ASSESSMENT OF WATER QUALITY IN NON-COAL MINING AREAS OF MISSOURI

By B.J. Smith

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
ton	0.9072	megagram
square mile	2.590	square kilometer
mile	1.609	kilometer
cubic yard	0.7646	cubic meter
foot	0.3048	meter
acre	0.4047	hectare
inch	25.4	millimeter
gallon per minute	0.06308	liter per second

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ABSTRACT

A study was conducted in the non-coal mining areas of Missouri to determine whether mining has caused or has the potential to cause adverse changes in the water quality in the mined areas.

Lead and zinc mining have had the most significant effects on water quality. Some effects include possible contamination of aquifers and large quantities of trace elements in ground water, mine water, surface water, fish, and other aquatic life. In the Old Lead Belt, in southeastern Missouri, the lead concentration in two ground-water samples was 59 and 106 micrograms per liter. In southwestern Missouri, in the Tri-State district of Missouri, Oklahoma, and Kansas, the maximum zinc concentration in mine water was 35,000 micrograms per liter. The Missouri drinking-water standard for lead is 50 micrograms per liter and for zinc it is 5,000 micrograms per liter. Water quality in the Viburnum Trend, in southeastern Missouri, generally has been affected less than in the other two primary lead and zinc mining areas of the State.

In the Fredericktown subdistrict, in southeastern Missouri, where cobalt and nickel were mined, large quantities of trace elements have been detected in surface water and stream-bottom material. The cobalt concentration in a stream near a large tailings pile was 6,500 micrograms per liter, the nickel concentration was 9,900 micrograms per liter, and the copper concentration was 10,800 micrograms per liter. The lead content in stream-bottom material was 12,000 micrograms per gram in a sample from near Fredericktown. The Missouri water-quality standard for livestock and wildlife watering for cobalt is 1,000 micrograms per liter. The water-quality standard for protection of aquatic life for nickel is 1,000 micrograms per liter, and the drinking-water standard for copper is 1,000 micrograms per liter.

The primary effect of barite mining on water quality has occurred through the failure of tailings-pond dams. Dam failure results in sediment that enters the stream; this causes fish kills, damage to benthic environment, and esthetic degradation. Increased turbidity and suspended-sediment concentration have been detected downstream from iron-mining activities, which have occurred throughout much of southern Missouri. Data are insufficient to fully assess the water-quality effects caused by the mining of other non-coal minerals, including copper, manganese, silver, tungsten, sand and gravel, clay and shale, and stone.

There is need for additional study in the Old Lead Belt to determine if contamination is occurring and the magnitude and extent of any contamination. Localized ground-water contamination may occur in the Tri-State district and the Fredericktown subdistrict.

INTRODUCTION

Missouri is rich in mineral and water resources. From shallow abandoned pits dug by hand to underground mines excavated by the most modern equipment available, mining has affected the water resources of the State. In addition to active mines, 1,520 abandoned and inactive underground metal-producing and 36 nonmetal-producing mines have been documented in Missouri (Baker, 1975).

The Abandoned Mine Land Section of the Missouri Land Reclamation Commission, the Missouri Department of Natural Resources, Division of Environmental Quality, is responsible for the identification and evaluation of the effects of abandoned mine lands on the environment and human health. The U.S. Geological Survey, in cooperation with the Missouri Land Reclamation Commission, investigated the effects of mineral extraction, excluding coal, on the water resources as related to human health and aquatic life, and livestock and wildlife in Missouri.

Purpose and Scope

The purpose of this study, the results of which are described in this report, was to determine whether mining of non-coal minerals in Missouri has caused or has the potential to cause adverse changes in the water quality in the mined areas. An integral part of the study was a literature review to identify the non-coal minerals produced in the State, to determine location of mining, period and method of mining, and disposal of waste material. Effects of mining on water quality in a given area were determined and previous investigations concerning water quality in these areas were reviewed. Areas with water resources affected by mining were located, and areas that need additional study were identified.

Acknowledgments

The author expresses appreciation to the following for technical assistance and documentation of previous investigations: J.A. Martin, Missouri Division of Geology and Land Survey; J.C. Ford, C.S. Decker, and J.A. Burris, Missouri Water Pollution Program; F.M. Ryck, Jr. and Linden Trial, Missouri Department of Conservation; B.G. Wixson, University of Missouri-Rolla; J.E. Teiger and T.J. Nash, U.S. Fish and Wildlife Service; R.J. Smith, U.S. Army, Corps of Engineers; and R.D. McCumer, A.P. Green Refractories. Thanks are extended to J.E. Carter, St. Joe Minerals Corporation, for information on mining and a tour of the Old Lead Belt.

TRACE ELEMENTS AND CHEMICAL CONSTITUENTS

Trace elements and chemical constituents generally are detected in ground and surface water in small concentrations, and some are considered essential to animal life. However, certain trace elements and chemical constituents, in sufficiently large quantities, are toxic to humans, aquatic life, and livestock and wildlife. Large concentrations of these elements and constituents may occur naturally, but commonly are associated with mining (Detroy, Skelton, and others, 1983).

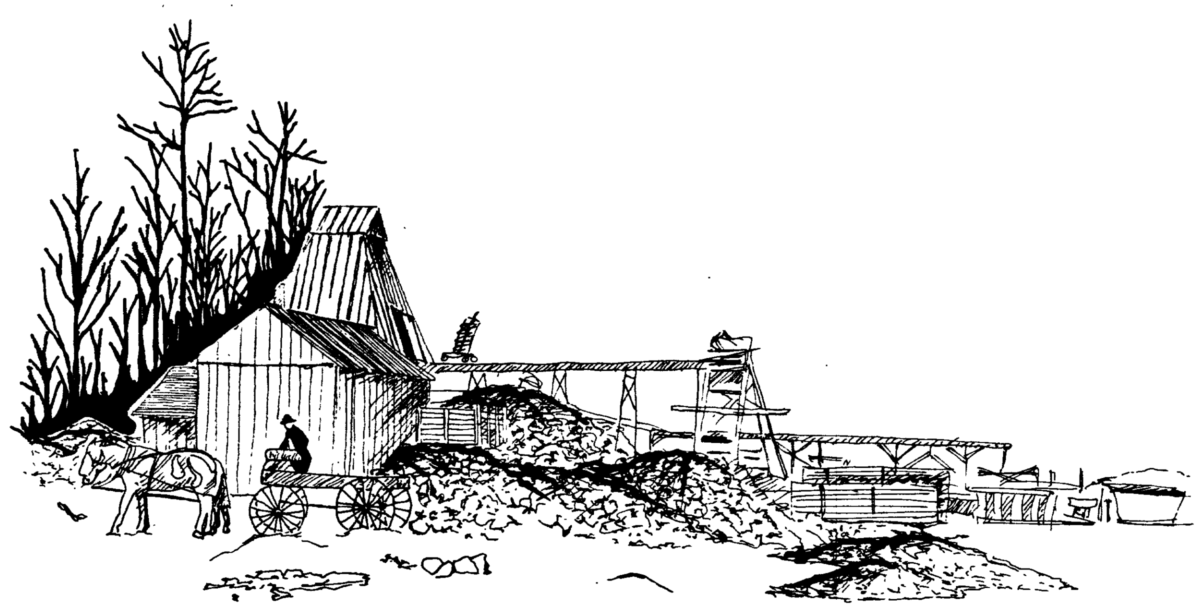
Missouri water-quality Standards

Water-quality standards for drinking water, protection of aquatic life, and livestock and wildlife watering have been established for trace elements and chemical constituents. The standards established by the State of Missouri for selected trace elements and chemical constituents are shown in table 1 (Missouri Department of Natural Resources, 1984).

Table 1.--Missouri water-quality standards

[All values in micrograms per liter, unless otherwise noted; mg/L, milligrams per liter; --, no standard determined; values for trace elements are dissolved]

	Drinking-water supply	Protection of aquatic life	Livestock, wildlife watering
Arsenic	50	20	--
Barium	1,000	--	--
Cadmium	10	12	--
Cobalt	--	--	1,000
Copper	1,000	20	500
Iron	300	1,000	--
Lead	50	50	--
Nickel	--	100	200
Selenium	10	10	--
Zinc	5,000	100	2,000
Sulfate, mg/L	250	--	--



Known or Potential Effects of Selected Trace Elements and Chemical Constituents on Human Health and Aquatic Life

Arsenic is associated with lead and zinc ores, commonly as arsenopyrite. Arsenic is thought to be carcinogenic. Symptoms of arsenic poisoning in humans include fatigue, loss of energy, kidney degeneration, and altered skin pigmentation. The drinking-water standard for arsenic established by Missouri is 50 µg/L (micrograms per liter; Missouri Department of Natural Resources, 1984). Long-term survival of benthic organisms would be possible with an arsenic content as large as 1,920 µg/g (micrograms per gram) in stream-bottom material (U.S. Environmental Protection Agency, 1976b). Missouri has established a standard of 20 µg/L for protection of aquatic life (Missouri Department of Natural Resources, 1984); no standard has been established for livestock and wildlife.

Barium, occurring in barite, can cause an increase in blood pressure by constricting the blood vessels in humans. Adverse gastrointestinal effects, such as vomiting and diarrhea, also can be caused by barium (U.S. Environmental Protection Agency, 1976a). The drinking-water standard for barium established by Missouri is 1,000 µg/L (Missouri Department of Natural Resources, 1984). Barium concentration generally would have to exceed 50,000 µg/L before toxicity to aquatic life would be expected. In a stream environment, sufficient sulfate or bicarbonate ions may be present to precipitate barium (U.S. Environmental Protection Agency, 1976b). No standards have been established by Missouri for protection of aquatic life or livestock and wildlife.

Cadmium occurs in zinc ores. Cadmium has no known beneficial value to human health and can be toxic to humans when ingested or inhaled. Cadmium is stored in the kidneys and liver and is slowly excreted. Excessive quantities can produce chronic kidney disease. Excessive quantities also can produce itai-itai disease that causes the bones to become flexible. The drinking water standard for cadmium established by Missouri is 10 µg/L (Missouri Department of Natural Resources, 1984). Cadmium can affect growth, survival, and reproduction in aquatic life (U.S. Environmental Protection Agency, 1976b). Missouri has established a standard of 12 µg/L for protection of aquatic life (Missouri Department of Natural Resources, 1984); no standard for livestock and wildlife has been established.

Cobalt occurs in sulfide ores and is commonly associated with nickel. A water-quality standard for cobalt has not been established for drinking water supply or for protection of aquatic life. A cobalt concentration of 1,000 µg/L has been established for livestock and wildlife watering (Missouri Department of Natural Resources, 1984).

Copper occurs in sulfide ores, commonly as chalcopyrite. Excessive concentrations of copper in drinking water may cause liver damage in humans, but public drinking-water supplies seldom have copper concentrations large enough to cause such damage. Copper concentrations larger than 1,000 µg/L may have adverse taste effects (U.S. Environmental Protection Agency, 1976b). For this reason, Missouri has established a standard of 1,000 µg/L (Missouri Department of Natural Resources, 1984). Toxicity of copper to aquatic life is dependent upon hardness, pH value, and presence of organic compounds in water. Adult fish may tolerate relatively large concentrations of copper for short periods of time, but copper is more toxic to young fish. In most natural fresh waters in the United States, copper concentrations of less than 25 µg/L are not immediately fatal to most common fish species (U.S. Environmental Protection Agency, 1976b). Missouri has established a standard of 20 µg/L for protection of aquatic life. To protect livestock and wildlife, Missouri has established a standard of 500 µg/L (Missouri Department of Natural Resources, 1984).

Iron is prevalent throughout Missouri, both in ore deposits in mining areas and in soils and rocks in nonmining areas; therefore, concentrations of iron in water generally are moderate to large. The drinking-water standard of 300 µg/L for iron was established to minimize adverse taste effects and staining of laundry and plumbing fixtures (Missouri Department of Natural Resources, 1984; U.S. Environmental Protection Agency, 1979). Iron hydroxides may inhibit the respiratory function of fish gills, and large concentrations may smother fish eggs (Colorado Department of Health, 1976). To protect aquatic life, Missouri has established a standard of 1,000 µg/L (Missouri Department of Natural Resources, 1984); no standard has been established for livestock and wildlife.

Lead is a toxic metal that accumulates in tissues of humans and other animals. Largest accumulations of lead occur in the liver and kidneys. Lead concentration in water is a primary concern for small children because their food and water consumption is proportionally larger than an adult's. A narrow range exists between acceptable daily exposure and exposure that is considered harmful. This narrow range makes it imperative that the standard of 50 µg/L for lead in drinking-water supplies be rigidly adhered to (Missouri Department of Natural Resources, 1984; U.S. Environmental Protection Agency, 1976a). The health and environmental effects of lead are similar to cadmium and can affect growth, survival, and reproduction in aquatic life (U.S. Environmental Protection Agency, 1976b). For these reasons, Missouri has established a standard of 50 µg/L to protect aquatic life (Missouri Department of Natural Resources, 1984); no standard has been established for livestock and wildlife.

Nickel is associated with sulfide ores. Nickel is nontoxic to humans, but it can impair species reproduction in aquatic life. Sensitivity to nickel varies among species of aquatic life; sensitivity varies with changes in physical and chemical characteristics of the water (U.S. Environmental Protection Agency, 1976b). A standard for nickel of 100 µg/L has been established by Missouri for protection of aquatic life and a standard of 200 µg/L has been established for livestock and wildlife (Missouri Department of Natural Resources, 1984).

Selenium occurs in sulfide ores and is present in small quantities in pyrite. Selenium is toxic to humans and aquatic organisms and produces symptoms similar to arsenic. The presence of arsenic in drinking water accentuates the toxicity of selenium. A standard of 10 µg/L has been established for drinking water and for protection of aquatic life (Missouri Department of Natural Resources, 1984); no standard has been established for livestock and wildlife.

Zinc is an essential and beneficial trace element for humans. Zinc deficiency can result in growth retardation. Excessive quantities in drinking water can produce adverse taste effects and possible adverse gastrointestinal effects. The drinking water standard of 5,000 µg/L is intended to prevent adverse taste effects (Missouri Department of Natural Resources, 1984; U.S. Environmental Protection Agency, 1979). Zinc can be exceedingly toxic to aquatic life. Zinc is similar to other trace elements because the degree of toxicity to aquatic life is dependent on several factors, including hardness of water, dissolved-oxygen concentration, water temperature, and pH value. In fish, zinc can induce cellular breakdown of the gills, can cause general enfeeblement and changes to other organs, and possibly can clog the gills with mucus (U.S. Environmental Protection Agency, 1976b). Missouri has established a standard of 100 µg/L to protect aquatic life. Because livestock and wildlife are more tolerant to zinc, a standard of 2,000 µg/L has been established (Missouri Department of Natural Resources, 1984).

Sulfate, like iron, is prevalent in water throughout Missouri; larger concentrations generally are associated with mining areas where sulfide minerals comprise a large percentage of the ore. Excessive sulfate can cause adverse taste effects and may produce a laxative effect in humans. The drinking water standard of 250 mg/L (milligrams per liter) sulfate has been established to prevent that effect (Missouri Department of Natural Resources, 1984). No standards have been established for aquatic life or livestock and wildlife.

