fork, and Forche a Renault Creek. Renault continued to mine until 1744 when his mines closed; lead mining continued sporadically until about the end of the 18th century. Sometime between 1775 and 1780, Francis Azor and Peter Boyer discovered lead at the surface at what would become known as Mine a Breton (sometimes written as Mine a Burton), but the name later changed to Potosi.

A major advancement in lead mining in Missouri happened with the arrival in 1798 of Moses Austin, an American, who transformed lead mining from a seasonal endeavor carried out between the end of the harvest and winter to a year-round industry. Until this time most of the ore in the district was dug from shallow diggings. Austin sank a shaft to a depth of 80 ft in 1799 and erected a shot tower about 1 mile northwest of Potosi. Austin also established the port town of Herculaneum on the Mississippi River in 1809 and built a shot tower there.

Other mining areas in the Southeast Missouri Barite District were developed in the early part of the 19th century, including Fourche a Courtois in southwestern Washington County (also known as the Palmer Mines or the Shirley-Palmer area), the French Diggings and La Beaume Mines at what would become known as the Richwoods Mines in northeastern Washington County. Zinc became a valuable resource after the Civil War, and the Valles Mines was an important supplier of zinc as well as lead, with at least some production up until the 1920’s. Lead mines continued to operate during the Civil War, though at reduced production. It is unclear if production decreased or remained more or less uniform after the war through the latter part of the 19th century, but it did decline in the early part of the 20th century as mining in the Old Lead Belt, Mine La Motte, and the Tri-State District expanded.

Lead mining was primitive by modern standards, and production from individual mines was small compared to future production from underground mines of the Old Lead Belt and Viburnum Trend. The earliest lead mines were diggings (also called pits or shafts) in the residual soil and were normally 15–20 ft deep. Round holes about 4 ft in diameter were dug with pick and shovel, and a hand windlass and bucket were used to hoist material to the surface. The shafts were normally dug to bedrock where the ore commonly was concentrated, and drifts about 4 ft by 4 ft were dug a short distance laterally from the bottom of the shafts, undermining the residuum. The process was repeated a short distance away until a large area was covered with pits. Austin’s 1799 shaft was the first that was more like a modern shaft; later, more mining in the bedrock was done, with shafts as deep as 170 ft and up to several hundred feet of lateral drifts.

The material brought to the surface consisted of lead ore, which was mostly galena, with lesser cerussite and anglesite mixed with clay, dolomite, druzy quartz, zinc minerals, and barite. Galena was cleaned by cobbing with a hammer to remove clay and other gangue prior to smelting. Waste, which included cerussite, anglesite, zinc ore, and barite, until the value of these minerals increased sufficiently to warrant recovery, was discarded in dumps.

Smelting of the lead ore to elemental lead was first done using a log hearth, also called a log furnace, and was the only type of furnace used until 1798. Log furnaces were probably built wherever there was mining; there probably were many log furnaces in the Southeast Missouri Barite District and the Valles Mines. Log furnaces were inefficient; estimates have been made that only about 50 percent of the lead was recovered and the remainder was lost to the ashes (slags) and to volatilization. About 20 log furnaces were in operation near Potosi when Moses Austin arrived in 1798. Austin built two more-efficient reverbatory furnaces, one for smelting primary ore and the other for smelting ashes (called an ash furnace). An ash furnace thus supplemented the log furnace. Log furnaces and ash furnaces, sometimes collectively termed a log and ash furnace when they worked in tandem, were used in Missouri for many years but were gradually replaced by other furnaces, including the Scotch hearth. Estimates have been made that the recovery of lead by a Scotch hearth was 80–90 percent with 10–20 percent loss to slag and volatilization, but estimates of 67- and 70-percent recovery have been made. At least three types of reverbatory furnaces were used in Missouri: the ash furnace; the Drummond furnace, also called the air furnace; and the Flintshire furnace. Different estimates of the recovery of lead by an air furnace are 80–90 percent and 63 percent.

The first zinc furnace in Missouri was the Hesselmeyer Furnace built in Potosi in 1867 to smelt zinc ore from the Valles Mines. Zinc was more profitable than lead at the Valles Mines, but the furnace did not operate for very long. Much of the zinc ore was shipped out of the area, either to a smelter in St. Louis, Missouri, or to other smelters.

The total lead and zinc production from the Southeast Missouri Barite District and the Valles Mines is estimated at 180,000 tons of lead and 60,000 tons of zinc. An estimated 97,000 tons of lead and an estimated 120,000 tons of zinc were lost during smelting. The loss of zinc during smelting was likely not as widespread in the study area as that of lead. There were fewer zinc furnaces than lead furnaces, and most of the zinc smelting seems to have been outside the study area. The estimated losses do not include losses at the mine site during mining and preparation for smelting, such as the loss of fine-grained galena during hand cleaning or the discarding of zinc ore before its value was known, for which no estimates are available.

