July 2005 Mineral of the Month: Galena

> "It is one of the most attractive of minerals because of its very striking properties. It has a brilliant metallic luster, the granular and cleavable types glittering with an exceptionally beautiful sparkle."– George Letchworth English, *Getting Acquainted with Minerals*, 1934

PHYSICAL PROPERTIES

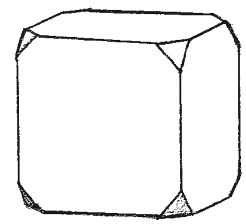

Figure 1 Galena cube, modified by octahedron

Chemistry: PbS   Lead Sulfide, often contains varying amounts of silver.
Class: Sulfides
Group: Galena
Crystal System: Isometric (Cubic)
Crystal Habits: Commonly in well-formed cubes and combinations of cubes and octahedrons; dodecahedrons less frequent. Also occurs in coarse- and fine-grained massive form, as cleavage fragments, and occasionally in fibrous form. Twinning common. Increasing silver content produces smaller crystals and often causes curvature of cleavage planes.
Color: Light-to-dark lead-gray, sometimes with bluish tint; fresh cleavage surfaces bright silver-gray.
Luster: Metallic
Transparency: Opaque
Streak: Light to dark lead-gray
Cleavage: Perfect in three directions
Fracture: Usually cleaves, fractures are rare and subconchoidal; brittle.
Hardness: Average 2.5, varies somewhat with impurities
Specific Gravity: 7.4-7.6
Luminescence: None
Distinctive Features and Tests: Lead-gray color, density, cubic cleavage, and softness.
Dana Classification Number: 2.8.1.1

NAME

Pronounced gah-LEE-nah, the name stems from the Latin *galena*, a term for both lead ore and the dross from molten lead. Because of its long use as an ore of lead, galena has many alternative names, including "lead glance," "sulfur lead," "potters' ore," "lead sulphuret," "black lead," "blue lead," "acerilla," "plumbum ore," "plumbite," "blyglans," "galenit," "galenite," and "bleiglanz." Galena's variety names include "argentiferous galena" (silver-rich galena), "auriferous galena" (gold-rich galena), "selenian galena" (selenium-rich galena), and "U-galena" (uranium-rich galena).

COMPOSITION

For our 113th month, we're featuring another of the minerals we've wanted to highlight for years, but could never find enough of at one time. We also had to be careful that the specimens were not too large, or it might end up costing more to ship them than to purchase them! It is most fitting that these come from Missouri, known as the "Cave State," whose state mineral is galena, and is one of the world's greatest sources of this lustrous lead ore. This is the second mineral we have featured from Missouri's Viburnum Trend–way back in February 1997, we featured marcasite as our monthly mineral, and sent Club members amazing specimens of gray calcite crystals, many with phantoms inside, coated to varying degrees with tiny iridescent marcasite crystals, from the Brushy Creek Mine, Reynolds County, near the center of the Viburnum trend. These wonderful specimens came from a one-time find, a network of underground caves about 1000 feet below the surface, in which the cave floors and walls were covered by the wonderful specimens. A group of collectors was allowed by the mining company to spend about eight months collecting underground–imagine walking and crawling about on large, sharp calcite crystals! Since this was a one-time find, specimens are rarely seen for sale now–too bad we didn't purchase a whole bunch then and hold them.

The chemical formula PbS identifies galena as lead sulfide containing the elements lead (Pb) and sulfur (S). By weight, galena consists of 86.60 percent lead and 13.40 percent sulfur. Within the galena molecule, the +2 charge of the lead cation balances the -2 charge of the sulfur anion.

Galena is among the most abundant and familiar members of the sulfide class of minerals. Sulfides, simple compounds of one or more metals or semimetals with sulfur, have great economic importance as the ores of many essential metals. Like most metal sulfides, galena is dense and brittle with a metallic luster. The Dana mineral classification number 2.8.1.1 first identifies galena as a sulfide (2). The subclassification (8) next defines it by the general formula $A_mB_nX_p$, in which the ratio of m+n:p is 1:1, a relationship reflected in galena's single lead cation and single sulfur anion. Galena is then assigned to its own group (1) as the first (1) of nine members.

