

ROCKS^{and} MINERALS of Kentucky

by Warren H. Anderson



KENTUCKY GEOLOGICAL SURVEY
Donald C. Haney, State Geologist and Director
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COVER: Kentucky agate from
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ROCKS AND MINERALS OF KENTUCKY

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INTRODUCTION

Throughout history minerals have been a vital part of man's culture. Minerals were utilized by early Neanderthal and Cro-Magnon man for paints and decorative ointments. Early Greeks and Egyptians used gold, rubies, and sapphires for jewelry; copper and iron for tools and weapons; and clays for bricks and stones. Today, beautiful mineral specimens are collected and proudly displayed in homes, museums, and rock shows across Kentucky. Students, scouts, and rock collectors of all ages enjoy learning about the beauty and science of minerals. Kentucky has a variety of rocks and minerals for collecting, including agates, geodes, and crystals.

This publication gives information about rocks and minerals of Kentucky and is organized to (1) help in your identification and study of Kentucky rocks and minerals, (2) explain how rocks and minerals are formed and why they are important to the Commonwealth, and (3) be a simplified reference.

Collecting Rocks and Minerals

One golden rule you should always observe is GET PERMISSION FROM THE LANDOWNER to collect rock and mineral specimens on private property. Most landowners are friendly and helpful when informed of your interest. Mine dumps and quarries are excellent sources for rock and mineral specimens, but should be entered only after you receive permission from the mine or quarry superintendent, since most operators require supervision of mineral collectors for safety. You should always think "safety first" and watch for falling rocks from highwalls, overhangs, and traffic along roadcuts.

Rock and mineral collecting in caves and State and National parks is prohibited by law. The Kentucky Geological Survey provides information only, and cannot grant permission for collecting on public or private properties.

Rock Collections and the Amateur Collector

When you begin to assemble a collection, it is wise to identify and give the location of the specimens. Rocks themselves are valuable, but many have added value because of their location. A label should have the name of the rock or mineral, an identification number, the name of the person who collected it, location where collected, date, and any other pertinent information. A permanent label may be made by placing a small patch of white enamel on one corner of the specimen. After the enamel is dry, an identification name or number may be lettered with waterproof ink. A field notebook may also be used to write down any additional information.

Each specimen should be wrapped with paper or other packing material in the field. This practice will guard against scratching or breakage during transportation.

Some of the basic tools a rock collector needs are hammer, chisel, hand lens or magnifying glass, gloves, goggles or impact-resistant glasses, pocket knife, pencil and note pad, knapsack or backpack, and boxes. Boots or comfortable shoes should be worn in appropriate areas.

Serious collectors have display cases or cabinets for their best specimens. Specimens are usually stored in shallow, rectangular boxes called "flats," which can be stacked easily.

Numerous rock and mineral clubs throughout the United States sponsor field trips and mineral shows. A few of the local rock and mineral clubs are the Bluegrass Rock and Mineral Club (Lexington), Kyana Gem and Mineral Club (Louisville), Kentucky Lake Rockhounds (Gilbertsville), and clubs in Owensboro and Bowling Green. Numerous rock shows are also held throughout the Midcontinent area in Cincinnati, Louisville, and Detroit, usually in the early spring and summer. Many public-service organizations such as the Kentucky Geological Survey, Department of Agricultural Extension 4-H program, geology departments of major colleges and universities, and various museums can help you as well.

ROCKS, MINERALS, AND THE EARTH

The basic building blocks of all rocks, minerals, liquids, and gases are chemical elements, which are made up of various combinations of atoms. For example, when lead (Pb) atoms combine with sulfur (S) atoms, the mineral galena is formed. The elements mentioned in the text and their chemical symbols are listed in Table 1.

Table 1.—Common Chemical Elements.

<i>Element</i>	<i>Symbol</i>	<i>Element</i>	<i>Symbol</i>
Silver	Ag	Magnesium	Mg
Aluminum	Al	Molybdenum	Mo
Gold	Au	Manganese	Mn
Barium	Ba	Nickel	Ni
Carbon	C	Oxygen	O
Calcium	Ca	Lead	Pb
Cadmium	Cd	Platinum	Pt
Chlorine	Cl	Sulfur	S
Cobalt	Co	Silicon	Si
Fluorine	F	Strontium	Sr
Iron	Fe	Titanium	Ti
Hydrogen	H	Tungsten	W
Mercury	Hg	Zinc	Zn
Potassium	K		

A mineral is a naturally occurring solid with a definite chemical composition and crystal structure. Rocks are naturally occurring solids composed of one or more minerals. Rocks are identified by the minerals they contain and are grouped according to their origin into three major classes: sedimentary, igneous, and metamorphic. Each group is subdivided on the basis of texture and mineral composition.