MINING OF LEAD AND ZINC AND WATER QUALITY IN MINED AREAS

Lead and zinc usually occur together in ore deposits and will be discussed together in this report. Lead and zinc ores have been and presently (1987) are being mined in southern Missouri. By 1967 more than 10.8 million tons of lead valued at more than $1.6 billion, and more than 3.7 million tons of zinc valued at more than $500 million were produced from these ores (Wharton and others, 1969).

Three general areas of lead and zinc deposits have been outlined in southern Missouri (fig. 1). Zinc was the primary metal mined in the southwest region; lead was and is the primary metal mined in the central and southeast districts. The southwest region includes the Missouri part of the Tri-State district (Missouri, Oklahoma, and Kansas), where most of the mining in the southwest region occurred. From 1870 to 1879 the value of zinc and lead produced from the Tri-State district exceeded $16 million. From 1858 to 1945, when mining virtually ceased, estimated value of production from the eastern part of the southwest region was $10 million (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967). Hydrologic effects of mining in the Tri-State district will be discussed in the following section. Insufficient data are available to determine the magnitude and extent of the hydrologic effects of mining in the eastern part of the southwest region.

The central district includes numerous small deposits mined for lead, zinc, and barite in an area of about 2,000 square miles. Lead and zinc produced before 1947 were valued at less than $4 million. The last year of zinc production was 1945; the last year of lead production was 1950 (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967). Insufficient data are available to determine the magnitude and extent of the hydrologic effects of mining in the central district.

Lead and zinc deposits have been mined at numerous locations throughout the southeast district. Except for the Old Lead Belt and the Viburnum Trend subdistricts, where most of the mining for lead and zinc has occurred, and the Fredericktown subdistrict, where cobalt and nickel also were mined, insufficient data are available to determine the magnitude and extent of the hydrologic effects of mining in the southeast district.

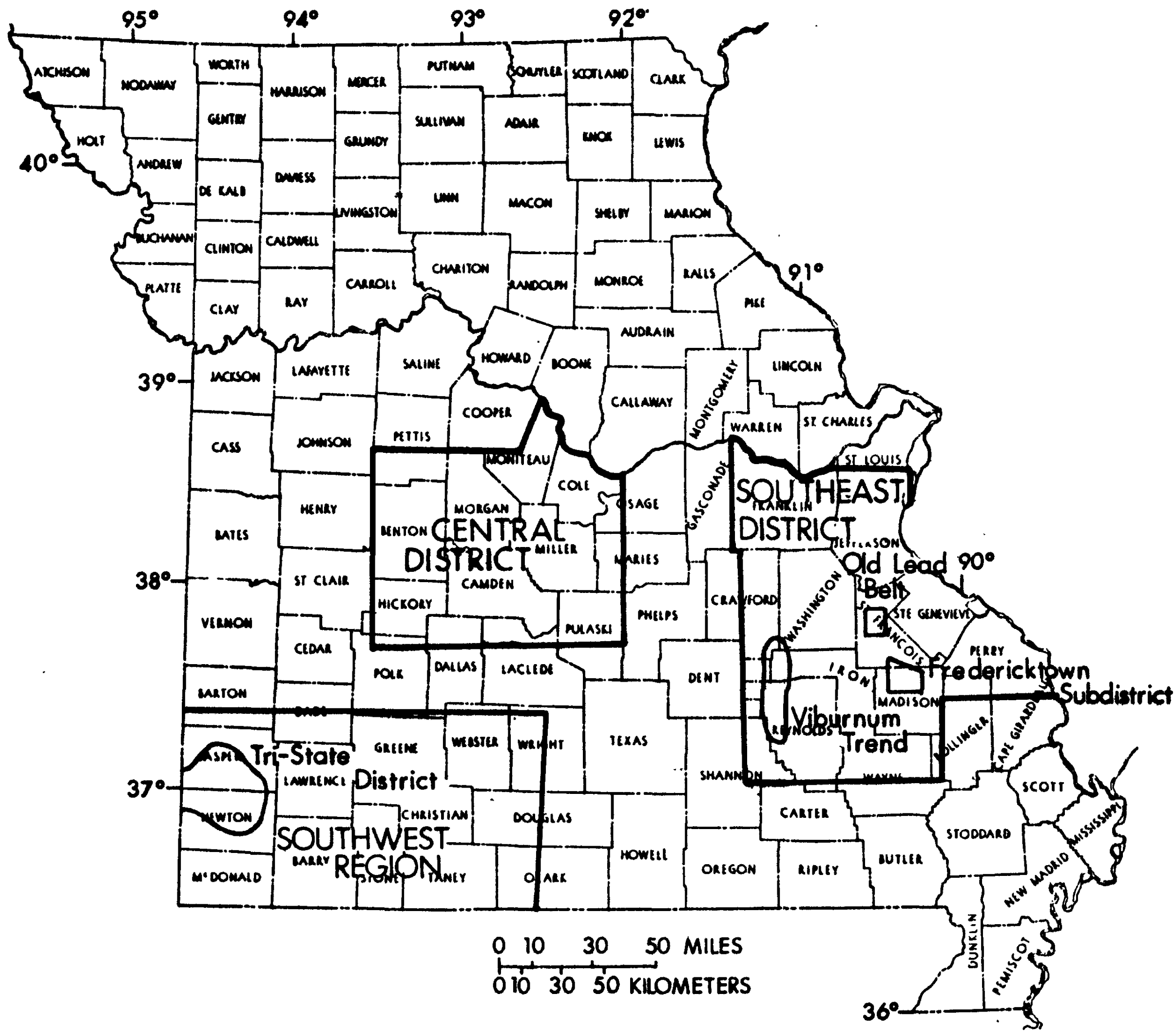


Figure 1.--Principal lead- and zinc-producing areas (modified from U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Tri-State District

Lead and zinc deposits of the Tri-State district formed one of the most productive mining districts in the world (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967). About 460 million tons of lead and zinc ore were produced from the Tri-State district, and about 40 percent of the production was from the Missouri part of the district (Spruill, 1984).

In Missouri, most mining operations were in the vicinity of Joplin, Jasper County, in southwestern Missouri (fig. 2). Mining operations extended from the Kansas State line eastward about 55 miles, north of Joplin about 12 miles, and south of Joplin about 15 miles (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Mining Activity

Lead mining began during 1848 east of Joplin. At that time, zinc ore, associated with lead ore, was not mined because of economic infeasibility (Brichta, 1960). From 1850 to 1869, Granby was the most significant mining camp, and zinc was first mined there during 1870. Discoveries of large lead deposits within the present (1987) city limits of Joplin resulted in rapid expansion for the Tri-State district during 1870. Before 1876, when ore deposits were discovered in Kansas, mining was confined to Missouri. From 1890 to 1900 mining continued to increase and the value of zinc mined exceeded that of lead. During 1911 and 1912, mining operations began to shift to Oklahoma after large ore deposits were discovered. However, Missouri had its largest tonnage and revenue from the Tri-State district during 1916 and was the leader in production until 1918. Since 1957, no production has been reported from Missouri, except for one small mining operation in Jasper County during 1966 (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Deposits were classified as circles, runs, and sheet ground. Circle deposits were relatively shallow, mineralized breccia in sinkholes; some of the smaller deposits were mined by underground methods, whereas the larger deposits were mined by open-pit methods. Runs, or linear deposits, were the source of most of the production throughout the Tri-State district. Sheet-ground deposits were horizontal deposits along bedding planes and were significant near Joplin and Granby (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967). Runs and sheet-ground deposits commonly were mined by underground methods.

A total of 9,606 mine openings were mapped in an area of about 230 square miles in the vicinity of Joplin; 2,033 openings were shafts and 7,573 were prospect holes. Of the total, 469 were classified as hazardous sites because of open shafts and pits, or land subsidence (McFarland and Brown, 1983).

Disposal of Tailings

Tailings, or mining and milling wastes, were separated into surface piles according to the size of the waste material. About 80 percent of the tailings have been removed or reworked (Stewart, 1980); however, about 8 million cubic yards of tailings remain (McFarland and Brown, 1983).

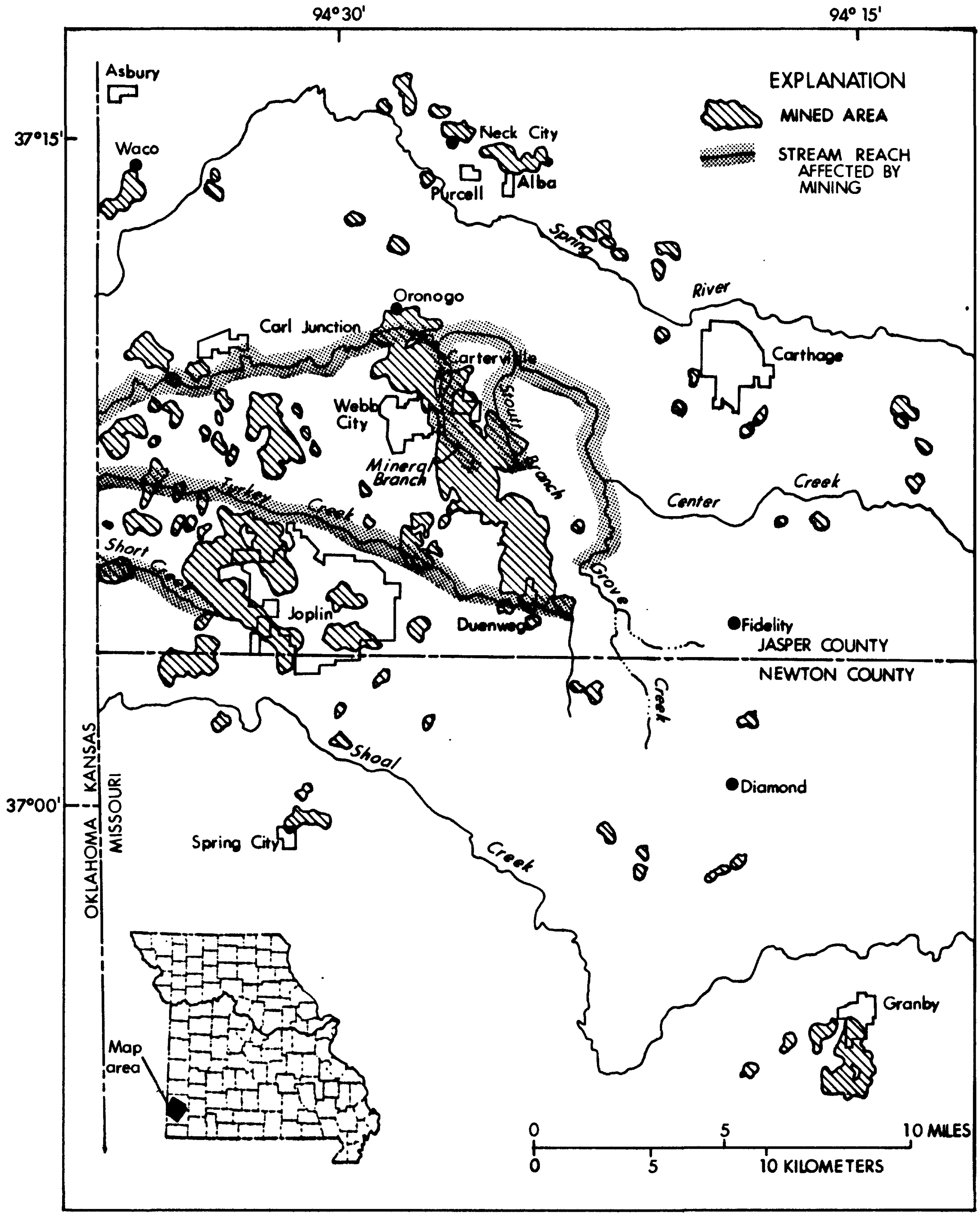


Figure 2.--Mined areas and affected streams in the Missouri part of the Tri-State zinc-lead district (modified from Brichta, 1960).

Water Quality in Mined Areas

Effects of mining on water quality generally are confined to surface-water flows of perennial streams. The ground-water has been affected little, or none at all, except where wells have intersected underground zones of ore deposition (Stewart, 1980).

Potential effects of mining on water quality

Two aquifers are present in the Joplin area. The shallow aquifer consists of Mississippian chert and limestone about 300 feet thick. The deep aquifer, separated from the shallow aquifer in most places by a confining unit of shale and dense limestone, is composed of Cambrian and Ordovician dolostone (Feder and others, 1969). Fractures, faults, abandoned wells, and prospect drill holes may cause the two aquifers to be hydraulically connected. Contamination of the shallow aquifer may exist from lateral migration of water from abandoned underground mines. Water levels in the deep aquifer are lower than those in the shallow aquifer because of water withdrawals from past mining activities and increased domestic and industrial use. This may cause the downward movement of water from the shallow aquifer into the deep aquifer and, consequently, may result in contamination of the deep aquifer (Spruill, 1984).

Mine-water discharge and runoff from tailings piles are sources of trace elements in streams. Runoff from tailings piles also may add sediment that has a large trace-element content into the streams. Increased trace-element content, concentrated and deposited in stream-bottom material, can result from wastewater discharges from mining activities (Barks, 1977). Base flow can be provided by ponded water in tailings piles that seeps into nearby streams.

Ground water

From 1964 to 1966, analyses of water from 39 shallow wells in four counties, most of which were in Jasper County, had dissolved-zinc concentrations that ranged from 50 to 6,700 µg/L, dissolved-iron concentrations ranged from almost zero to 2,400 µg/L, dissolved-sulfate concentrations that ranged from 1.6 to 466 mg/L, and dissolved-solids concentration that ranged from 162 to 981 mg/L. Large median dissolved concentrations of zinc (900 µg/L) and iron (240 µg/L) in water from shallow wells probably were caused by galvanized plumbing or mineral deposits or both (Feder and others, 1969).

Barks (1977) sampled 21 shallow wells in the western one-half of Jasper County in 1976. Lead concentrations ranged from 2 to 38 µg/L, zinc concentrations ranged from 20 to 8,800 µg/L, cadmium concentrations ranged from almost zero to 30 µg/L, iron concentrations ranged from almost zero to 2,600 µg/L, and sulfate concentrations ranged from about zero to 560 mg/L (all concentrations were dissolved). Galvanized plumbing or mineral deposits, or both may have caused average dissolved concentrations of zinc and iron to be 1,100 µg/L and 350 µg/L (Barks, 1977). Shallow wells in or near mines may have large dissolved trace-element concentrations, but few data exist to indicate widespread movement of mineralized water into the shallow aquifer.

Water from the deep aquifer generally is of suitable quality for most purposes. Of 38 deep wells sampled from 1932 to 1965, dissolved-iron concentrations ranged from almost zero to 1,700 µg/L and dissolved-sulfate concentrations ranged from 3.7 to 68 mg/L. Lead concentrations were 10 µg/L or less and zinc concentrations ranged from less than 100 to 270 µg/L in samples from five deep wells analyzed for dissolved trace-element concentrations in 1965 (Feder and others, 1969).

Analyses of water samples from 14 deep wells in the western one-half of Jasper County during 1976 indicated that lead concentrations ranged from 2 to 31 µg/L, zinc concentrations ranged from 20 to 350 µg/L, cadmium concentrations ranged from almost zero to 2 µg/L, iron concentrations ranged from almost zero to 170 µg/L, and sulfate concentrations ranged from 14 to 110 mg/L (all concentrations were dissolved). Analyses of samples from two wells in Webb City and one well in Carthage indicated some mixing of water from the shallow and the deep aquifer, based on zinc, sulfate, and dissolved-solids concentrations (Barks, 1977). Analysis of water from a well completed in the deep aquifer in Webb City near an underground mine containing water with a large dissolved-solids concentration (840 µg/L) indicated the possibility of mine-water contamination (Barks, 1977).