Barite mining in southeastern Missouri was active by at least the 1860’s. Mining was by hand for many years; production increased after 1905 as more uses for barite were developed. The peak of hand mining was from 1905 to the 1930’s, when several thousand people were engaged in barite mining. An important development happened around 1926 when barite began to be used as a weighting agent (drilling mud) for oil well drilling, leading to increased demand for barite. Mechanized open-pit mining of old barite diggings began in 1924 to recover barite left behind by hand mining, and large-scale washing plants were used to clean the clay from the barite. Hand mining, however, continued to thrive, and washer plants began to close in 1931, unable to compete with cheap labor of hand mining during the Great Depression. Nearly all of the barite produced before 1937 was by hand mining. Mechanized mining and washing returned in the 1940’s, and barite was last mined in Missouri in 1998.

Most of the barite that was mined in the Southeast Missouri Barite District was from the residuum, and for many years the mining method was hand digging in the same way as earlier lead mining. Barite also was cleaned by cobbing to remove clay and other impurities in much the same way as clay was separated from galena during lead mining. The barite was then placed in a rattle box, shaped somewhat like a baby’s cradle, which, when rocked back and forth, forced the barite against metal spikes inside the rattle box, further cleaning the barite.

Early mechanized mining used shovels powered by steam, gasoline, or electricity to mine the residuum to a depth of 12 to 15 ft, and ore was loaded onto rail cars for shipment to washer plants. The processing (milling) of barite ore was a matter of washing the barite to remove the clay, breaking the pieces of ore to reduce their size and remove coarse waste material, and then concentrating the barite. Clay was removed from the barite using a log washer, and a jig was used to concentrate the barite. Log washers consisted of paddles rotating around an axis (log) that, with the addition of water, removed clay from the ore. Overflow from the log washers was waste and went to a mud (tailings) pond. The coarse jig tailings went to tailings piles or were used as railroad ballast and, later, to create roads within the mine pit. By the 1940’s barite mining and processing were mechanized at a larger scale, using power shovels and, later, draglines and front end loaders to remove the ore, and trucks rather than rail cars for haulage to washer plants. Some barite was ground, depending on its final use, and some ground barite was bleached using a hot solution of sulfuric acid to remove impurities such as iron minerals and lead sulfide (galena). An earlier bleaching process used lead-lined tanks.

Large quantities of water were required for milling the barite; some was recirculated water and the remainder came from dammed streams or was pumped from wells. Tailings and wastewater were impounded behind dikes that were built across small valleys and were increased in height as necessary using washer waste and any overburden that had been stripped. In some cases, dikes were built across valleys that had already been mined for barite.

The total production of barite from the Southeast Missouri Barite District and the Valles Mines is estimated to have been about 13.1 million tons. Most of the barite production was from Washington County. Hand mining and processing of barite was inefficient. Estimates of barite recovery range from less than one-fourth to about one-half because the pillars between the shafts in the residuum needed to be left unmined for stability. Also, some barite (and galena) would have broken into smaller pieces in the rattle box and would have passed through the slots and onto the ground. With mechanized mining, large amounts of barite were lost during the milling process. It has been estimated that about 30 percent of the barite was lost and that about two-thirds of the lost barite was fine-grained and was discharged to the tailings ponds. Some galena was lost to the tailings ponds.

A 1972 inventory of tailings ponds by the Missouri Geological Survey identified 67 ponds in the Southeast Missouri Barite District. Four ponds were drilled, and samples were scanned using x-ray fluorescence spectrometry to determine barium concentrations, from which barite concentrations were calculated. Results from the 4 ponds were used to estimate that the 67 ponds contained almost 39 million tons (or cubic yards) of tailings averaging about 5 percent barite, for a potential reserve of 1.935 million tons of barite. The 67 tailings ponds inventoried in 1972 are fewer than the 93 tailings ponds in the study area listed in the IMOP database.

The ore deposits contained lead (and zinc) minerals as well as barite. It is not known how much lead was removed during barite mining, either by hand or mechanized mining and processing, how much lead was recovered, or how much lead went as fines to the tailing ponds or as coarse material to mine roads or was otherwise lost.

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Back cover photographs. Upper left: Barite (barium sulfate). Specimen on display at the Missouri Geology Survey, Rolla, Missouri (photograph by Douglas N. Mugel). Lower right: Galena (lead sulfide) (photograph by Douglas N. Mugel).

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