Most of the rocks found in Kentucky are sedimentary. Sedimentary rocks are formed from (1) the weathering and transport of

pre-existing rocks and (2) the chemical precipitation of sediments. Examples of sedimentary rocks are limestones, sandstones, and shales. Igneous rocks result from the cooling of molten rock or magma to create rocks like granites, basalts, and rhyolites. Metamorphic rocks have been physically and mineralogically changed by heat and pressure to form another type of rock; for example, the sedimentary rock, limestone, will become the metamorphic rock, marble; the sedimentary rock, shale, will become the metamorphic rock, slate; and the igneous rock, granite, will become the metamorphic rock, gneiss (pronounced *nice*). Igneous and metamorphic rocks are not common in Kentucky but have been observed in glacial outwash gravels in northern Kentucky, and have been found as constituents in sandstones in eastern Kentucky and in deep wells drilled throughout the State.

Geology of Kentucky

Kentucky is composed dominantly of flat-lying sedimentary rocks of Paleozoic age (Fig. 1). The oldest exposed rocks in Kentucky date back about 480 million years to the division of geologic time called the *Ordovician Period* (Fig. 2). Most of the older rocks (Ordovician, Silurian, Devonian, and Mississippian) are limestones, dolomites, and shales, which were formed in ancient seas when the Eastern Interior of the continental United States was submerged under seas. These rocks are stratified (layered), and ma-



Figure 1. Generalized geologic map of Kentucky.

rine fossil remains can be found in them in many places. The younger rocks (Pennsylvanian, Cretaceous, and Tertiary) are sandstones, shales, and coal beds, which were deposited on low coastal plains. Plant remains are found in the coals, clays, and associated rocks and give evidence of ancient forests and swamps. The youngest rocks are of Tertiary age and are located in western Kentucky. Quaternary sediments are very recent, and are located in Kentucky as valley-bottom deposits.

During the Pleistocene Ice Age (first part of Quaternary), many kinds of rocks were transported into parts of northern Kentucky and along the Ohio Valley by glacial ice sheets and their associated meltwater streams. Varieties of igneous (granite and basalt), metamorphic (quartzite and schist), and sedimentary (limestone and siltstone) rocks were deposited. They are called *erratics* because they have been transported from their original source by glaciers.

Structural processes such as folding and faulting of stratigraphic units creates uplift, which also accelerates the erosional process. In areas where uplift has occurred, erosion has been more extensive and older rocks are exposed. These processes are another part of the geologic history of Kentucky: As illustrated in Figure 1, the oldest rocks in the State occur in central Kentucky where structural events have caused older rocks (Ordovician) to be uplifted along a domal structure called the Jessamine Dome. The Jessamine Dome is located along an elongate north-trending structural flexure termed the Cincinnati Arch. The Cincinnati Arch extends from Cincinnati, Ohio, through Cumberland County in southern Kentucky. These same rocks exposed on the surface in central Kentucky occur below the surface in eastern and western Kentucky, where they are downwarped into geologic structures called *basins*. Rocks at the surface in the east (Appalachian Basin) and west (Illinois Basin) are much younger and at one time extended across the State but have since been removed by erosion in the central part of the State. The Rome Trough in eastern Kentucky and the Rough Creek Graben in western Kentucky are major downwarped structures associated with the Appalachian and Illinois Basins, respectively. The Reelfoot Rift in western Kentucky is a large, deep-seated crustal fault system developed during an attempted continental breakup and is the focus of numerous earthquakes.

These basins, arches, and rifts are major structures that are cut by faults caused by folding and buckling of strata. Several major

Era	Significant Events	Rocks Exposed in Kentucky	Period	Cumulative Age
Cenozoic 67 ±	Man		Quaternary (1)	1
			Tertiary (65)	66
Mesozoic 179 ±	Dinosaurs		Cretaceous (88)	144
			Jurassic (64)	208
			Triassic (37)	245
			Permian (41)	286
Paleozoic 325 ±	Coal Reptiles		Pennsylvanian (34)	320
			Mississippian (40)	360
			Devonian (48)	408
			Silurian (30)	438
			Ordovician (67)	505
			Cambrian (65)	570
Precambrian	Diverse Marine Life			
Proterozoic				2,500
Archean	Primitive Marine Life			3,800

Figure 2. Geologic time column. The first column lists the eras and the duration of each era, in millions of years. The second column lists significant events that occurred during each era. The shaded areas in the third column indicate that rocks from these periods occur in Kentucky. The fourth column subdivides the eras into periods; the duration of each period, in millions of years, is indicated in parentheses following each period. The fifth column lists the cumulative age for each period.

fault systems are in Kentucky, including the north-trending Lexington Fault System along the Cincinnati Arch and Jessamine Dome in central Kentucky, the east-west-trending Kentucky River and Irvine-Paint Creek Fault Systems in eastern Kentucky, the Rough Creek and Pennyrile Fault Systems in western Kentucky, and the Pine Mountain Overthrust Fault in southeastern Kentucky.