Analyses of samples collected from 1925 to 1964 indicated that water from springs generally was more uniform in chemical composition than well or mine water. Dissolved-iron concentrations ranged from almost zero to 770 µg/L, dissolved-sulfate concentrations ranged from 1.2 to 192 mg/L, and dissolved-solids concentrations ranged from 123 to 520 mg/L (Feder and others, 1969).

Water from 24 mine shafts and open-pit lakes in Mississippian rocks was collected during 1964. Dissolved-lead concentrations ranged from 20 to 150 µg/L. Dissolved-zinc concentrations ranged from 200 to 35,000 µg/L and had a median value of 7,700 µg/L. Iron concentrations ranged from almost zero to 33,000 µg/L and dissolved-sulfate concentrations ranged from 104 to 1,350 mg/L (Feder and others, 1969).

Water in 14 underground mines that were sampled during 1976 had lead concentrations that ranged from 4 to 28 µg/L; zinc concentrations ranged from 540 to 17,000 µg/L, and had an average concentration of 9,400 µg/L. Cadmium concentrations ranged from 2 to 54 µg/L, iron concentrations ranged from 20 to 67,000 µg/L, and sulfate concentrations ranged from 140 to 1,100 mg/L (all concentrations were dissolved; Barks, 1977).

Surface water and stream-bottom material

Surface drainage from eight tailings areas in 1976 had lead concentrations that ranged from 3 to 1,300 µg/L. Zinc concentrations ranged from 540 to 35,000 µg/L. Cadmium concentrations ranged from 1 to 74 µg/L, iron concentrations ranged from 10 to 390 µg/L, and sulfate concentrations ranged from 25 to 490 mg/L (all concentrations were dissolved). Runoff from the tailings can sustain large dissolved metal and sulfate concentrations in area streams during storm runoff. Storm drainage from a 7-acre tailings area northeast of Joplin was collected before it entered Stoutt Branch. After a 5-inch rain, dissolved-lead concentrations in drainage ranged from 56 to 400 µg/L. Dissolved-zinc concentrations ranged from 3,800 to 200,000 µg/L. Dissolved-cadmium concentrations ranged from 46 to 1,400 µg/L, dissolved-iron concentrations ranged from 30 to 340 µg/L, and dissolved-sulfate concentrations ranged from 22 to 390 mg/L (Barks, 1977).

Large zinc concentrations in Center Creek probably are derived from zinc concentrations in Grove Creek, Stoutt Branch, and Mineral Branch. In 1966 dissolved-zinc concentration in Grove Creek was 9,700 µg/L. In Center Creek, downstream from Grove Creek in the area affected by mining, dissolved-zinc concentrations ranged from 410 to 1,000 µg/L (Feder and others, 1969). In

Center Creek from near Fidelity to near the Kansas State line, the dissolved-zinc concentration increased from 20 (in the unmined area) to 700 µg/L. For this reach of Center Creek, zinc content in bottom material increased from 110 to 540 µg/g, and the lead content increased from 10 to 350 µg/g. Increases in zinc concentration during base flow probably were caused by mine discharges into Mineral Branch, which had dissolved-zinc concentrations that ranged from 6,000 to 19,000 µg/L. During high flow, the dissolved-zinc concentration in Center Creek is sustained from seepage and runoff from tailings that primarily discharge to Stoutt Branch and Mineral Branch. A dissolved-zinc concentration of 18,000 µg/L was measured in Stoutt Branch in 1976 (Barks, 1977).

All of Turkey Creek that has perennial flow has been affected by mining. Substantial quantities of tailings were present in the streambed. In 1976, the average dissolved-lead concentration in water was 14 µg/L and the average lead content in stream-bottom material was 230 µg/g. The average dissolved-zinc concentration in water was 200 µg/L and the average zinc content in stream-bottom material was 2,300 µg/g. In addition to effects from past mining activities, runoff from urban areas and discharge from a sewage-treatment plant at Joplin contribute to the flow in Turkey Creek downstream from Joplin (Barks, 1977).

In July 1969, during low flow, Short Creek had a lead concentration of 40 µg/L, a zinc concentration of 32,000 µg/L, a cadmium concentration of 330 µg/L, a sulfate concentration of 2,500 mg/L, and a pH of 3.4 (all concentrations were dissolved). In March 1976, during greater than average flow, Short Creek had a lead concentration of 8 µg/L, a zinc concentration of 1,600 µg/L, a sulfate concentration of 120 mg/L, and a pH of 5.9 (all concentrations were dissolved). In addition to the effects of mining, the stream probably is affected by seepage from a gypsum pile that receives effluent from a fertilizer plant (Barks, 1977).

Streams in the Tri-State district that are considered not to be affected by mining include the Spring River, Center Creek upstream from the mouth of Grove Creek, and Shoal Creek (Feder and others, 1969). From 1962 to 1982 at Shoal Creek above Joplin, median dissolved concentrations included: lead, 5 µg/L; zinc, 47 µg/L; and sulfate, less than 10 mg/L (J.V. Davis, U.S. Geological Survey, written commun., 1987). In mined areas, these streams may have short reaches where water contains large trace-element concentrations; such reaches also may occur in tributaries of the Spring River near Alba, Neck City, and Waco. Tributaries of Shoal Creek near Granby and Joplin may also be affected (Missouri Water Pollution Control Program, 1984).

Trace-Element Content in Biota Tissue

The World Health Organization (1972) has established a maximum daily safe dietary intake of lead of 0.3 µg/g. In June 1981, 157 fish were collected from the Spring River, Center Creek, Turkey Creek, and Shoal Creek and analyzed for lead content in edible tissue. Six types of fish were collected, including two species of benthic-feeding suckers. The mean lead content in the fish tissues ranged from 0.03 ± 0.009 to 0.11 ± 0.03 µg/g (Czarnezki, 1985).

Decreased numbers and diversity of benthic invertebrate organisms have been attributed to the large concentration of zinc in Center Creek and to wastes from industries that manufacture phosphorus and nitrogen fertilizer and explosives (Howland, 1974; Missouri Water Pollution Control Program, 1984). From 1961 to 1965, the number of the organisms was decreased and the diversity was unbalanced in Center Creek downstream from the mouth of Grove Creek, which receives the wastes from the industries. After 1965, the benthos count had increased, probably because of process modifications, improved waste treatment, and recycling of waste discharges by the various industries, but the total number of organisms still was minimal (Howland, 1974). A similar condition of decreased number and unbalanced diversity of organisms has been documented for Turkey Creek (Ryck, 1974a; SCS Engineers, 1984).

Old Lead Belt

For more than 100 years lead was mined from the Old Lead Belt in Missouri. From 1907 to 1953 this area was the Nation's largest producer of lead. About 8 million tons of lead were produced (Kramer, 1976).

The Old Lead Belt is in southeastern Missouri about 70 miles south of St. Louis (fig. 3). Located entirely within St. Francois County, the Old Lead Belt has an area of about 110 square miles in the central part of the southeast district (Kramer, 1976).

Mining Activity

Lead was discovered in southeastern Missouri about 70 miles west of the Old Lead Belt in about 1700 (Kramer, 1976). In 1720, lead was discovered in Madison County, south of St. Francois County. Before the mid-1860's, lead mining consisted of individual, shallow workings, scattered throughout the southeast district. The St. Joseph Lead Co. acquired 964 acres in St. Francois County and began mining at Bonne Terre in 1864. In 1869 diamond-bit core drilling indicated lead deposits underlying Bonne Terre, Desloge, Flat River, Leadwood, and Elvins. From the late 1800's to the early 1900's as many as 15 companies operated mines in the area. By 1933 the St. Joseph Lead Co. had acquired the properties of the other mining companies in the area. The St. Joseph Lead Co. mined at Bonne Terre from 1864 to 1961, at Desloge from 1929 to 1958, and at Leadwood from 1915 to 1962 (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967). The mines were gradually shutdown during the late 1950's and early 1960's as the ore deposits were depleted and production from the Viburnum Trend (New Lead Belt), with its higher grade ore, exceeded that of the Old Lead Belt. In October 1972, the Federal Division of the St. Joseph Lead Co., the last mining operation in the Old Lead Belt, closed (Kramer, 1976).

Early mining in the Old Lead Belt was restricted to lead crystals that could be removed from shallow pits. Most of the surface deposits were depleted by the mid-1860's. From 1800 to 1850 a few mine shafts as much as 80 feet deep were completed in the Cambrian dolostone. However, until 1869, shallow workings, either pit or trench, were the primary means of ore removal. Ore deposits were discovered about 120 feet beneath several of the present day towns in the area during 1869 using diamond-bit core drilling (Kramer, 1976). Numerous underground shafts were excavated to remove the ore. About 100,000 diamond drill holes were completed (Snyder and Gerdemann, 1968). About 250 miles of underground railroad lines connected mines in Leadwood, Flat River, and Elvins (Kramer, 1976).

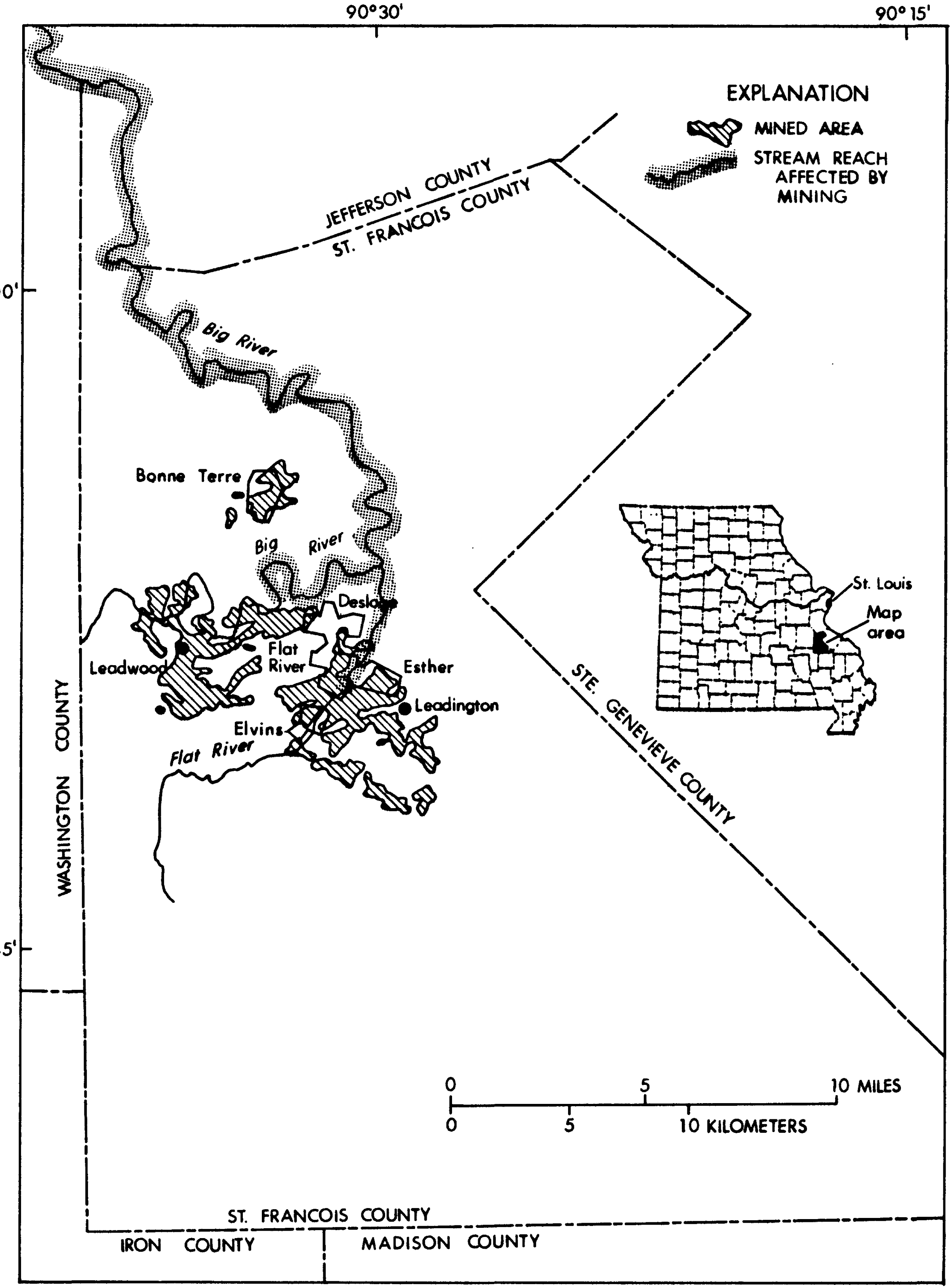


Figure 3.--Mined areas and affected streams in the Old Lead Belt (modified from Association of Missouri Geologists, 1969).

Disposal and Trace-Element Content of Tailings

During the early years of mining in the Old Lead Belt, coarse tailings were produced from mechanical separators that concentrated the ore. With improvements in technology, chemical separators were introduced that produced finer-grained tailings (Wixson and others, 1982). However, both methods produced tailings that contained varying quantities of trace elements. About 250 million tons of tailings were produced in the Old Lead Belt (Kramer, 1976). The tailings were placed in piles directly on the land surface (fig. 4), some close to streams and some covering hundreds of acres. The Big River drainage basin is estimated to contain about 3,000 acres of tailings (Kania and Nash, 1986).

In the late 1970's, the lead content in tailings from the Desloge tailings pile ranged from 850 to 2,400 µg/g. The zinc content ranged from 680 to 1,000 µg/g, the cadmium content ranged from 14 to 25 µg/g, and the copper content ranged from 11 to 41 µg/g (Novak and Hasselwander, 1980).

In 1975, the lead content in tailings from the Elvins tailings pile ranged from 2,360 to 26,200 µg/g. The zinc content ranged from 288 to 20,900 µg/g, the cadmium content ranged from 8 to 158 µg/g, and the copper content ranged from 12 to 610 µg/g. The largest content of trace elements was detected in the smallest size fraction, which is susceptible to surface-water runoff and wind transport (Kramer, 1976).

In 1981, the lead content in tailings from the National tailings pile ranged from 1,177 to 9,283 µg/g. The zinc content ranged from 34 to 5,055 µg/g with most values less than 1,000 µg/g. The cadmium content ranged from 2 to 87 µg/g, and the copper content ranged from 32 to 628 µg/g (Elliot, 1982). No data are available for the trace-element content of the Bonne Terre, Leadwood, and Federal tailings piles.

A primary concern in the Old Lead Belt is erosion of tailings piles and deposition of the tailings in streams and adjacent areas. The Desloge tailings pile was used from 1929 to 1958 and covers about 500 acres. At the present time (1987), part of the tailings pile is used as a landfill. In December 1977, about 50,000 cubic yards of tailings were washed into the Big River from the Desloge tailings pile after intense rainfall. Additional material may be washed into the Big River because the slopes of the pile are steep and unstable and may be undercut by the Big River (Novak and Hasselwander, 1980).