As in all minerals, galena's atomic structure explains its physical properties. In galena, lead atoms are covalently bound to sulfur atoms by sharing two electrons. Within the galena lattice, each lead atom is surrounded by six sulfur atoms, and each sulfur atom by six lead atoms. This covalent, right-angle bonding creates a repetitive, cubic, boxlike structure in which all the crystal faces are perpendicular to the adjacent faces. These predominant, rigid, covalent bonds explain why galena is brittle with no malleability.

But galena's physical properties are also influenced by a lesser degree of metallic bonding that exists between its lead atoms. Some loosely held outer electrons of the lead atoms move freely throughout the lattice to form a common electron "pool." Metallic bonds form when the lead ions' positive nuclei attract the negative charges of the pooled, free electrons. This relatively weak metallic bonding predominates only between the cubic planes to give galena perfect, three-directional cleavage. Galena's free-electron pool also accounts for other properties. First, it provides enough electrical conductivity to make galena an electrical semiconductor. Second, by immediately absorbing or reflecting all incident light at the surface of the lattice, this free-electron pool accounts for galena's metallic luster and opacity.

Galena's unusually high density (specific gravity 7.4-7.6) is due to the high density of lead itself (specific gravity 11.37) and also to the radically different sizes of sulfur and lead atoms which make possible close atomic packing. Despite its considerable mass, lead has a small ionic radius that is less than one-quarter that of sulfur. Thus, lead ions nestle within the small spaces between the larger sulfur atoms to maximize the spatial density of the lattice.

Lead is among the heaviest of elements, or more correctly said, has greater mass than all but a few of the natural elements. (Scientists are phasing out the term "atomic weight" and replacing it with "atomic mass.") Lead's atomic number is 82, indicating that it has 82 protons in its nucleus, and its atomic weight (mass) is 207.62, meaning it has 208 protons and neutrons in its nucleus. Compare this to sulfur, atomic number 16, atomic weight 32.065, which has just 16 protons, and 32 protons and neutrons. Lead has six and a half times the mass, which explains why substances containing lead are so heavy!

As the most abundant lead-bearing mineral, galena occurs in several mineralogical environments. It is usually emplaced by medium- and low-temperature hydrothermal solutions in vein-type deposits. Its most important type of occurrence, certainly from the mining perspective, is with barite (barium sulfate, $BaSO_4$), sphalerite (zinc sulfide, ZnS), and marcasite (iron disulfide, FeS_2) in massive and disseminated hydrothermal replacement deposits within limestone or dolomite rock. In skarn (contact zones between igneous intrusions and limestone) of hydrothermal metamorphic rocks, galena is associated with pyrite (iron disulfide, FeS_2), chalcopyrite (copper iron sulfide, $CuFeS_2$), and the garnet-group member andradite [calcium iron silicate, $Ca_3Fe_2(SiO_4)_3$]. To a lesser extent, galena also occurs in disseminated form in certain igneous and sedimentary rocks. In oxidation environments, galena alters into cerussite (lead carbonate, $PbCO_3$) and anglesite (lead sulfate, $PbSO_4$).

Because it oxidizes readily, simple smelting procedures can chemically reduce galena to metallic lead at relatively low temperatures that can be attained with drafted wood fires. These smelting reactions are based on oxygen's great affinity for sulfur and on carbon's affinity for oxygen. When mixed with charcoal or a similar carbon source and heated in an oxygenated environment, crushed galena undergoes a two-phase chemical reaction. First, it oxidizes to form lead oxide and sulfur dioxide according to the formula $2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$. Then the carbon immediately reduces the lead oxide to metallic lead and carbon dioxide as shown in the formula $2PbO + C \rightarrow 2Pb + CO_2$.

Lead, the metallic component of galena, ranks 36th among the elements in crustal abundance. It is soft at Mohs 2.5, quite dense (specific gravity 11.37), extremely malleable, and melts at the low temperature of 662 F. (328° C.). Although lead is toxic, its unusual properties and ready availability give it many industrial uses. The chemical symbol for lead, Pb, along with the English words "plumbing" and "plumber," all derive from *plumbum*, the Latin word for lead.