Sedimentary Rocks

Sedimentary rocks are the most abundant rock type exposed at the surface of the earth and cover about 99 percent of Kentucky. They were formed by the accumulation of rock fragments, shell fragments, plant material, muds, and sands, which were transported to their present locations by water, air, wind, or ice to form sandstones, shales, coals, and conglomerates (Fig. 3). Coal is a very common sedimentary rock formed from plant material, and different coals are formed from variations in temperature and pressure. Limestone was formed in marine depositional environments and as a chemical precipitate from sea water. Dolostone is a limestone that has been chemically altered. Evaporites such as anhydrite, gypsum, and salt were precipitated by the evaporation of water in arid environments.

Other sedimentary rocks accumulated because of physical processes where rivers, deltas, and beaches produced sand deposits and conglomerates. Many of these types of sedimentary rocks accumulate to thousands of feet of thickness in large depositional basins known as *sedimentary basins*. Under the pressure of their in-

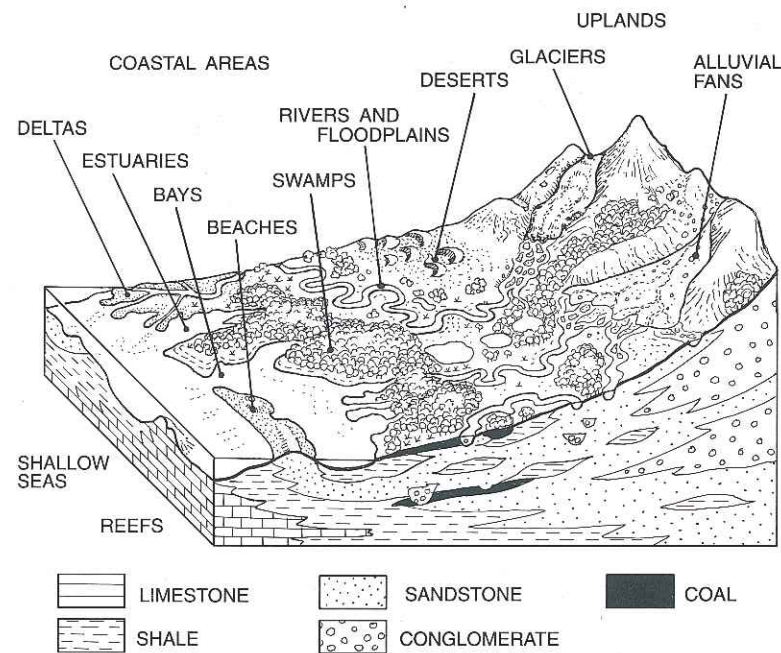


Figure 3. How sedimentary rocks are formed.

creasing weight, the sediments were compacted, hardened, and cemented together to form solid rock. By compaction and cementation, gravels became conglomerates, muds became shales, sands became sandstones, and lime sediments became limestones. Most sedimentary rocks were originally deposited underwater and are therefore nearly flat lying. However, subsequent movements of the earth's crust have deformed or tilted them in some places, causing them to dip steeply. Most sedimentary rocks can be identified from characteristic features that may be seen in a hand specimen. The following sedimentary rocks are common in Kentucky.

Coal

Coal (Fig. 4) is formed from peat, which is an accumulation of decayed vegetation usually associated with swamps. The process of the transformation from peat to coal is called coalification. In the stages of coalification, peat is altered to lignite, lignite is altered to sub-bituminous coal, sub-bituminous coal is altered to bituminous coal, and bituminous coal is altered to anthracite coal. Most Ken-

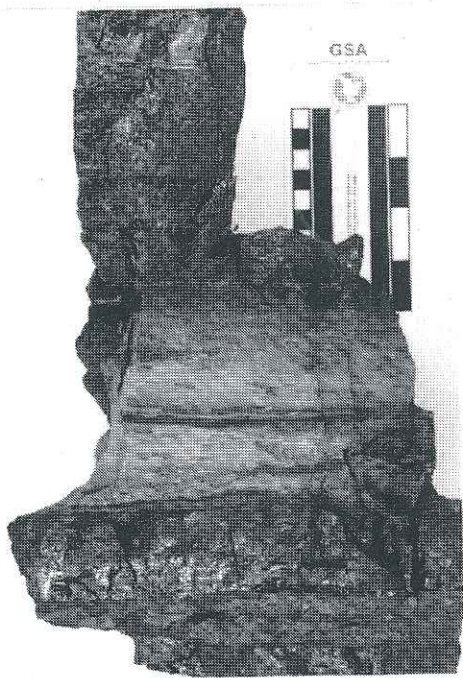


Figure 4. Coal sample with flint clay partings.

tucky coal is bituminous, but some lignite occurs in western Kentucky.