Water Quality in Mined Areas

Water quality in the Old Lead Belt has been affected to a large extent by the tailings piles in the area. Increased quantities of trace elements can occur in both water and stream-bottom sediment.

Potential effects of mining on water quality

In the Old Lead Belt, ore deposits were mined from the same stratigraphic unit that is the aquifer for the area. Lateral migration of water containing large trace-element concentrations from the abandoned, flooded underground mines may cause contamination. Runoff and seepage from tailings piles also are a source that can supply trace elements to the receiving streams. Wind and intense rainfall can erode the tailings piles and transport the tailings into the environment (Zachritz, 1978). Deposition of tailings in streambeds can occur tens of miles from the source of tailings (Missouri Water Pollution Board, 1964).

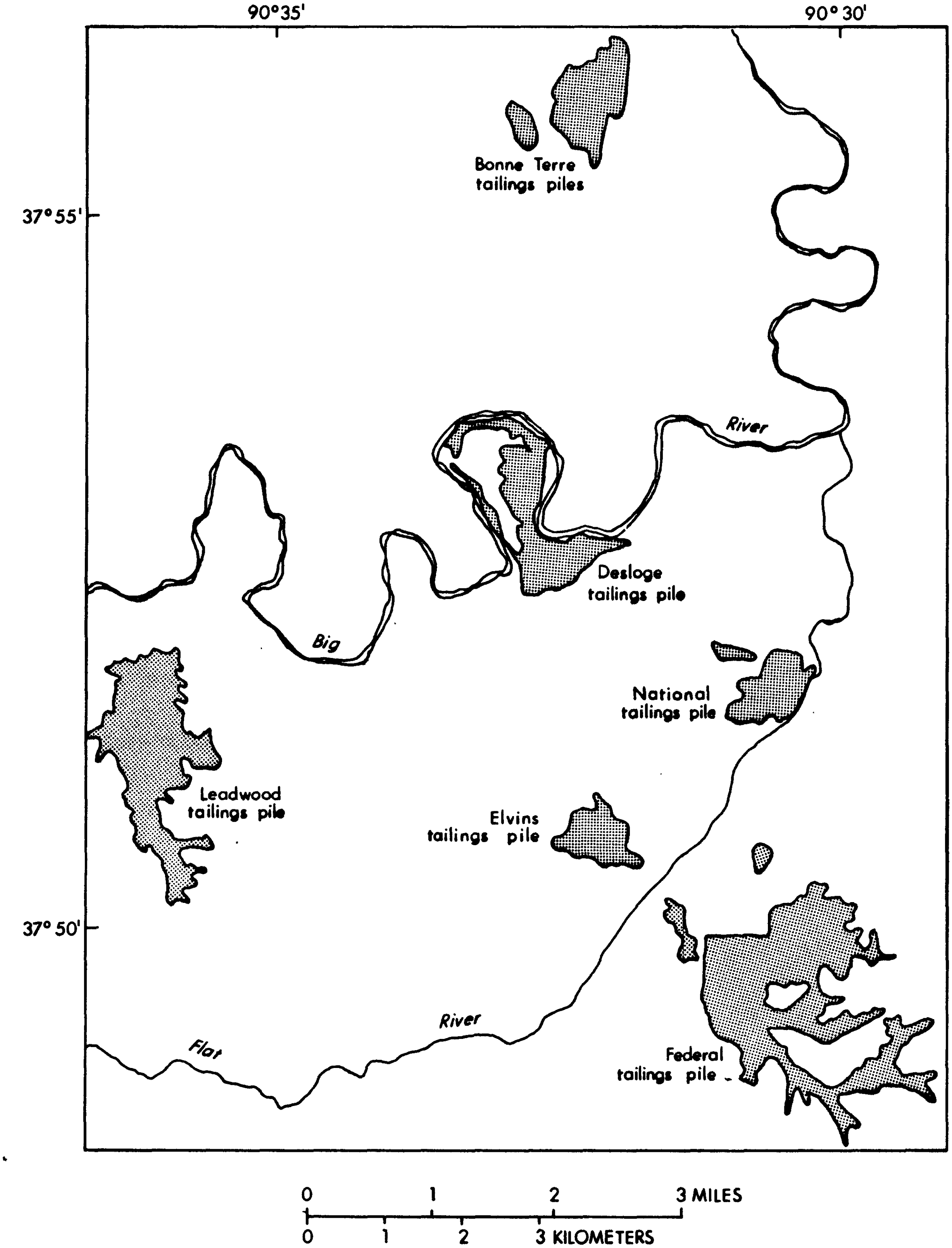


Figure 4.--Location of tailings piles in the Old Lead Belt.

Ground water

In 1980, water from a well about 2,000 feet west and down gradient from the Desloge tailings pile had a dissolved-lead concentration of 106 µg/L, which exceeded the Missouri drinking-water standard of 50 µg/L. This well, probably drilled into an abandoned mine, may provide public drinking water (Missouri Division of Geology and Land Survey, written commun., 1980). Water from a drill hole upgradient from the Desloge tailings pile had a lead concentration of 59 µg/L (Wixson and others, 1982).

At the present time (1987), the town of Flat River receives about 80 percent of its public drinking-water supply from flooded abandoned mines (Ron Warren, Superintendent, Flat River Water District, oral commun., 1986). Flat River supplies the towns of Desloge, Elvins, Esther, and Leadington with drinking water. In September 1984, untreated mine water had a lead concentration of 15 µg/L and a sulfate concentration of 510 mg/L and treated water had a lead concentration of less than 10 µg/L and a sulfate concentration of 504 mg/L. In January 1986, untreated mine water had a lead concentration of 21 µg/L and a sulfate concentration of 504 mg/L and treated water had a lead concentration of less than 10 µg/L and a sulfate concentration of 486 mg/L. Lead concentrations in the public drinking-water supply for Bonne Terre, which obtains its water from wells, were less than 10 µg/L in 1984 and 1985 and sulfate concentrations ranged from 38 to 84 mg/L for the same period (Missouri Public Drinking Water Program, written commun., 1986).

Surface water and stream-bottom material

In 1964, the Missouri Water Pollution Board published a water-quality survey of the Big River that drains the Old Lead Belt. The Board stated that mining had adversely affected the water quality of the Big River downstream from the mining district. Trace-element concentrations did not exceed the current (1987) standards for the protection of aquatic life. Tailings were present in the Big River downstream from Leadwood for about 40 river miles.

During 1980 and 1981, background concentrations for dissolved lead and zinc were determined for the Big River upstream from the Old Lead Belt. The background lead concentration was 5 µg/L and the background zinc concentration was less than 10 µg/L. Downstream from the Desloge tailings pile in July 1980, the dissolved-lead concentration was 20 µg/L and the dissolved-zinc concentration was 310 µg/L during low flow. In May 1981, the dissolved-lead concentration was 12 µg/L, and the dissolved-zinc concentration was 100 µg/L during high flow (Schmitt and Finger, 1982).

During a low-flow period in June and July, 1975, changes in water quality in the Flat River were caused by seepage from the Elvins tailings pile. Upstream from the tailings pile in the Flat River, lead concentrations were less than 50 µg/L, the zinc concentrations were 80 µg/L or less, and cadmium concentrations were 10 µg/L or less. At the Elvins tailings pile, lead concentrations in water ranged from 100 to 150 µg/L, zinc concentrations ranged from 7,800 to 9,200 µg/L, and cadmium concentrations ranged from 30 to 40 µg/L. After seepage entered the Flat River downstream from the tailings pile, lead concentrations in the Flat River ranged from less than 50 µg/L to 150 µg/L, zinc concentrations ranged from 3,200 to 4,800 µg/L, and cadmium concentrations ranged from 10 to 40 µg/L. Values of pH ranged from 7.1 to 8.1. In late July and August 1975, trace-element concentrations at the Elvins tailings were determined in seepage flowing through a series of impoundments before entering the Flat River. Lead concentrations in seepage ranged from 10 to 230 µg/L, zinc concentrations ranged from 4,000 to 18,000 µg/L, and cadmium concentrations ranged from 20 to 40 µg/L. All concentrations of samples at and near the Elvins tailings piles were dissolved (Kramer, 1976).

In the Big River, upstream from the Old Lead Belt, background lead contents of stream-bottom material ranged from 50 to 100 µg/g, zinc contents ranged from 55 to 340 µg/g, cadmium contents ranged from 1 to 5 µg/g, and copper contents ranged from 12 to 15 µg/g. Within the Old Lead Belt, lead contents of stream-bottom material ranged from 673 to 8,150 µg/g, zinc contents ranged from 1,025 to 8,558 µg/g, cadmium contents ranged from 11 to 180 µg/g, and copper contents ranged from 35 to 360 µg/g. An increased trace-element content in stream-bottom material was detected for about 60 river miles downstream from the Old Lead Belt (Zachritz, 1978).

Lead contents in stream-bottom material of the Flat River, downstream from the Elvins and the Federal tailings piles ranged from 2,050 to 3,140 µg/g, zinc contents ranged from 322 to 7,450 µg/g, cadmium contents ranged from 7 to 24 µg/g, and copper contents ranged from 54 to 181 µg/g. Stream-bottom material from the seepage channel at the Elvins tailings pile had a lead content of 3,900 µg/g, a zinc content of 36,200 µg/g, a cadmium content of 35 µg/g, and a copper content of 96 µg/g. Stream-bottom material from two seepage channels at the Federal tailings pile had lead contents of 3,420 and 3,360 µg/g, zinc contents of 441 and 1,960 µg/g, cadmium contents of 10 and 13 µg/g, and copper contents of 154 and 161 µg/g (Kramer, 1976).

During 1982, stream-bottom material samples collected from the Flat River upstream from the National tailings pile had a maximum lead content of 10,123 µg/g and a maximum zinc content of 3,146 µg/g. Runoff from the Elvins and the Federal tailings piles probably was the cause of the large quantities of trace elements measured. Stream-bottom material in the Flat River and the Big River downstream from the National tailings pile had lead contents that ranged from 1,013 to 7,221 µg/g. Zinc contents ranged from 115 to 4,875 µg/g, cadmium contents ranged from 5 to 889 µg/g, and copper contents ranged from 56 to 332 µg/g. As the quantity of tailings in the streambed decreased with increasing distance downstream from the tailings pile, the content of trace elements increased in bottom material. The content of trace elements also increased with a decrease in particle size (Elliot, 1982).

Trace-Element Content in Biota Tissue

During 1980, the Missouri Department of Health and Missouri Department of Conservation recommended that black redhorse sucker, golden redhorse sucker, and northern hog sucker, which are three species of fish caught in a 40-mile reach of the Big River downstream from the Desloge tailings pile, were not suitable for human consumption. These fish are benthic feeders that incidentally ingest bottom material and detritus. From December 1979 to June 1981, 74 to 95 percent of the suckers collected 3 to 75 river miles downstream from the Desloge tailings pile contained lead that exceeded the World Health Organization's recommended safe dietary lead content of 0.3 µg/g per day. Lead contents in edible tissue of the three species of sucker fish ranged from 0.62 ± 0.06 to 0.88 ± 0.07 µg/g 3 river miles downstream from the tailings pile. Thirty-nine river miles downstream from the tailings pile, lead contents in these fish ranged from 0.31 ± 0.06 to 0.42 ± 0.13 μg/g (Czarnezki, 1985). Redhorse suckers collected downstream from the Desloge tailings pile during 1980 and 1981 had an average lead content of 0.57 μg/g; those collected from Washington State Park, about 40 river miles downstream from the Old Lead Belt, had an average lead content of 0.43 μg/g. The average lead content of northern hog suckers in the Big River near Leadwood was 0.44 μg/g (Schmitt and Finger, 1982). Lead content was larger in bony structures, including gill arches and scales, than in tissue (Gale and Wixson, 1983). Suckers collected during 1983 and 1984 had lead contents that ranged from 0.265 ± 0.05 to 0.667 ± 0.12 μg/g (Gale and Wixson, 1985). In 34 samples of northern hog sucker collected during 1985 from the Big River downstream from the Leadwood tailings pile, the lead contents ranged from 0.206 to 0.799 μg/g. The lead contents of 24 samples of black redhorse sucker ranged from 0.185 to 0.854 μg/g (Gale and others, 1986).

Tailings piles are a source of potentially toxic trace elements to aquatic life in the Big River downstream from the Old Lead Belt. Trace elements are actively transported by the river, and most are transported in the solid phase (Schmitt and Finger, 1982). Biota that live primarily on or in stream-bottom material have larger lead and cadmium contents than biota that live primarily above the streambed. Increased contents of lead, zinc, and cadmium were detected in algae, rooted plants, crayfish, and mussels in the Big River. Tissue from bullfrogs collected near the Desloge tailings pile had lead contents that ranged from 1.70 to 6.30 μg/g and zinc contents that ranged from 12.7 to 109.0 μg/g; the maximum cadmium content was 40.70 μg/g (Niethammer and others, 1985). Crayfish collected near the same location had a composite lead content of 140 μg/g, a composite zinc content of 200 μg/g, and a composite cadmium content of 1.5 μg/g (Schmitt and Finger, 1982).

Decreased productivity and scarcity of some benthic organisms have been attributed to mining in the Old Lead Belt. Two possible causes of the impaired benthos were: (1) Mine tailings in the streambed causing a shifting and unstable habitat for organisms and (2) the release of toxic concentrations of trace elements from the tailings that are deposited on the streambed. Fish habitat also has decreased because of the sedimentation of pools by tailings (Missouri Water Pollution Board, 1964). Before the Federal Division of St. Joseph Lead Co. closed in 1972, species diversity and abundance had decreased, and considerable quantities of tailings were present in the Flat River (Fuchs, 1972). After the Federal Division closed, water quality and diversity and abundance of benthos improved in the Flat River. However, differences in water quality and benthos still exist between the affected and the unaffected reaches of the Flat River (Trial, 1983).

Viburnum Trend

During 1970 the Viburnum Trend, also known as the New Lead Belt, became the largest lead-producing district in the world. During that year, 432,576 tons of lead valued at about $135 million were produced, which was 74 percent of the entire United States' production (Wixson and Tranter, 1972). During 1975 the value of lead mined from the Viburnum Trend exceeded $220 million. Seven mines in the Viburnum Trend produced 511,275 tons of lead, or 85 percent of the United States' production during 1975 (Wixson, 1978).

The Viburnum Trend is in southeastern Missouri; most of the mines are in Reynolds and Iron counties (fig. 5). Most of the mining area of 350 square miles is within the Mark Twain National Forest. The Viburnum Trend is about 35 miles southwest of the Old Lead Belt.

Mining Activity

As the ore deposits were depleted in the Old Lead Belt, exploration was begun to find new deposits. In 1947, lead was discovered by the St. Joseph Lead Co. near Indian Creek in northern Washington County. Production began there in 1953 and ended in 1982. Even though the Indian Creek deposit is northeast of the Viburnum Trend, it is not considered part of the Viburnum Trend. In 1955, lead was discovered near Viburnum, Iron County. By 1962 the "trend" had been delineated for about 35 miles (Wixson and others, 1969). By 1970, four mines were operating and another mine was under construction. During the early 1980's, 10 mines were in operation. At present (1987) fewer than five mines are operating at full capacity and two additional mines are operating at a decreased capacity (J.E. Carter, St. Joe Minerals Corporation, oral commun., 1986).