COLLECTING LOCALITIES

Galena is abundant worldwide and is present in most hydrothermally emplaced lead, zinc, silver, copper, and multi-metal deposits. Quality specimens have been collected at literally thousands of sites. Galena is rarely mine-specific; when present in a mining district, it tends to occur in most mines within that district.

In France, excellent galena specimens occur at Langeac in Auvergne and Rhône-Alpes in Savoie. In Italy, galena is found in numerous mines in the provinces of Tuscany, Sardinia, and Liguria. German sources of galena include mines in Bavaria, Westfalen, and the Black Forest region of Baden-Württemberg. Austrian specimens have come from many mines in Carinthia, Tyrol, Salzburg, and Styria. Spanish sources include the huge Río Tinto Mine in the Huelva District of Andalusia and mines in Catalonia's Aran Valley. The historic Madan Orefield in southern Bulgaria continues to provide specimens.

In South America, fine galena specimens come from mines in Peru's Huaron District, Alcides Carrión Province, Pasco Department, and from the Julani District, Angaraes Province, Huancavelica Department. Bolivian specimens are collected at mines at Bostillos, Oruro Province, Potosí Department. Fine Mexican specimens are collected at the Congreso-León Mine, Nuevo Casas Grandes, Chihuahua, and at the Bamboullita Mine, Moctezuma, Sonora. Australia's sources include mines in the Broken Hill and New England districts in New South Wales. In Canada, galena is collected in Ontario's Sudbury and Timiskaming districts.

In the United States, some 36 states have significant galena occurrences. Among the most important are the Coeur d'Alene, Murray, and Pine Creek districts in Shoshone County, Idaho. Noted Illinois sources include the Cave-in-Rock and Empire districts in Hardin County, the Galena District in Jo Daviess County, and the Illinois-Kentucky Fluorspar District in Pope County. In Wisconsin, galena is abundant throughout the Upper Mississippi Valley District in Grant and Lafayette counties. Alaskan sources include the Red Dog Mine in northwest Alaska and the Green Creek District mines near Juneau. Among Colorado's many galena localities are the Leadville District in Lake County, Creede District in Mineral County, Ouray and Sneffels districts in Ouray County, Alma District in Park County, Aspen District in Pitkin County, and Silverton District in San Juan County. Utah localities include the Bingham, Big Cottonwood, and Little Cottonwood districts in Salt Lake County, the North Tintic and Gold Hill districts in Tooele County, and the American Fork District in Utah County. Among Montana's sources is the Butte District in Silver Bow County. The famed Tri-State Lead District (Joplin District), which covers parts of Cherokee County in Kansas, Jasper County in Missouri, and Ottawa County in Oklahoma, has produced many large galena specimens. Missouri has produced more than its share of fine galena specimens, as we will see.

JEWELRY & DECORATIVE USES

Too heavy, too soft, and too easily cleaved, galena has no use as a gemstone but is valued by mineral collectors for its well-developed crystals and interesting composite specimens.

HISTORY & LORE

Galena was mined in Egypt and the Near East as early as 3500 B.C. for use as a pottery glaze. Lead, no doubt recovered from galena, is mentioned several times in the Bible. At Job 19:23, 24, Job wants his words written down "with an iron stylus and with lead," alluding to the ancient practice of pouring liquid lead into engravings on stone, making them permanent. In his victory song after the Israelites passed through the Red Sea, Moses sang of the Egyptians: "They sank like lead in majestic waters." Later, the prophet Ezekiel refers to the "silver, iron, tin, and lead" mined in Tarshish, an ancient name for Spain.

Anthropologists believe that galena's metallic luster suggested to early metallurgists that certain minerals represented sources of metals. Later Greek and Roman writers described how wildfires, coupled with wind and carbon sources, actually converted outcrops of galena to metallic lead. Galena was among the first ores to be reduced to metal by artificial smelting, and the knowledge gained in working with galena greatly impacted the history and advancement of metallurgy.

Romans conducted the first great galena-mining venture in what is now Spain, shipping large quantities of metallic lead back to Rome for manufacture into plumbing fixtures, roofing sheets, floor tiles, and countless miles of pipe for elaborate plumbing and water-supply systems. By 1300 A.D. rich galena mines in central Europe were providing large supplies of lead for such uses as pigments for canvas and fresco art, projectiles for early firearms, lead-tin alloys for moveable type in early printing presses, and sheathing for ship hulls.