Coal is found in Pennsylvanian-age (Fig. 1) rocks in eastern and western Kentucky, where it is interbedded with shales, sandstones, conglomerates, and thin limestones. The Pennsylvanian Period began approximately 320 million years ago and lasted about 30 million years; it is commonly referred to as the Coal Age. Minor coal deposits are also found in Cretaceous and Tertiary rocks in the Jackson Purchase Region of Kentucky (Fig. 1).

LIGNITE

Brown coal, or lignite, is composed of woody material embedded in decomposed vegetable matter. It has a very high moisture content and a low heating or energy value. In the Jackson Purchase area, lignite deposits occur in Cretaceous and Tertiary sediments and also in the form of carbonized twigs and leaves and logs. In-place stumps occur in Jackson Purchase sands and clays of the Tertiary Epoch.

BITUMINOUS COAL

Bituminous coal is brownish black to black, banded, and commonly breaks into cubical or prismatic blocks. It has a low moisture content and a high heating value; it ignites rapidly and burns with a smoky yellow flame.

Bituminous coal is the most important mineral resource in Kentucky. In 1991, mines in 39 Kentucky counties produced 170 million short tons, valued at over \$3 billion. Kentucky produced 17 percent of the Nation's coal. There were 105 billion tons of coal calculated as original resources in Kentucky.

CANNEL COAL

This variety of coal, which is composed chiefly of pollen and spore material, has a dull luster, breaks with a conchoidal (glass-like) fracture, and is preferred for fireplace use because it does not soil the fingers. In recent years, cannel coal has been mined at Cannel City in Morgan County.

Limestone

Most than 50 percent of the surface rocks in Kentucky are limestones. Limestone (Figs. 5–6) is chiefly composed of the mineral



Figure 5. Oolitic limestone.

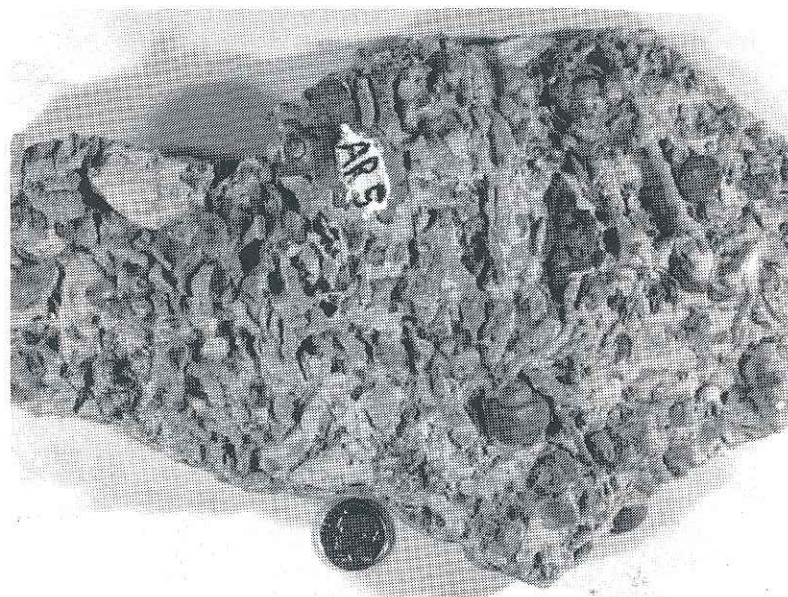


Figure 6. Fossiliferous limestone.

calcite (calcium carbonate), but may contain small amounts of clay, silt, chert, and dolomite. Most limestones are layered and contain fossils of shellfish and other animals that lived in shallow seas. Limestones are shades of bluish gray to tan. The brown and yellow shades are usually caused by iron oxide impurities and the dark-gray to black colors are caused by organic material. The texture of limestone ranges from coarsely crystalline to very fine grained. The large crystals can be seen by the unaided eye, while the crystals in the very fine-grained material, which is usually mixed with clay, are visible only under magnification. Limestone effervesces (fizzes rapidly) when treated with cold dilute hydrochloric acid and is easily scratched by a knife blade. Vinegar, which contains acetic acid and water, will also cause limestone to effervesce.