In the Viburnum Trend, ore is mined underground at depths ranging from 700 to 1,200 feet. Because the ore deposits are mined from an aquifer, water is pumped out of the mines, usually at a rate of 2,000 to 7,000 gallons per minute for each mine.

Disposal and Trace-Element Content of Tailings

After underground crushing, the ore is transported to the mill for concentration by various physical and chemical methods. Some excess mine water is used in the milling processes. The mill effluent and excess mine water, about 2,000 gallons per minute, generally are conveyed to one or more tailings or settling ponds. In the Viburnum Trend, the tailings ponds are in valleys that have been dammed so the solid waste material and mill reagents can settle out. The water that drains from the tailings ponds is discharged into nearby streams (Bolter and Tibbs, 1971).

During 1980, the St. Joe Minerals Corporation tailings pond at Viburnum received mill wastes transported in a slurry of about 35 percent solid material. In July 1982, water from the pond had a lead concentration of less than 84 μg/L, a zinc concentration of 620 μg/L, an arsenic concentration of 43 μg/L, cadmium and copper concentrations of less than 2 μg/L, and a selenium concentration of 81 μg/L (all concentration were dissolved). During 1980, the fresh tailings had a lead content of 736 μg/g, a zinc content of 260 μg/g, an arsenic content of 34 μg/g, a cadmium content of less than 10 μg/g, a copper content of 449 μg/g, and a selenium content of 6.1 μg/g. Settled solids had a lead content of 358 μg/g, a zinc content of 222 μg/g, an arsenic content of 8 μg/g, a cadmium content of less than 10 μg/g, a copper content of 35 μg/g, and a selenium content of 1 μg/g (PEDCo Environmental, Inc., 1983a).

Water Quality in Mined Areas

Initial effects of mining in the area were the presence of large quantities of algae in the streams and the concentration of trace elements by the algae. After certain mining and milling techniques were developed, the water quality for most streams in the Viburnum Trend in 1977 was considered to be at pre-mining conditions. Organic compounds that are used in mining and milling processes may represent at least as much, if not more, of a concern that trace elements (Wixson, 1977).

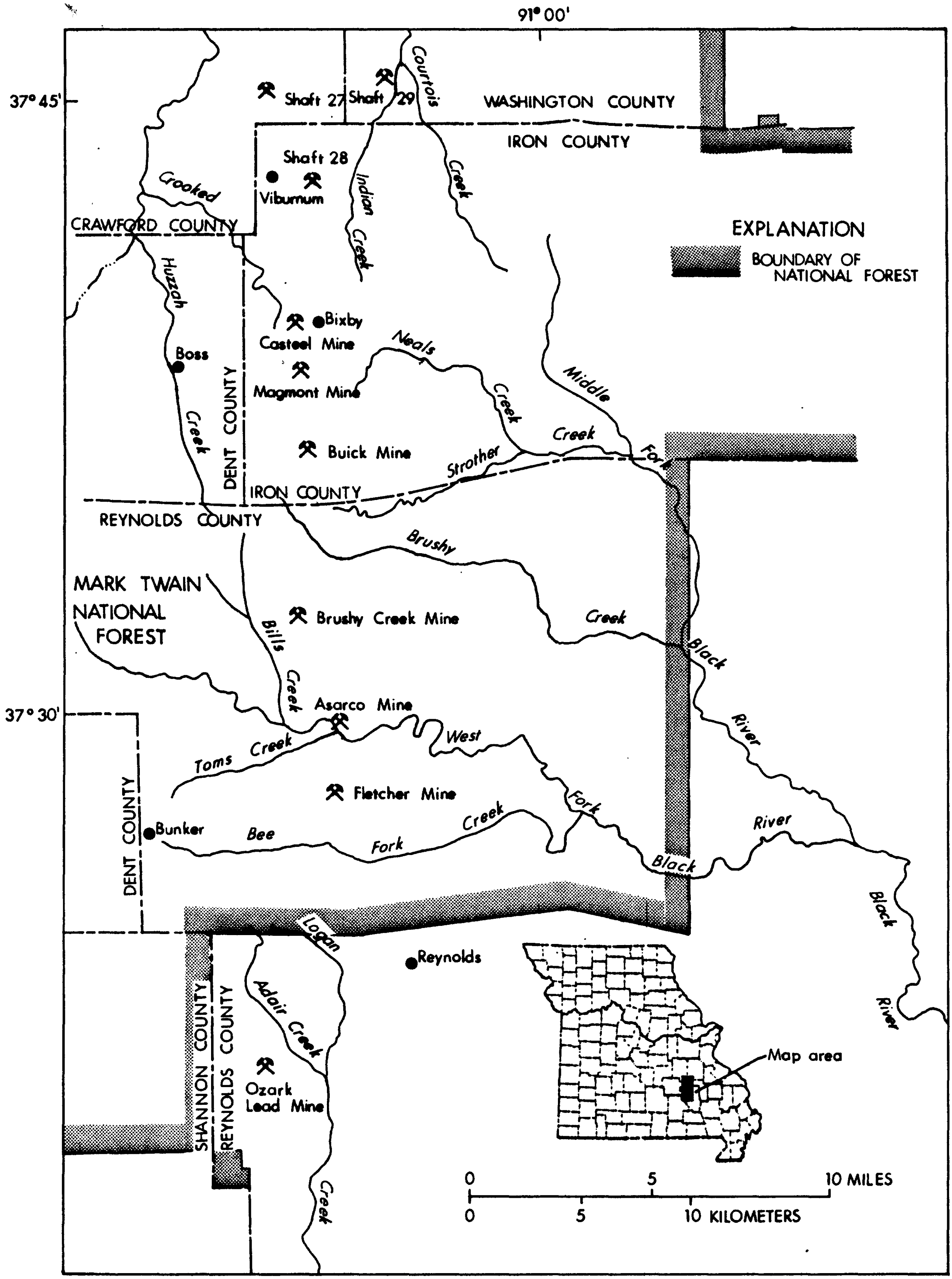


Figure 5.--Location of mines in the Viburnum Trend.

Potential effects of mining on water quality

Dewatering of the mine eliminates dust problems, but the mine water can contain oil, diesel fuel, crushed rock with a large trace-element content, and other material from mining operations. Excess mine and mill water, possibly containing large trace-element concentrations, are discharged to the streams from the tailings ponds. Potential ground-water contamination exists from losing streams (streams that lose 30 percent or more of their flow through natural processes) that have a large trace-element concentration. Chemicals, especially organic compounds from the milling processes, can be nutrients for algae and bacteria in the stream (Jennett and others, 1973). Trace elements can be released from stream-bottom material by changing geochemical conditions that can be induced by acidic spills and possibly by the biochemical reactions of anaerobic organisms in the stream-bottom material (Wixson, 1977).

Tailings can be deposited in streams and available trace elements can enter the stream environment. Breaching of a tailings-pond dam and subsequent release of tailings into the stream can impair water quality. Dried tailings and ore concentrate from mills can be transported by wind and subjected to surface runoff. Sinkhole formation near one mine possibly could be linked to mine dewatering (Warner, 1974).

Ground water

Two samples of mine water collected underground in 1971 had lead concentrations of 8.5 and 24 μg/L, zinc concentrations of 6 and 16 μg/L, copper concentrations of 1.2 and 5 μg/L, and cadmium concentrations of less than 1 μg/L (all concentrations were dissolved). Mine water sampled at land surface during 1970 and 1971 had dissolved-lead concentrations that ranged from 20 to 65 μg/L and dissolved-zinc concentrations that were less than 21 μg/L (Bolter and Tibbs, 1971). Dissolved-lead concentrations of 3 and 44 μg/L were measured in mine water from two drill holes at the faces of new underground workings (Feder, 1979).

At present (1987), the town of Viburnum obtains its public drinking water from an abandoned mine. In January 1986, untreated mine water had a lead concentration of 21 μg/L, a zinc concentration of 280 μg/L, a cadmium concentration less than 5 μg/L, and a copper concentration of 50 μg/L. The sulfate concentration was 388 mg/L in untreated water and was 386 mg/L in treated water (Missouri Public Drinking Water Program, written commun., 1986).

During 1981 and 1982, the area near a tailings pond in Viburnum was monitored for ground-water quality. Three wells downgradient from the tailings pond and one well adjacent to the pond ranged from 85 to 120 feet deep. The dissolved-lead concentration in the ground water was less than 84 μg/L (PEDCo Environmental, Inc., 1983a).

An investigation of ground-water quality adjacent to the two smelters near Bixby in the Viburnum Trend (fig. 5) and near Glover, about 20 miles east of the Viburnum Trend (fig. 6) was begun, but was discontinued because of several factors. The small number of wells in the areas was considered statistically insignificant, well logs were determined to be inadequate, and extensive use of galvanized pipe would make trace-element studies difficult (Wixson, 1977).

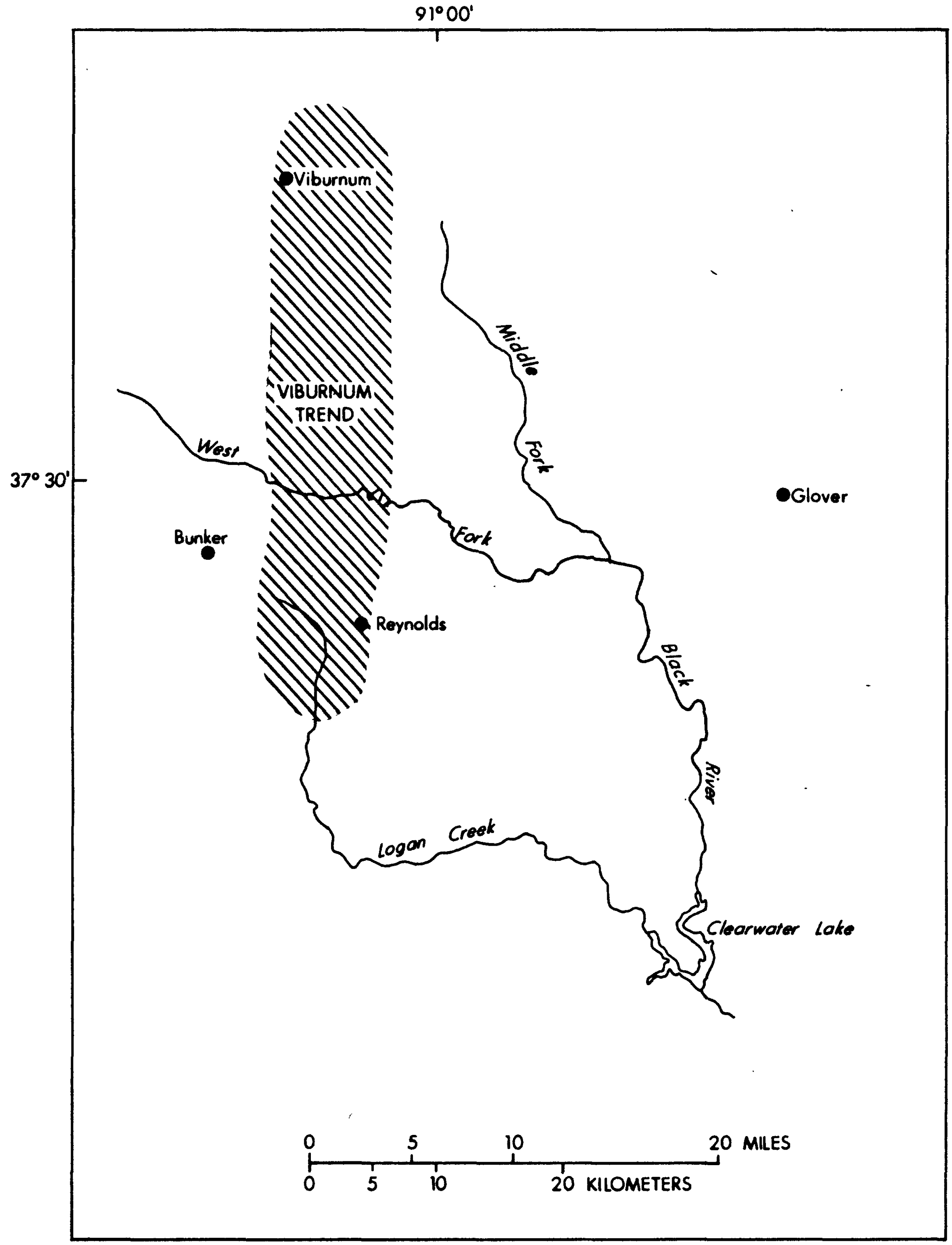


Figure 6.--Location of the Viburnum Trend in relation to Clearwater Lake.

Surface water and stream-bottom material

Because of the topography in the Viburnum Trend, discharge from individual mines and tailings ponds is released to separate tributaries of the Meramec River including Huzzah, Crooked, Indian, and Courtois Creeks, or the Black River. The source of discharge with large trace-element or organic-compound concentration from the milling processes can readily be identified (Wixson and Bolter, 1969).

Background dissolved concentrations of trace elements in water were determined for the Viburnum Trend before many of the the mines opened. Background concentrations of lead, zinc, and copper generally were less than 20 µg/L, and most of the concentrations ranged from 4 to 6 µg/L. An increase of two to three times the background concentration was measured in Bee Fork Creek downstream from the Fletcher Mine (Tibbs, 1969). The average lead concentration in Bee Fork Creek downstream from mine discharge was 19.7 µg/L, the average zinc concentration was 19.7 µg/L, and the average copper concentration was 17.3 µg/L. Background concentrations in Bee Fork Creek were again obtained about 5 river miles downstream from Fletcher Mine (Handler, 1969).

From December 1971 through November 1973, streams in the Viburnum Trend were sampled bimonthly at 15 sites and analyzed for dissolved trace-element concentrations. Dissolved-lead concentrations in 15 of 325 samples were larger than 50 µg/L; the largest lead concentration measured was 660 µg/L from Bee Fork Creek. The mean lead concentration for all sites was less than 30 µg/L. A lead concentration of 440 µg/L, associated with storm runoff, was measured at a control site on Logan Creek. Zinc concentrations were larger than 100 µg/L in 29 samples. The largest zinc concentration of 4,800 µg/L and largest cadmium concentration of 4,000 µg/L also were measured in Bee Fork Creek. However, concentrations of cadmium and copper usually were less than 10 µg/L (Wixson, 1977).

Much of the discharge from mining and milling operations in the Viburnum Trend enters the Black River or Logan Creek before impoundment by Clearwater Lake (fig. 6). About 10 river miles upstream from the lake, dissolved-lead concentrations in surface water were 5 µg/L during 1980 and 1981. Zinc concentrations were less than 10 µg/L, cadmium concentrations were 1 µg/L, and copper concentrations were 5 µg/L (all concentrations were dissolved; Schmitt and Finger, 1982).

One of the critical factors controlling the trace element concentration in stream water from mine and mill discharges is retention time in tailings pond. Insufficient retention time causes larger concentrations of trace elements to discharge into the stream. Copper and lead receive adequate retention time in small ponds, but zinc requires the longer retention time supplied by larger tailings ponds (Bolter and Tibbs, 1971).