With the 1859 invention of the electric storage battery in which lead plates were vital, lead became a modern industrial metal and galena mining quickly increased. In the United States, prospectors first found huge galena deposits in Illinois, Wisconsin, and Missouri, then moved west to discover even larger deposits of argentiferous galena. Although many western mining camps that exploited argentiferous galena ores became famed for their silver output, most actually produced by weight as much as 20 to 30 times more lead.

Galena was the first material ever employed as semiconductor. During the first half of the 20th century, crystal radio sets enjoyed great popularity as inexpensive radio-wave receivers and classroom science projects. The heart of the crystal set was a tiny galena crystal that acted as a semiconductor to modify complex electrical microcurrents and separate the audio components of broadcast radio waves. Semiconductors are solids with variable levels of electrical conductivity that fall between those of highly conductive metals like copper and non-conductive, insulating materials like glass. In 1874, German physicist Ferdinand Braun (1850-1918) discovered that electrical resistance in metal-sulfide crystals varied with the direction of current flow. Concentrating his research on galena, Braun learned that current modification was greatest when one of the electrodes was a pointed wire, a phenomenon now known as the "point-contact electrical rectifier effect."

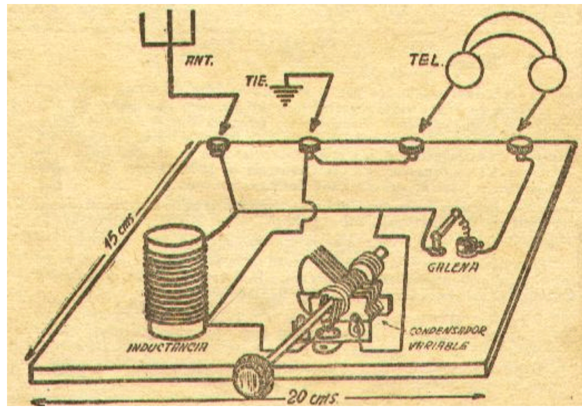

Figure 2 Crystal set schematic

In 1910, American researchers found that galena crystals could detect radio signals amid electrical currents—knowledge that led directly to the development of the first radio receivers. Called "crystal sets," these consisted of a wire aerial to capture broadcast signals as alternating microcurrents, a tuning circuit of two concentric wire coils, an earphone, and a single, quarter-inch, cubic crystal of galena as a "detector." The operator "detected" the audio portion of the microcurrent by brushing a "cat's whisker"—a thin, copper wire—across the face of the galena crystal until the audible signal was strongest. Crystal sets were simple and very inexpensive. Even their power—the 1/1000th of a watt of microcurrent that the broadcast wave induced in the aerial—was free. And the galena crystals themselves cost only pennies.

Galena's ability to rectify alternating current is due to the repetitive sequence of lead and sulfur atoms in its crystal lattice. Pure galena would conduct current only weakly. But galena always contains small amounts of impurities which create either an excess or a deficiency of free electrons at regular points in the lattice. These act as electron "traps" that permit electron motion in one direction only. Knowledge derived from the study of galena's electrical properties has since resulted in the development of an array of semiconducting materials, among them silicon (Si), germanium (Ge), and gallium (Ga), that are used in such modern semiconducting devices as solid-state and light-emitting diodes, transistors, diacs, and triacs, which are essential to everything from computers to cell phones.

Because of the toxicity of lead, galena has seen little use in medicine. Modern metaphysicists consider galena a "stone of harmony" that enhances healing, calmness, efficiency, receptivity, communication, and insight, and aligns energies.

Both Wisconsin and Missouri have officially designated galena as their state minerals. Galena has appeared on the 50-cent stamp of Kenya in 1977, the two-schilling stamp of Uganda in 1988, the 42-cent stamp of Canada in 1992, the 29-peseta stamp of Spain in 1994, and the 0.42-franc stamp of Belgium in 2003.

TECHNOLOGICAL USES

Galena has always been the primary ore of lead and provides about 98 percent of all newly mined lead. Three-quarters of the lead produced worldwide is used in automotive products such as wet-cell storage batteries, fuel tanks, solder, seals, and bearings. The remainder is fabricated into electrical, electronic, and communication products; ammunition; television and computer-monitor glass; plates for nuclear-shielding applications; ceramic glazes; high-lead crystal glass; type metal; and specialty foils and wire.