In 1991, crushed limestone sold or used by producers in Kentucky amounted to 46,266,000 short tons valued at \$191,893,000. Crushed limestone is used extensively for road surfacing and making concrete; other uses are for agricultural lime, railroad ballast, and fluxing stone. Limestone is much in demand as an ornamental or building stone.

Dolostone

In the past, the term "dolomite" was applied to both the mineral and the rock. In this publication, the term "dolomite" is restricted to the mineral, and the term "dolostone" is restricted to the rock.

Dolostone is a sedimentary rock composed chiefly of the mineral dolomite, which is magnesium calcium carbonate. It is closely related to limestone, both physically and chemically; in fact, when the magnesium content decreases, it is often referred to as magnesian or dolomitic limestone. Dolostones often exhibit a sugary (saccharoidal) texture and commonly weather to a buff or brown color caused by iron carbonate in the rock. Dolostone effervesces very slowly in dilute hydrochloric acid and is slightly heavier and harder than limestone.

The most extensive deposits of dolostone in Kentucky occur in a north-south belt extending from Oldham County to Marion County and from Wayne County toward Lewis County. Geologists have referred to these strata as the Laurel and Brassfield Dolomites of Silurian age and the Renfro Member of the Borden Formation of Mississippian age, respectively (Fig. 1). In the subsurface in Green and Taylor Counties, the Laurel is a good oil reservoir rock and is called the "Blue sand" by drillers. The "Corniferous" is another drillers'

term for oil-bearing Silurian and Devonian dolomitic rocks in eastern Kentucky.

Dolostone is used as a building and ornamental stone; for road aggregate, and as agricultural lime; in the making of rock wool; as a flux in the production of pig iron in the blast furnace; for the making of natural cement; and in the manufacture of magnesium and dolomite refractories.

Conglomerate

Conglomerate (Fig. 7) is a sedimentary rock usually composed of rounded quartz pebbles, cobbles, and boulders surrounded by a matrix of sand and finer material, and cemented with silica, iron oxide, or calcium carbonate. The rock fragments are rounded from being rolled along a stream bed or a beach during transportation. If the fragments embedded in the matrix are angular instead of rounded, the rock is called a breccia (pronounced *brech'i-a*).

The Lee Formation (Pennsylvanian), which borders the Eastern Kentucky Coal Field, contains a conglomerate termed the Rockcastle Member. This conglomerate is very resistant to weathering

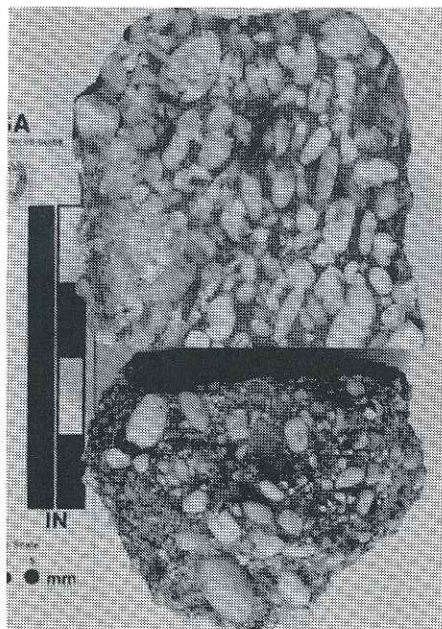


Figure 7. Conglomerate.

and caps the tops of mountains throughout much of its extent. Excellent exposures of the Lee Formation occur at Cumberland Falls in Whitley County, Natural Bridge in Powell County, and along Pine Mountain.

Certain poorly cemented conglomerates may be crushed and used for the same purposes as unconsolidated sands and gravels. Levi Jackson State Park has a collection of millstones that are conglomerates and coarse sandstones that were used for grinding corn and wheat.

Sandstone

Sandstone (Plate 1) is composed of mineral grains (commonly quartz) cemented together by silica, iron oxide, or calcium carbonate. Sandstones are typically white, gray, brown, or red. The red and brown sandstone shown in Plate 1 is colored by iron oxide impurities. Most sandstones feel gritty, and some are easily crushed (friable) and break up to form sand. Sandstones have pore spaces between each grain of sand; this property, called *porosity*, makes them good reservoirs for oil and natural gas.