Average lead, zinc, cadmium, and copper contents in stream-bottom material at a control site in the upstream reach of Bee Fork generally were less than 80 µg/g. At a control site in the upstream reach of Indian Creek, the average lead content was 718 µg/g, the average zinc content was 388 µg/g, and the average copper content was 62 µg/g during the mid-1970's. In three streams receiving discharge from mines and mills in the Viburnum Trend, the average lead content ranged from 213 to 798 µg/g during the mid-1970's. The average zinc content ranged from 163 to 332 µg/g and the average copper content ranged from 28 to 38 µg/g (Wixson, 1977).

Investigation of Clearwater Lake as a potential "sink" for trace elements indicated that trace elements are increasing in the bottom material (Wixson, 1977). Increased contents of lead, zinc, and copper were detected in the lake-bottom material. The lead content was larger than 60 μg/g in the lake-bottom material adjacent to the dam. Primarily because of shallow depth and frequent flooding, Clearwater Lake seems to be only a temporary receptacle for trace elements (Gale and others, 1976).

Trace-Element Content in Biota Tissue and Algae

As trace-element concentrations increase in streams of the Viburnum Trend, total and calcium hardness also increases. Hardness and the alkaline nature of the streamflow (pH of 7.0 to 8.8) promote the precipitation of trace elements, thereby making them more inaccessible to aquatic life (Handler, 1969). However, a considerable quantity of trace elements are present in a finely divided suspended-particulate state (Gale and others, 1973; Jennett and others, 1973).

No appreciable concentration of trace elements has been detected in the lower or the higher trophic levels in the Viburnum Trend (Gale, Wixson, Hardie, and Jennett, 1972). In December 1980, fish were collected from four locations in the Viburnum Trend. In edible tissue from 99 samples of four different fish, including bottom-feeding suckers, lead contents ranged from 0.03 ± 0.04 to 0.09 ± 0.02 μg/g (Czarnezki, 1985). The lead content in several animals, including the northern water snake, bullfrog, green-backed heron, and muskrat, was significantly larger in the Old Lead Belt than in the Black River drainage basin (Atkinson and others, 1985).

In addition to trace elements discharged into the streams, milling reagents are discharged to the streams. Excessive algal growth, enhanced by the nutritive properties of some of the milling reagents, traps particulate matter. Excessive growth of algae is undesirable because it may be a food source for aquatic life that could accumulate trace elements. Algae are a temporary filter for trace elements because algal mats may detach as they decompose or break loose during storms. Meanders downstream from tailings ponds have decreased the algal-mat size and lessened the quantity of trace elements available for storage in the mats (Jennett and others, 1973). The lead content in the algal mats was as large as 8,035 μg/g about 0.2 river mile downstream from a tailings pond. Background lead contents of 10 to 30 μg/g were measured 5 to 8 river miles downstream from the pond (Gale, Hardie, Jennett, and Aleti, 1972).

Benthic populations have been affected by various mining activities in the Viburnum Trend. Mine construction at one location temporarily destroyed the benthos (Dieffenbach, 1968). Excessive algae growth was the reason for decreased benthic diversity and number from the late-1960's to the late-1970's (Ryck, 1974d, c; Trial and Robinson-Wilson, 1981). Improvements to the population of the benthic community were noted after the construction of a meander system downstream from the tailings pond, and after increasing the height of a tailings dam to increase retention time (Ryck, 1974c; Trial, 1982). During 1981 all streams in the Viburnum Trend, except Logan Creek, were classified as uncontaminated (Trial, 1983).

During the spring of 1977, intense rainfall caused a tailings pond dam to break, discharging tailings into Logan Creek. Increased turbidity was noted as far as Clearwater Lake, about 40 river miles downstream from the dam. Limited recovery of the benthos began about 60 days after the dam failure. Dissolved trace-element concentrations were less than the standards for protection of aquatic life. Physical and chemical effects of the tailings were considered the primary causes of degraded water quality (Duchrow and others, 1980).

However, benthic-population analysis has not achieved widespread acceptance as a reliable criterion for water quality in the Viburnum Trend (Wixson and Bolter, 1969). Flash floods with accompanying sudden stage rises and declines tend to scour the stream bed (Fuchs, 1972). This scouring action and marked decrease in benthic organisms is common whenever the stream stage is increased by 3 feet or more (Ryck, 1974b).

MINING OF COBALT AND NICKEL AND WATER QUALITY IN THE MINED AREA

One of the few locations in the United States where cobalt- and nickel-bearing minerals occur is the Fredericktown subdistrict. The subdistrict is almost alone as an actual producer of these metals. Other minerals, including lead, zinc, and copper, have been mined in the subdistrict for about 250 years (Proctor and Sinha, 1978a).

The Fredericktown mining district, in southeastern Missouri, is about 75 miles south of St. Louis (fig. 7). The district is in northern Madison County and southern St. Francois County, about 50 miles east of the Viburnum Trend.

Mining Activity

Lead was discovered north of Fredericktown in 1720. Mining operations in the area were under the direction of a Frenchman named La Motte and the area became know as Mine La Motte. The mines became the second most productive in the subdistrict and were operated on a periodic basis from 1720 until final closing in 1959. The Mine La Motte area was the primary domestic source of nickel at various times during the 1800's (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Several mines were developed in the Fredericktown subdistrict, but most operated only intermittently. Until 1844, mostly lead and zinc were mined, but after this date, cobalt and nickel were mined because milling techniques had improved (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

The most productive mine and last to close was the Madison Mine, 1 mile southeast of Fredericktown. From the mid-1950's to the closing of the mine in 1961, production was limited to cobalt and nickel. In January 1984, the Madison Mine was to reopen for mining of cobalt, nickel, and copper (Anschutz Mining Corp., 1981), but because of unfavorable economic conditions the mine remained closed.

Ore deposits in the Fredericktown district occur at the land surface and to depths of 400 feet. Early mining was confined to pit or near-surface workings. Underground-mining methods were later used.

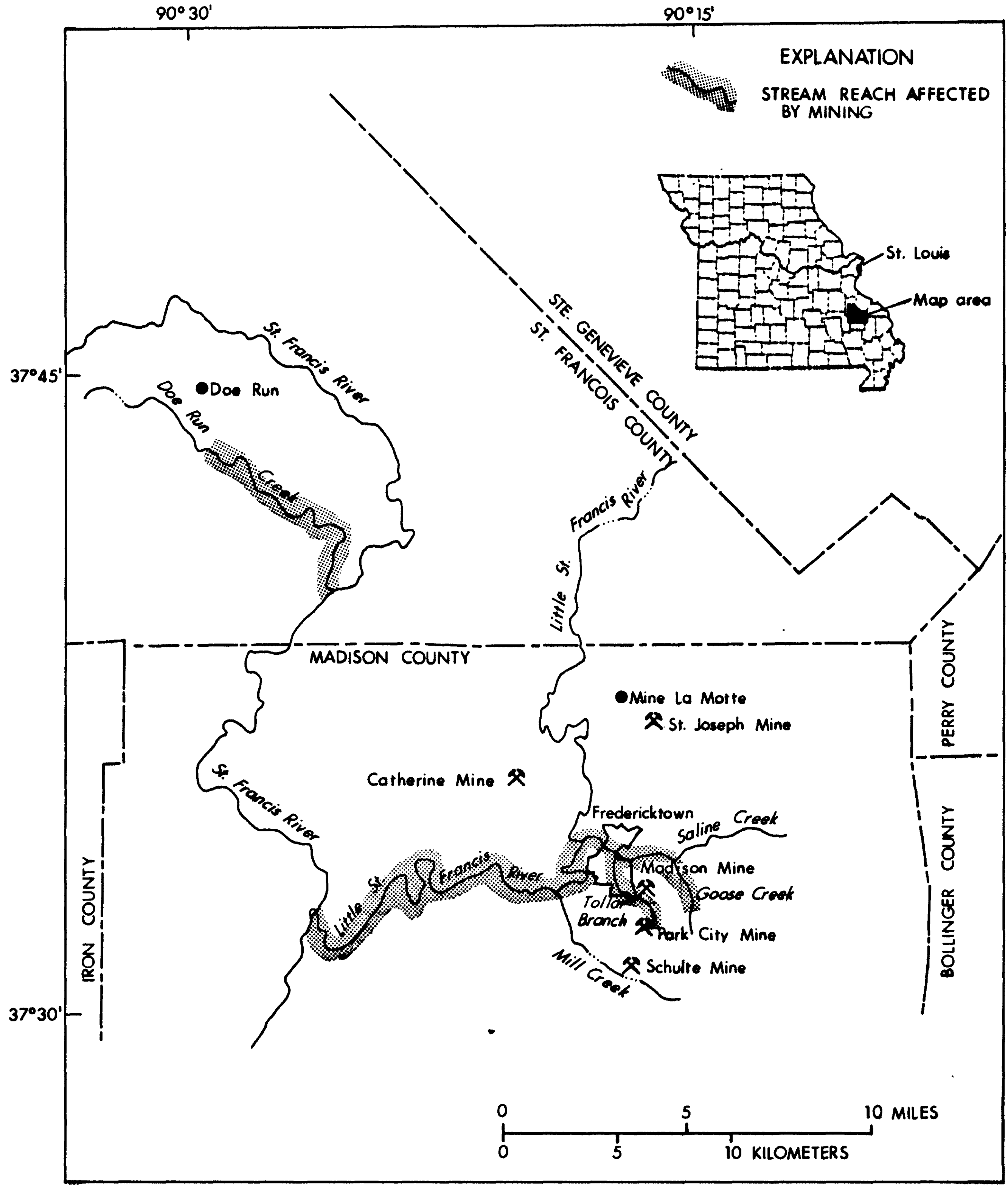


Figure 7--Location of some mines and affected streams in the Fredericktown subdistrict.

Disposal and Trace-Element Content of Tailings

Tailings were placed on land surface near the mines. Substantial quantities of trace elements remain in the tailings. In the late 1970's average cobalt content in tailings from near Fredericktown was 3,799 µg/g, the average nickel content was 6,081 µg/g, the average lead content was 6,692 µg/g, the average zinc content was 347 µg/g, and the average copper content was 13,856 µg/g. The average lead content in tailings from Doe Run was 9,440 µg/g (Sinha, 1980).

Water Quality in the Mined Area

Water quality in the Fredericktown subdistrict has been affected by increased concentrations of trace elements in artesian flow from a mine shaft in the area, in streamflow in some of the area streams, and water seeping from a tailings pond. Increased trace-element contents also were detected in stream-bottom material.

Potential Effects of Mining on Water Quality

Tailings piles generally contain large quantities of trace elements. Seepage from piles can contain large trace-element concentrations that enter nearby streams. Ground-water contamination from lateral movement of water from abandoned mines and tailings piles may occur. Large quantities of tailings can be transported into streams during runoff from tailings piles and failure of tailings-pond dams. Trace elements from tailings can be mobilized by acidic water. Acidic water could enter streams from seepage and possible failure of tailings-pond dams.

Ground Water

In preparation for the proposed reopening of the Madison Mine, the mining company dewatered the mine. Before the mine was dewatered during 1980 (Anschutz Mining Corp., 1981), water from an artesian well that flowed into Goose Creek had a cobalt concentration of 3,750 µg/L, a nickel concentration of 4,600 µg/L, and a zinc concentration of 190 µg/L (all concentrations were dissolved). The well stopped flowing during the dewatering process and, at that time, mine drainage had a dissolved-cobalt concentration of 2,710 µg/L and a dissolved-nickel concentration of 3,700 µg/L. At the time the well stopped flowing, a cobalt concentration of 2,980 µg/L and a nickel concentration of 3,700 µg/L were measured in Saline Creek, and a cobalt concentration of 1,690 µg/L and a nickel concentration of 2,400 µg/L were measured in the Little St. Francis River (all concentrations were dissolved; Hufham, 1981).

Surface Water and Stream-Bottom Material

In the Fredericktown subdistrict, background dissolved concentrations of cobalt, nickel, lead, zinc, and copper in surface water were less than 20 µg/L. Mining has affected Saline Creek from near Fredericktown to the junction with the Little St. Francis River (Sinha, 1980). In April 1977, dissolved trace-element concentrations in Saline Creek southeast of Fredericktown near a large tailings pile included 6,500 µg/L cobalt, 9,900 µg/L nickel, 460 µg/L lead, 671 µg/L zinc, and 10,800 µg/L copper. Dissolved-cobalt concentrations of 98 and 227 µg/L, dissolved-nickel concentrations of 110, 215, and 220 µg/L, and a dissolved-copper concentration of 82 µg/L were measured near Fredericktown in April 1977 (Proctor and Sinha, 1978a; Sinha, 1980).

In tailings-pond water near Fredericktown, pH values were 2.6 and 3.6 in the late 1970's. About 1.25 river miles downstream from the tailings pond, the pH value increased to 5.6 (Sinha, 1980).

Doe Run Creek drains the predominately lead and zinc mining area near Doe Run, northwest of Fredericktown. Seepage from tailings enters Doe Run Creek, where the maximum lead concentration was 57 µg/L in April 1977. Lead concentrations in water from much of Doe Run Creek to the junction with the St. Francis River were larger than 50 µg/L (Sinha, 1980).

In the late 1970's background trace-element contents in stream-bottom material near the Fredericktown district were: cobalt, less than 70 µg/g; nickel, less than 35 µg/g; lead, less than 570 µg/g; zinc, less than 140 µg/g; and copper, less than 100 µg/g (Proctor and Sinha, 1978). Maximum trace-element contents in stream-bottom material near Fredericktown were: cobalt, 680 µg/g; nickel, 431 µg/g; lead, 12,000 µg/g; zinc, 1,825 µg/g; and copper, 3,160 µg/g (Proctor and Sinha, 1978a; Sinha, 1980). The large trace-element contents can be directly related to past mining activities and extended for more than 12 river miles downstream from mining activities. Trace-element contents in stream-bottom material from Doe Run Creek included a cobalt content of 90 µg/g, a nickel content of 71 µg/g, lead contents of 11,900 and 29,420 µg/g, a zinc content of 2,330 µg/g, and a copper content of less than 50 µg/g (Proctor and Sinha, 1978a; Sinha, 1980). Organic-rich stream-bottom material, leaf litter, and algae can contain quantities of trace elements equal to or larger than those values associated with stream-bottom material (Sinha, 1980).

In March 1977, a 6-inch rain caused a tailings-dam failure southeast of Fredericktown. Tailings entered Tollar Branch, Saline Creek, and the Little St. Francis River and caused extreme turbidity (Duchrow and Trial, 1980). Increased cobalt, nickel, and copper contents in stream-bottom material were detected for about 12 river miles downstream from the tailings dam (Sinha, 1980). No fish were observed to have been killed, but the number of benthic invertebrates in Saline Creek and, to a lesser extent, in the Little St. Francis River markedly decreased after the failure of the dam (Duchrow and Trial, 1980).

Trace-Element Content in Algae

Anomalous trace-element contents in algae were detected in streams near Fredericktown and in Doe Run Creek in the late 1970's. Near Fredericktown, the trace-element contents in algae were: cobalt, 1,663 µg/g; nickel, 2,319 µg/g; lead, 1,280 µg/g; zinc, 296 µg/g; and copper, 1,288 µg/g. The lead content in algae from Doe Run Creek was 2,410 µg/g (Proctor and Sinha, 1978a).

MINING OF BARITE AND POTENTIAL EFFECTS OF MINING ON WATER QUALITY

More barite has been mined from Missouri than from any other State in the United States. From 1850 to 1964, about 10 million tons of barite valued at $85 million were mined (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Barite mining has occurred in the central district, primarily in Cole, Miller, Moniteau, and Morgan Counties. Deposits were small and production was insignificant. Insufficient data exists concerning effects on water quality for this district.