Lead's toxicity has been studied extensively. When lead is ingested or inhaled, the body's red blood cells absorb the metal (or its compounds) and concentrate it first in the liver and kidneys and eventually in the bones. Lead adversely affects most physiological and neurological systems, damaging the central nervous system and penetrating the blood-brain barrier that normally protects the brain from harmful compounds. In adults, lead-poisoning symptoms include hypertension, memory loss, headache, sterility, muscle and joint pain, and loss of ankle and wrist control. Over the past 40 years, lead and lead compounds have been removed from, or reduced in, many products, most notably automotive fuels, paints, and plumbing solders. Again, we're reminded to wash our hands after handling our mineral specimens!

Galena mining, milling, and smelting, nevertheless, remains a major international industry. Each year, mines turn out some three million metric tons of lead. The top lead-mining nations are Australia and China, followed by the United States. The U.S. produces about 500,000 metric tons of lead per year, mainly from mines in Alaska, Missouri, Montana, and Utah. The current price of lead in the U.S. is about 23 cents per pound.

ABOUT OUR SPECIMENS

Our specimens come from the important Viburnum Trend, Iron County, Missouri. Missouri's lead-mining industry is centered in the Southeast Missouri Lead District, a seven-county area roughly an hour's drive south of St. Louis. Within this district are several subdistricts, most importantly the historic Old Lead Belt and the Virburnum Trend (also called the New Lead Belt), the latter of which now accounts for all Missouri lead production. Both of these districts can be seen in the map in Figure 3. Southeast Missouri Lead District ores are found in the dolostone (a sedimentary rock containing at least 50 percent dolomite [calcium magnesium carbonate, $CaMg(CO_3)_2$] of the Cambrian-aged Bonneterre Formation. Mineralization occurred after a geological uplift fractured the Bonneterre dolomite, allowing pressure to force metal-rich solutions from deep, adjacent sedimentary basins into the resulting faults and fissures. These solutions were rich in lead and lesser amounts of zinc, copper, nickel, cobalt, cadmium, silver, and iron.

Where impeded by anticlines and synclines (bends and folds) in the Bonneterre strata, the solutions dissolved away the dolomite to form "ore traps," spaces where metals could precipitate out of solution as sulfides to form bedded, or sheet-type, replacement deposits. These sulfide deposits consist primarily of galena with lesser amounts of sphalerite (zinc sulfide, ZnS); the copper-iron sulfides chalcopyrite and bornite ($CuFeS_2$ and Cu_5FeS_4, respectively); and the iron disulfides pyrite and marcasite (both FeS_2). Also present are minerals that are rare in most other districts, including siegenite (cobalt nickel sulfide, $CoNi_2S_4$); bravoite (a nickel-rich variety of pyrite); and millerite (nickel sulfide, NiS). Close to fifty other minerals have also come from mines of the Viburnum Trend!

Within the Bonneterre strata, galena occurs as disseminated crystals, crystalline aggregates, and fracture fillings. Bedding seams as thick as 18 inches consist of alternating layers of fine- and coarse-grained, massive galena. Where dolomite bedding planes have shifted, galena seams are crushed and even smeared. But where solution cavities and fracture zones provided room for growth, galena crystals are large, well-formed, and often spectacular, with individual crystals sometimes weighing several hundred pounds each!

Within the greater Southeast Missouri Lead District, galena occurs as both simple cubes and modified, complex cubes with two or more octahedral faces. Curved galena cleavage planes are common, and contact zones sometimes yield "sand-lead" crystals, with galena filling in the pores of quartz or dolomite sand. Galena, sphalerite, and siegenite are present in virtually all district ores, along with modest amounts of cadmium and silver, not as identifiable minerals, but in solid solution with galena and sphalerite. The primary gangue (non-economic) minerals are quartz and calcite, the latter forming white to yellow-brown crystals up to one foot in length. Pyrite and marcasite are abundant and occur in several habits, including unusual stalactitic forms.