Sandstones are very resistant to erosion and form bluffs, cliffs, ridges, rapids, arches, and waterfalls. Sandstones and conglomerates are responsible for most of the rugged topography in eastern Kentucky. Loose or unconsolidated sands cover much of the Jackson Purchase area of western Kentucky. These sands are varicolored, but commonly white to light brown. Silica (quartz-rich) sands and sandstones of high purity (white color) are used extensively in the glass industry for manufacturing window glass, light bulbs, and containers. At present, glass sands are obtained from unconsolidated deposits near New Concord, Calloway County. Tightly cemented sandstone is used as a building stone.

ROCK ASPHALT

Rock asphalt is a medium- to coarse-grained sandstone with asphalt (bitumen) filling the pore spaces. It is brown to black, has a pitchy to resinous luster, and when thoroughly saturated is very sticky.

Rock asphalt deposits were formed when erosion of the surface rocks exposed oil-bearing rocks and allowed the more volatile hydrocarbons to escape. The asphaltic-base crude gradually thick-

ened until only a heavy tar or asphalt remained. The bitumen content of commercial rock asphalt varies from 3 to 15 percent.

Rock asphalt was once mined on a large scale in Kentucky. Large deposits occur in Edmonson, Grayson, and Hardin Counties in western Kentucky, and Carter County in eastern Kentucky. Periodically and most recently during the early 1980's, attempts have been made to reclaim the petroleum in the rock asphalt by heat treatment, distillation, and other processes.

Rock asphalt is used principally for surfacing streets and highways. Other uses are roofing, waterproofing, flooring for factories, and blending with rubber.

Shale

Shale is the most abundant of all sedimentary rocks. It is composed primarily of soft clay minerals, but may include variable amounts of organic matter, calcareous material, and quartz grains. Shale may be any color, but is generally greenish gray to grayish black. It is relatively soft and has a smooth, greasy feel when freshly exposed, but is hard and brittle when dry. Most shales split into thin plates or sheets and are termed *fissile*, but others are massive (nonfissile) and break into irregular blocks. Shales weather very easily to form mud and clay. Numerous secondary minerals are associated with shales, including melanterite, copiapite, and halotrichite, which are described in a later section.

The most prominent shale in Kentucky is the Chattanooga (also called New Albany and Ohio) Shale, which crops out in southern Kentucky and around the Knobs area. It is brownish black, silty, pyritic, bituminous, and carbonaceous. This Chattanooga black shale contains sufficient organic matter to burn, and several attempts have been made to mine this "oil shale" as a fuel source.

The New Providence and Nancy Shales of Mississippian age, which also crop out in south-central Kentucky and around the Knobs area, are used in the brick industries of Kentucky. They are a bright-green to greenish-gray, relatively soft, plastic clay-shale.

Clays

The term "clay" is applied to various earthy materials composed dominantly of hydrous aluminum magnesium silicate minerals. The most familiar characteristic of clay is plasticity or ability of moist clay to be fashioned into a desired shape. The physical properties of a clay are plasticity, strength, and refractoriness. Plasticity enables the clay to be molded; strength permits it to be handled during the forming, drying, and burning processes; and refractoriness permits it to be burned into a hard body of permanent form. Many types of clay are found in Kentucky. The most important ones are described below. Mineralogy of the clays is described in a later section.

BALL CLAYS

Ball clays consist chiefly of the clay mineral kaolinite, with a minor amount of montmorillonite and organic material. Ball clay is lightweight, chalk-like in appearance, and used in china, whiteware, and various ceramic products.

BENTONITE

Bentonite is a soft, low-specific-gravity, expandable clay. It is altered volcanic ash and properly should be labeled *metabentonite*. Bentonite is found in central Kentucky in beds up to 3 feet thick near the top of the Tyrone Limestone. Drillers have labeled these bentonite beds the Mud Cave and Pencil Cave. Because of its peculiar property of expanding when wet, bentonite is effective as a water sealer, especially to prevent pond leakage, and is also used in rotary drilling muds to prevent contaminating formations with drilling fluid.

FLINT CLAY

Flint clay is medium gray to grayish brown, occasionally dark gray to black or red; harder than ball clay or fuller's earth; and has an earthy luster. The clay is a hard, tough, refractory clay consisting chiefly of the clay mineral kaolinite. Flint clay will not mix with water, and lacks the chief characteristic of clay, namely plasticity. It is compact, dense, breaks with a conchoidal fracture, and is resistant to erosion. The plant-root fossil *Stigmara* is commonly preserved in the clay as a carbonaceous film. The Olive Hill Clay Bed in north-eastern Kentucky is the principal source of flint clay, where it was used as firebrick. A special type of flint clay called *tonstein* occurs in

the Eastern Kentucky Coal Field and is the product of volcanic ash falls.