Most of Missouri's production of barite has been from the Washington County district, about 50 miles southwest of St. Louis (fig. 8). In addition to Washington County, the district includes parts of Franklin, Jefferson, and St. Francois Counties, an area of about 75 square miles (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Mining Activity

Mining in the Washington County area began around 1850. For 55 years, from 1885 through 1970, the district was either first or second in barite production in the United States. During 1971, 8 mining companies operated 15 mines in Washington County (Wharton, 1972). During 1983, two mines were operating in the district (U.S. Bureau of Mines, 1985).

Barite occurs as extensive residual deposits, generally about 10 feet thick, but as much as 50 feet thick, and may underlie as much as 100 acres (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967). Hand-dug pits were the only way to remove the ore until shortly after 1900. The pits usually were less than 5 feet in diameter and ranged from 5 to 15 feet deep. During 1904, steam shovels were introduced to the area. Shovels, draglines, and front-end loaders have been used in recent years to remove the barite.

Disposal of Tailings

Separation of barite from residual clays was done in washer plants. Excess water and clay materials were transported to tailings ponds. Sixty-seven tailings ponds have been identified in Washington County. Because of inefficiencies in milling procedures, a large percentage of barite was transported to the tailings ponds along with waste material. Much of the available tailings material can be considered to be commercial-grade ore (Wharton, 1972).

Potential Effects of Mining on Water Quality and Biota

Dissolved-barium concentrations in streams from areas affected by barite mining in the Big River basin ranged from 100 to 590 µg/L in 1980 and 1981 (Schmitt and Finger, 1982). The Missouri drinking water standard for barium is 1,000 µg/L.

On the basis of a literature review, failure of tailings-pond dams is a primary effect on water resources caused by barite mining. During intense rainfall, the dams are susceptible to failure. Large quantities of solid material can be released to receiving streams and can cause excessive turbidity and large suspended-sediment concentrations. However, these effects generally are of short duration and nonaccumulative (Zachritz, 1978).

The introduction of tailings into a stream from a break in a tailings-pond dam decreases the productivity and diversity of aquatic life (Zachritz, 1978). The tailings destroy the aquatic habitat and also destroy the tolerance for small dissolved-oxygen concentrations in aquatic life (Duchrow, 1982).

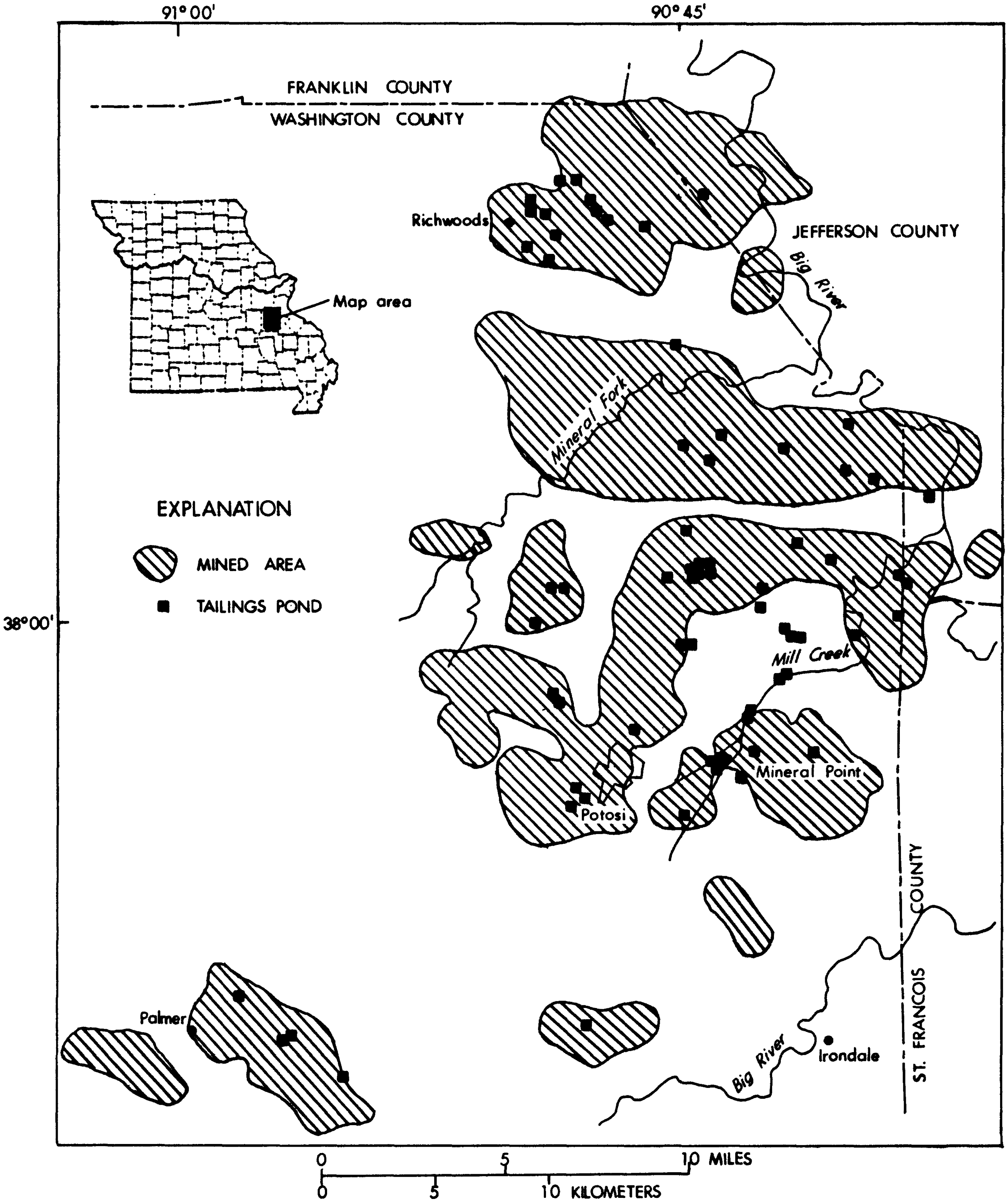


Figure 8.--Location of mined areas and tailings ponds in the principal part of the Washington County barite district (modified from U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

In August 1975, the failure of a barite tailings-pond dam caused an extensive fish kill 11.5 river miles downstream from the tailings pond. Increased turbidity was detected for more than 71 river miles downstream from the tailings pond. Recovery of the benthos in Mill Creek, the most severely affected stream, began 38 days after the dam failure. An impaired benthic community, including decreased number and unbalanced diversity, lasted 264 days. Esthetic degradation, in the form of increased turbidity, was the primary effect in the Big River, where benthic recovery began 14 days after the dam failure (Duchrow, 1982).

MINING OF OTHER NON-COAL MINERALS AND POTENTIAL EFFECTS OF MINING ON WATER QUALITY IN MINED AREAS

Copper, Iron, Manganese, Silver, and Tungsten

Ore deposits that primarily were mined for copper occur at three locations in southeastern Missouri (fig. 9). Mining of copper began during 1837 or 1838 in Shannon County and continued through the 1920's. In Crawford, Franklin, and Washington Counties, copper was mined from small filled-sink deposits from about 1848 to the early 1900's. In Ste. Genevieve County, mining began during 1863 and continued until 1916. From 1900 to the present (1987), copper production predominately has been a byproduct of lead and zinc mining. Copper has been recovered from the Tri-State district, the Old Lead Belt, the Viburnum Trend, and the Fredericktown subdistrict (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Iron mining began in Iron County, about 1815. Both open-pit and underground mining methods have been used. More than 22.7 million tons of iron had been produced by 1967, valued at more than $175.9 million (Wharton and others, 1969).

Iron deposits in Missouri were classified as filled sink, brown ore, and Precambrian (fig. 10). More than 125 filled-sink deposits have been identified on the northwest flank of the St. Francois Mountains, which are in Iron, Madison, Reynolds, St. Francois, and Washington Counties. No mining of these deposits has occurred since 1960. Brown-ore deposits were relatively small and located in the central, south-central, and southwestern part of the State. The most productive brown-ore deposits were in Howell, Oregon, and Wayne Counties (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Most of the iron production from Missouri has been from the Precambrian deposits that have been mined primarily at Pea Ridge, Pilot Knob, and Iron Mountain. The mine at Pea Ridge has operated intermittently since 1964. Mining stopped at Pilot Knob in 1980 and at Iron Mountain in 1966.

Downstream from the Pea Ridge and Pilot Knob mines, increased turbidity, fine material covering the streambed, and a decreased benthic-invertebrate population have been observed and possibly connected with mining activities (Ryck, 1974b). Data are insufficient to determine the magnitude and extent of the hydrologic effects of iron mining.

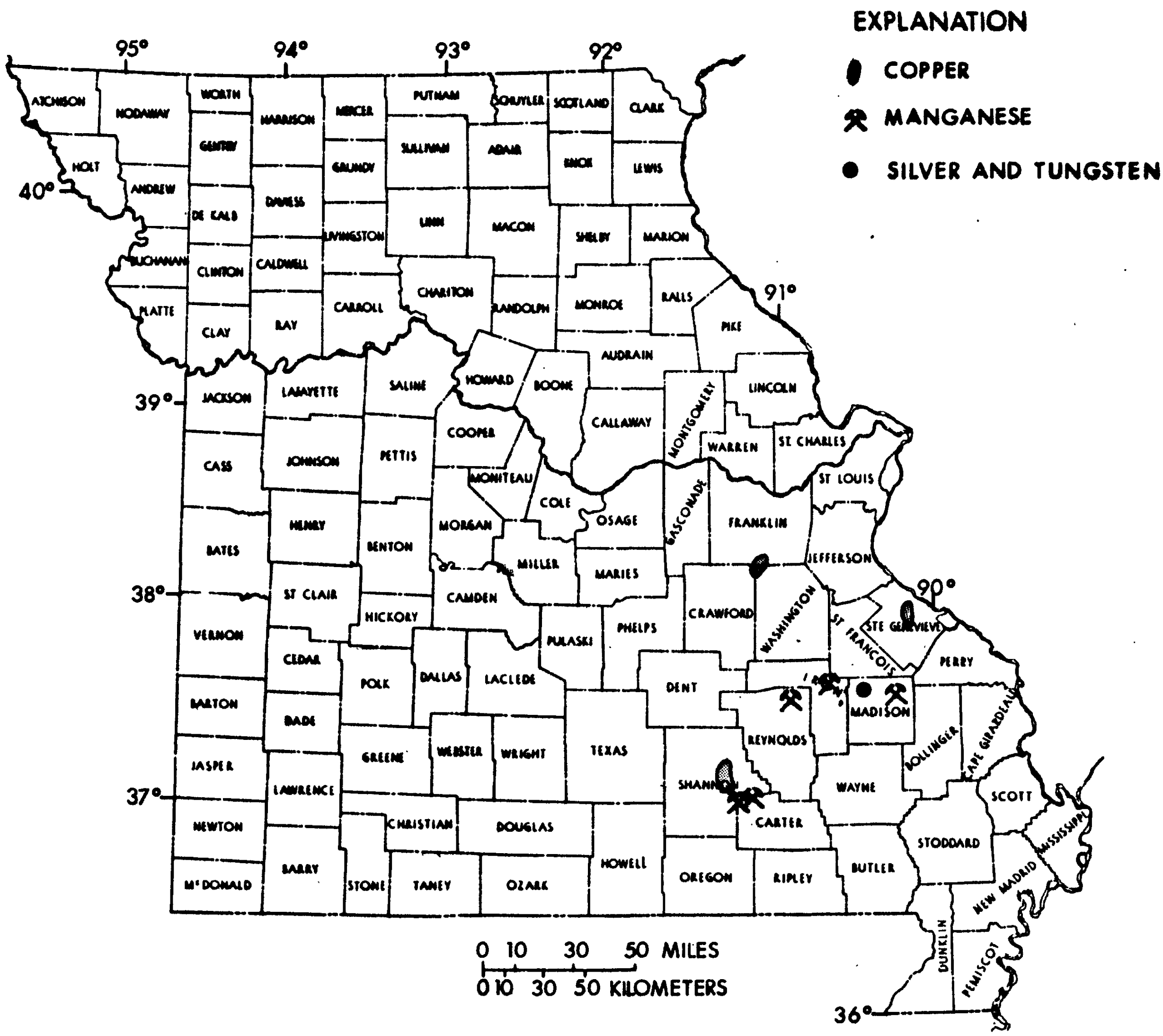


Figure 9.—Copper, manganese, silver, and tungsten deposits (modified from U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

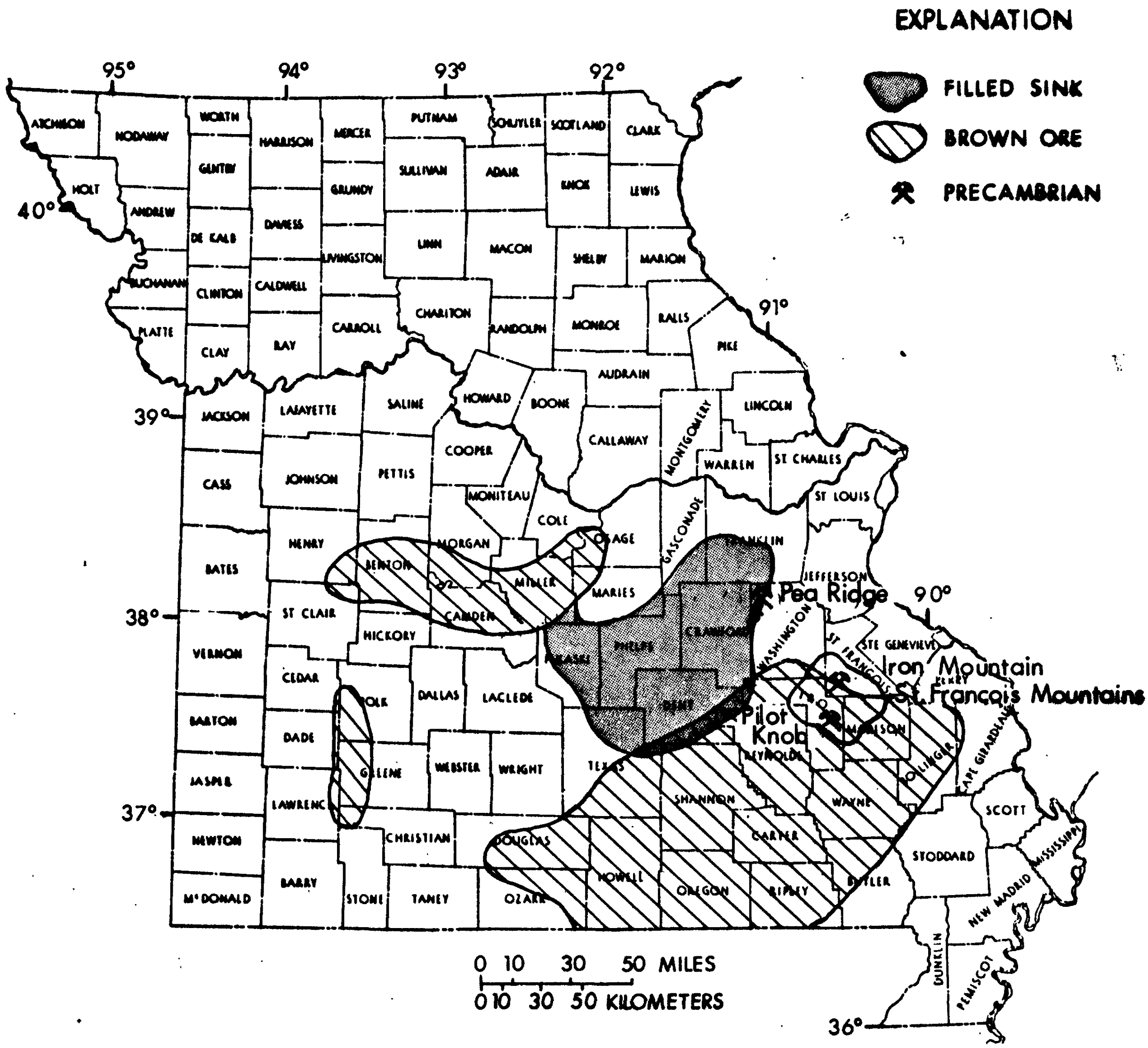


Figure 10.--Iron deposits (modified from U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Small, low-grade deposits of manganese occur in southeastern Missouri in Iron, Madison, Reynolds, Shannon, and Carter Counties. Mining has occurred in all counties except Carter (fig. 9). Manganese mining began in 1872 in Iron County and continued intermittently through 1958 (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967). The toxicity of manganese in surface water probably is relatively minor (Moran and Wentz, 1974).