French miners opened the Southeast Missouri Lead District in what is now the Old Lead Belt in the 1720s, digging shallow pits to expose galena veins. Although the high-grade ore required no concentration, poor smelting methods had only a 50-percent recovery efficiency. At the time, lead was being used to manufacture musket balls, small-bore cannon shot, and lead sheeting. Because of limited demand, the French mines operated only a few months each year. After 1803, when the Louisiana Purchase made Missouri part of the United States, lead demand increased steadily. By 1830, St. Francois County's five mines made it the center of Missouri's lead industry. Most of the county's 2,300 residents worked directly in lead mining or smelting, or in supporting activities.

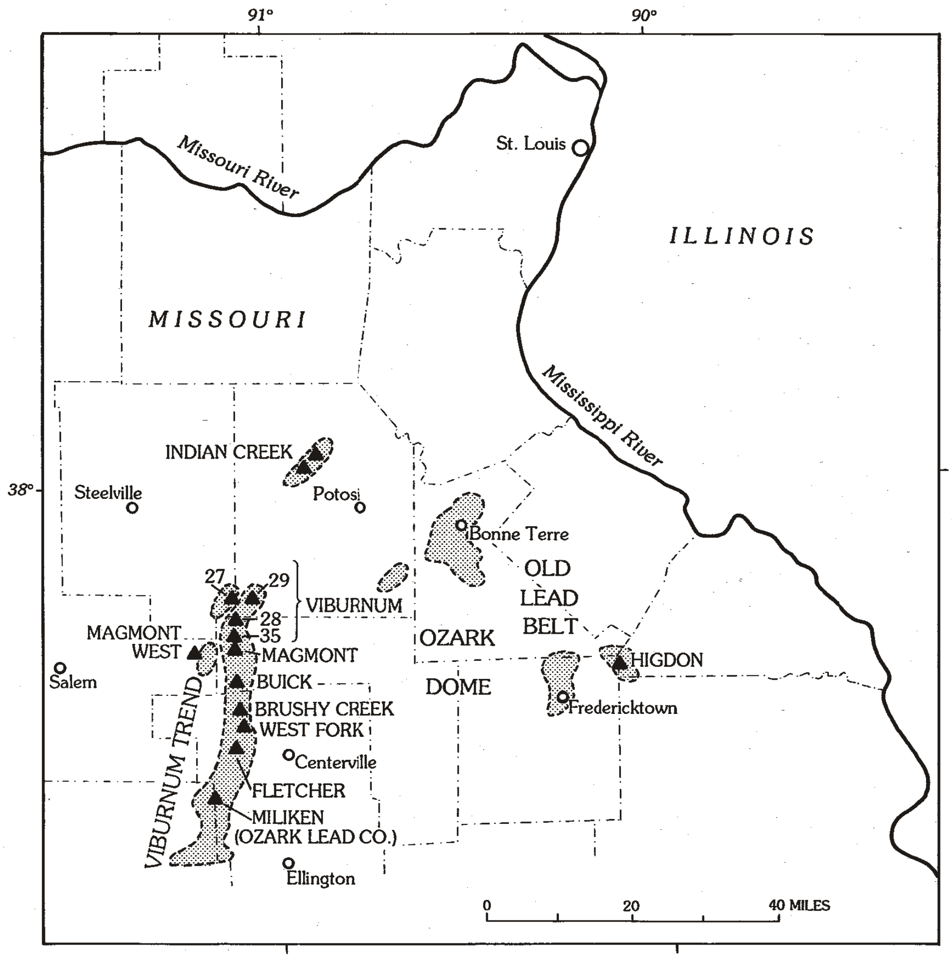

Figure 3 Location map of Viburnum Trend mines, courtesy of *Rocks & Minerals* magazine, used by permission

Missouri's modern mining era began when the Civil War generated unprecedented demand for lead in the manufacture of ammunition. In 1864, the St. Joseph Lead Company, familiarly known as "St. Joe," developed open pits that were soon followed by underground workings. The company also developed and applied advanced mining technologies. In 1869, St. Joe exploration crews employed the first diamond-core drills ever used west of the Mississippi to locate new lead deposits. By 1933, when the St. Francois County mines had already produced eight million tons of lead, St. Joe had consolidated some 15 mines to become the district's sole operator. The names of nearby towns—Leadington, River Mines, Old Mines, and Leadwood—reflected the economic importance of Missouri lead mining. By the 1950s, St. Joe's operations in the Old Lead Belt employed 5,000 workers, even though the district was then rapidly running out of ore.