FULLER'S EARTH

Fuller's earth is a variety of montmorillonitic clay that is a natural bleach. It was originally used by fullers to "full" or remove grease from cloth; hence its name. Fuller's earth clay is found in the Jackson Purchase Region in the Porters Creek Clay of Paleocene age. The Porters Creek is very fine grained and contains scattered flakes of mica (muscovite). Fuller's earth is used as an absorbant.

HALLOYSITE

Halloysite is a type of kaolinitic clay that occurs near erosional unconformities and is distinctive because of its tubular structure.

Igneous Rocks

Igneous rocks are very rare in surface exposures in Kentucky. They are formed by the cooling and solidification of molten rock (magma) that originated deep within the earth (Fig. 8). The two main types of igneous rocks are intrusive, which formed when magma cooled slowly and hardened beneath the earth's surface, and extrusive, which formed when magma solidified after it reached the surface.

In Kentucky, a dark-colored igneous rock, peridotite, occurs in sills and dikes (intrusions) in Elliott County in northeastern Kentucky (Fig. 9), and Caldwell, Crittenden, and Livingston Counties in western Kentucky. Peridotites formed very deep in the earth near the mantle under high temperature and pressure, and were thrust explosively toward the surface where they intruded into the host rocks. Peridotite consists in part of the minerals olivine and pyroxene. Approximately 25 minerals are found in or associated with these dikes, including garnets, apatite, biotite, calcite, chlorite, chromite, diopside, dolomite, enstatite, hornblende, hypersthene, ilmenite, magnetite, perovskite, plagioclase feldspar, quartz, serpentine, and titanite. These minerals will be discussed in following sections.

The Elliott County peridotite (Plate 2) is a special type of peridotite called *kimberlite*. It is dark green to black, and is composed of various grain sizes (porphyritic texture) in a fine- to medium-

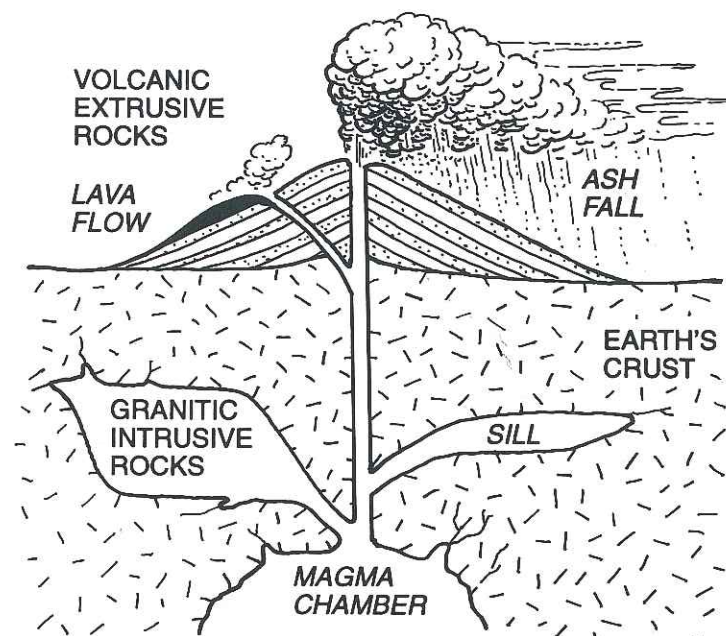


Figure 8. How volcanic igneous rocks are formed.

grained groundmass called a matrix. Numerous phenocrysts (individual crystals embedded in a finer grained groundmass) average from 2 to 10 mm in diameter, but some individual phenocrysts may reach 25 mm. Olivine is the most abundant mineral in the dikes and accounts for the greenish color of the rock. Most of the calcite in these igneous rocks is primary, meaning it is of magmatic origin.

Kimberlites are famous for containing diamonds. The dikes in Elliott County (Plate 2) are geologically similar to the diamond-bearing kimberlites in Kimberly, South Africa, and kimberlites in Arkansas, where diamonds have been mined extensively, but no diamonds have ever been authenticated from the Elliott County deposits.

Twenty-eight known peridotite dikes occur in Livingston and Crittenden Counties in the Western Kentucky Fluorspar District. These dikes vary in mineralogical content because of differences in the original parental magma.