The only area in Missouri to have been mined for silver and tungsten is the Einstein Silver Mine area in Madison County (fig. 9). Most of the silver production in Missouri has been as a byproduct of lead and zinc mining. Silver has been recovered from the Old Lead Belt and the Viburnum Trend, and was in the ore from the Tri-State district. Mining of tungsten occurred intermittently from 1916 to 1950 (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967).

Data are insufficient to determine the magnitude and extent of the effects of copper, manganese, silver, and tungsten mining on the water resources of Missouri.

Sand and Gravel

Sand and gravel operations are present in about one-half of Missouri's 114 counties. The largest production is from flood plain and in-channel deposits from rivers and streams. Upland terrace and glacial deposits also are commercially significant (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967; Wharton and others, 1969).

Increased turbidity and suspended-sediment concentration are the primary effects on water quality from sand and gravel removal. Turbidity lessens the recreational value of a stream, damages spawning areas, and decreases or eliminates the benthos because many groups of organisms are intolerant of silt. Increases of contaminants including trace elements, nutrients, and bacteria can be caused by desorption from disturbed sediment (J.C. Ford, Missouri Water Pollution Control Program, written commun., 1981). The effects of sand and gravel operations tend to be relatively localized, brief, and reversible (Simons, Li, and Associates, 1984).

Trace-element contents in stream-bottom material of the Big River near Irondale (fig. 8) increased after a gravel operation began upstream from the sampling site. Before the operation began in April 1978, the lead content was 65 μg/g, the zinc content was 16.4 μg/g, the cadmium content was 3 μg/g, and the copper content was 7.4 μg/g. In May and June 1978, after the gravel operation started and stream-bottom material was disturbed, lead contents ranged from 12 to 148 μg/g, zinc contents ranged from 233 to 646 μg/g, cadmium contents ranged from 3.1 to 7 μg/g, and copper contents ranged from 12.6 to 22 μg/g (Zachritz, 1978).

Gravel dredging and washing facilities along the downstream reach of the Osage River and the upstream reach of the Big River have been identified as destabilizing the substrate and eliminating aquatic life (Missouri Water Pollution Board, 1964). Along the downstream reach of the Kansas River, near Kansas City, Kansas, dredging was determined to have little or no effect on water quality, except at points where return flows from hydraulic dredging enter the river. Differences in abundance of many species of benthic invertebrates occurred between control and dredge sites because of the changing habitats created and modified by the dredging operations (University of Kansas, 1982).

Clay and Shale

Clay and shale have been mined in numerous locations across Missouri (fig. 11). Refractory- or fire-clay districts include the Northern district (Audrain, Boone, Callaway, Monroe Counties), the Southern district (Crawford, Franklin, Gasconade, Maries, and Phelps Counties) and the St. Louis district (eastern St. Louis County and the city of St. Louis). Nonrefractory clay and shale are present in the western, northern, and northeastern parts of the State (Wharton and others, 1969).

Trace elements are present in varying quantities in clay, shale, and limestone stockpiled near clay pits. Sulfuric acid can be produced from the weathering of pyrite and can increase the solubility and mobility of trace elements.

An abandoned claypit in northern Missouri that received runoff from weathered stockpiles had a pH of 4.27 and sparse aquatic life. Cobalt, nickel, and copper concentrations in the claypit water possibly were large enough to be toxic to aquatic life. Reproduction and growth were inhibited in beef cattle in the immediate area of the claypit (Ebens and others, 1973).

Data are insufficient to determine if circumstances similar are at other locations where material from clay and shale removal operations has been stockpiled and has weathered. If pyrite is present and acidic conditions result, large quantities of trace elements may be added to the environment. Runoff from stockpiles and areas of clay and shale mining can transport quantities of fine-grained material to nearby streams.

Stone

Eighty percent of the counties in Missouri have some type of stone removal operations. Included in this category are limestone, dolostone, sandstone, granite, and felsite (U.S. Geological Survey and Missouri Division of Geology and Land Survey, 1967). Runoff from stockpiles of crushed limestone has caused increased turbidity and a large suspended-sediment concentration (J.C. Ford, written commun., 1981). However, data are insufficient to determine the magnitude and extent of the effects of stone removal.

NEED FOR ADDITIONAL STUDY

Areas of localized contamination, such as Webb City, may exist in the Tri-State district. Wells that are completed in the deep aquifer need to be monitored for changes in ground-water quality by determining physical properties, dissolved-solids concentration, and concentrations of common inorganic compounds and trace elements.

In the Old Lead Belt, the ground-water quality needs to be determined in the abandoned mines, in areas adjacent to the tailings piles, and in the adjacent aquifer. A ground-water sampling network of private or public wells and mine-water discharge points needs to be established. Wells drilled into the abandoned mines and near the primary tailings piles would characterize the quality of the ground water. To determine the surface-water quality, specifically at high and low flows, sites need to be established on the Big River, the Flat River, small tributaries of the two rivers, and seepage channels

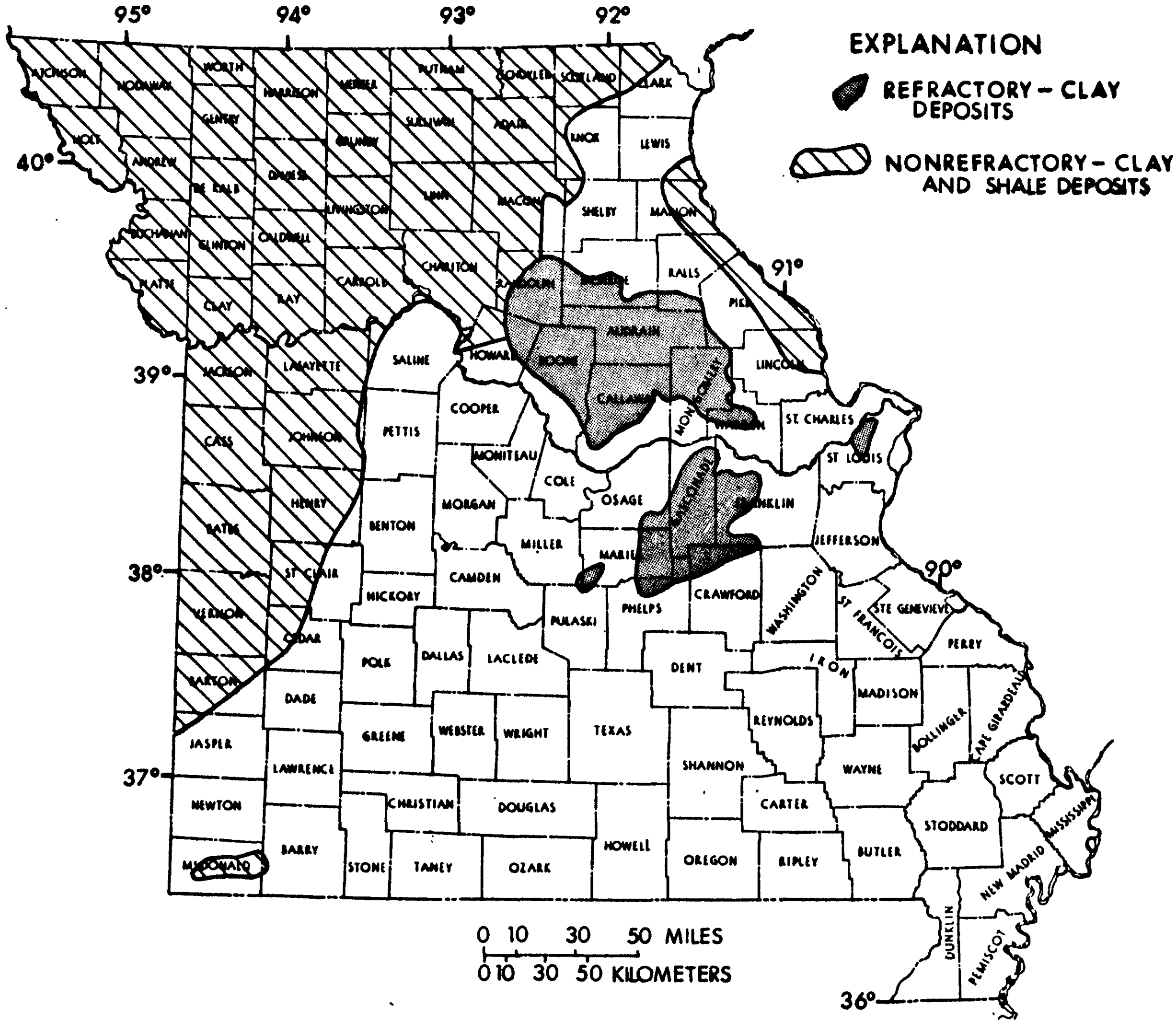


Figure 11. --Clay and shale deposits (modified from Wharton and others, 1969).

from the tailings piles. Physical properties and concentrations of common inorganic compounds and trace-element concentrations for ground water and surface water need to be determined. The extent surface-water quality is affected by ground-water quality needs to be determined. Samples of stream-bottom material from the surface-water sites would need to be collected and analyzed to determine the effects of trace-element contents on aquatic life. Limits on trace-element contents in bottom material in streams may need to be established if the effects on aquatic life are substantial.

Additional study is needed in the Viburnum Trend to determine the quality of ground water near the smelters, effects of mine dewatering on the potentiometric surface in the adjacent aquifer and on possible sinkhole formation, and magnitude and extent of ground-water contamination near losing streams, such as Logan Creek.

In the Fredericktown subdistrict, the effects of mining on ground-water quality have not been determined. Future study is needed to determine ground-water quality in the vicinity of the mines and adjacent to large tailings piles with the installation of monitoring wells. The quantity and quality of water seeping from the tailings piles needs to be determined.

SUMMARY

A study was conducted in the non-coal mining areas in Missouri to determine whether mining has caused or has the potential to cause adverse changes in water quality in the mined areas. Lead and zinc mining have had the most significant effects on water quality. Water-quality effects include contamination of aquifers from mine water, large trace-element concentrations in surface water from mine-water discharge, runoff and seepage from tailings piles, and large trace-element contents in stream-bottom material.

In the Tri-State district, little evidence exists to indicate widespread movement of contaminated water into the ground-water system. However, local contamination of the aquifer near mined areas may be possible. The maximum dissolved-zinc concentration in mine water was 35,000 µg/L. The maximum dissolved-lead concentration in drainage from tailings piles was 1,300 µg/L; the maximum dissolved-zinc concentration was 35,00 µg/L. The mineralization of water in parts of Center Creek, Grove Creek, Stoutt Branch, Mineral Branch, part of Turkey Creek, and Short Creek has increased as a result of mining.

In the Old Lead Belt, lead concentrations in two ground-water samples were 59 and 106 µg/L. The maximum dissolved-lead and dissolved-zinc concentrations in seepage from selected tailings piles were 230 and 18,000 µg/L. The maximum lead content in selected tailings material was 26,200 µg/g and the maximum zinc content was 20,900 µg/g. The maximum lead content in stream-bottom material in the Big River was 8,150 µg/g and the maximum zinc content was 8,555 µg/g. Aquatic life has been affected in the Big River, and the recommendation not to eat bottom-feeding suckers in a 40-mile reach of the Big River has been made by State officials.

In the Viburnum Trend, water from a mine had dissolved-lead and dissolved-zinc concentrations less than 25 µg/L. Dissolved trace-element concentrations of lead, zinc, cadmium, and copper in surface water in the area generally were less than 50 µg/L. The maximum lead content in stream-bottom material was 798

μg/g; the maximum zinc content was 332 μg/g. Fresh tailings had a maximum lead content of 736 μg/g and a maximum zinc content of 260 μg/g. On the basis of the number and diversity of benthic organisms, aquatic life has not been substantially affected in streams in the Viburnum Trend.

In the Fredericktown subdistrict, water from Saline Creek near a large tailings pile had a lead concentration of 460 μg/L, a cobalt concentration of 6,500 μg/L, a nickel concentration of 9,900 μg/L, and a copper concentration of 10,800 μg/L (all concentrations were dissolved). The trace-element contents in stream-bottom material from near Fredericktown were: lead, 12,000 μg/g; zinc, 1,825 μg/g; cobalt, 680 μg/g; nickel, 431 μg/g; and copper, 3,160 μg/g. Tailings from near Fredericktown had a lead content of 6,692 μg/g, a zinc content of 347 μg/g, a cobalt content of 3,797 μg/g, a nickel content of 6,081 μg/g, and a copper content of 13,856 μg/g.

Barite has been extensively mined in the Washington County district. Dissolved-barium concentrations in surface water from this area ranged from 100 to 590 μg/L. The primary effect of barite mining on water resources and aquatic life is produced by the failure of tailings-pond dams. Increased turbidity and suspended-sediment concentrations from the material released by the collapse of a dam can cause extensive fish kills.

Increased turbidity and decreased benthic population have been noted downstream from iron mining. Data are insufficient to fully determine the effects of iron mining as also is the case with copper, manganese, silver, and tungsten.

Trace-element contents in stream-bottom material in the Big River increased after a gravel operation began. Water in an abandoned claypit in northern Missouri had large concentrations of some trace elements, a small pH value, and sparse aquatic life. However, data are insufficient to determine the effects of sand and gravel, clay and shale, and stone removal.

Localized contamination of ground water in the Tri-State district and the Fredericktown subdistrict could be delineated with monitoring wells and physical and chemical analyses of ground and surface water. A need for additional study exists in the Old Lead Belt to determine the extent of ground-water contamination near the abandoned mines and tailings piles. With the use of monitoring wells, surface-water sampling sites, and physical and chemical analyses, the extent of contamination from interaction of ground and surface water could be determined. The quality of ground water, effects of mine dewatering, and effects of mining on losing streams have not been determined in the Viburnum Trend. The need for future study of barite mining would include the stability of tailings pond dams.

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