Just in time to save the southeast Missouri's lead-mining industry, core drilling revealed nearly identical types of ore deposits nearby to the west. This string of new deposits, called the Virburnum Trend, or New Lead Belt, attracted some of America's biggest mining companies, including St. Joe, the Homestake

Mining Company, and AMAX. In 1986, all Virburnum Trend properties were consolidated under The Doe Run Company, the successor to St. Joe and to the 1886 Doe Run Lead Company. Today, Doe Run, with eight mines, four mills, two smelters, a lead-recycling plant and two lead-fabrication plants, ranks as the world's premier lead-producing company. Doe Run's single-level, room-and-pillar mines exploit poly-metallic ores grading about five percent lead, one percent zinc, and one-half percent copper. After the ore is crushed and ground to a powder, the metals are concentrated by flotation separation, then smelted to recover the metals.

Table 4. Viburnum Trend mines.

Mine	Initial prod. date	
No. 27	July	1960
No. 28	Jan.	1962
No. 29	Nov.	1964
Casteel (No. 35)	Aug.	1983
Magmont	June	1968
Magmont West		1982
Buick	Feb.	1969
Brushy Creek	May	1973
West Fork	Sept.	1985
Fletcher	June	1967
Sweetwater (Milliken)	June	1968

Figure 4 Viburnum Trend mines, from *Rocks & Minerals* magazine, used by permission.

The quote by George Letchworth English that opened our write-up is certainly apropos, and no mineral collection is complete without at least one fine specimen of galena. Why, the featured mineral at the Tucson Gem & Mineral Show in 1989 was none other than galena! This was prior to our entry into the world of minerals, but we can imagine the phenomenal specimens that must have been on display there! *Rocks & Minerals* magazine has devoted many pages to Missouri galena, first in its January/February 1989 issue, printed in connection with the Tucson Show, and in its November/December 1997 issue which was devoted entirely to the minerals, fossils, and geology of Missouri. For those who want more information on Missouri mines and minerals, both these back issues are still available from Heldref Publishing at rocksandminerals.org or by calling (800)365-9753.

Our specimens come from several of the mines mentioned in Figure 4, though it is not possible to get an exact locality for each specimen. As mentioned earlier, the mines are all working the same basic ore body. Our specimens have great luster because they are recently cleaved from huge masses of galena, and have not been affected by weathering. Most galena specimens will not have this same bright luster, but rather a more dark-gray color with a bluish tint caused by weathering.

"Galena occurs in such variety that a large single-specimen collection could be made from it alone," states John Sinkankas in *Mineralogy*, and we concur. We hope our specimens have proved a worthwhile addition to your collection!

Dana's New Mineralogy, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts et al, Van Nostrand Reinhold Company; *2004 Fleischer's Glossary of Mineral Species*, Joseph Mandarino and Malcolm Back, The Mineralogical Record, Inc.; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Company; *Getting Acquainted with Minerals*, George Letchworth English, 1934; "*Ore Deposits of the United States: 1933-1967*, American Institute of Mining Engineers, New York, 1968; "Lead," *2003 Minerals Yearbook*, United States Geological Survey, "Toxic Treasure," Steve Voynick, *The World & I*, November 1999; "Connoisseur's Choice: Angelsite in Galena, Toussit Mine, Oujda, Morocco," Robert B. Cook, *Rocks & Minerals*, March-April 1999; "Tri-State and Virburnum Districts: An Overview," Raymond Lasmanis, and "Brushy Creek Mine, Reynolds County, Missouri," Les Presmyk, *Rocks & Minerals*, November-December 1997; "Galena From Mississippi Valley-Type Deposits," Raymond Lasmanis, *Rocks & Minerals*, January-February 1989; "Minerals of the Madan Orefield, Bulgaria," Svetoslav Petrossenko, *The Mineralogical Record*, November-December 1991; "Missouri's Lead-Mining Legacy, Steve Voynick, *Rock & Gem*, October 2001; "Galena: The First Semiconductor," Steve Voynick, *Rock & Gem*, December 2004