Other igneous rocks such as granites, basalts, gneisses, and amphibolites occur in the deep subsurface of Kentucky. Most of these rocks occur at depths of 5,000 to 15,000 feet below the sur-

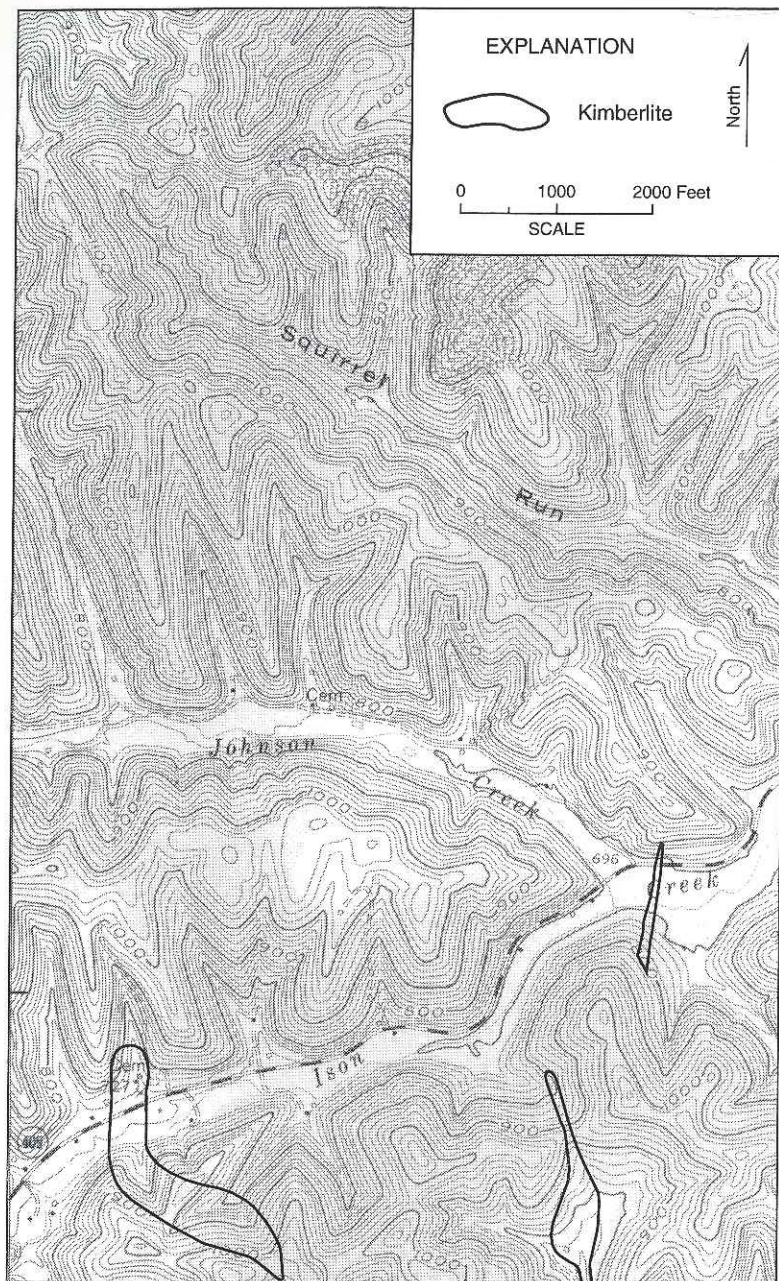


Figure 9. Portion of Willard topographic quadrangle map showing locations of peridotite dike outcrops.

face, and samples of these rocks are encountered when oil or mineral well tests are drilled. Igneous rocks have also been found in glacial deposits in northern Kentucky.

Metamorphic Rocks

Metamorphic rocks are sedimentary or igneous rocks whose physical and mineralogical characteristics have been profoundly altered by the action of heat or pressure, or both. The principal metamorphic rocks are schist, phyllite, gneiss, marble, quartzite, and slate. Some metamorphic rocks can also be found in glacial deposits in northern Kentucky. Metamorphic rocks also exist in the deep subsurface of Kentucky and have been encountered in oil and mineral drill holes. The nearest surface exposures of metamorphics are in the Blue Ridge and Piedmont areas of Virginia, West Virginia, and the Carolinas, and the Great Smoky Mountains in Tennessee and North Carolina.

Glacial Drift

During the previous ice ages, numerous igneous and metamorphic rocks from Canada and the northeastern United States were transported by glaciers and deposited by meltwater streams in northern Kentucky in Trimble, Carroll, Gallatin, Boone, Kenton, Campbell, Pendleton (Plate 3), and Bracken Counties. These glacial *erratics* are composed of igneous rocks such as granites and basalts, metamorphic rocks such as schist, phyllites, and gneisses, and sedimentary rocks such as limestone and siltstone. There is a wide assortment of igneous and metamorphic rocks in these deposits that are not normally found in Kentucky. It is remotely possible that some gold and diamonds may also be associated with these glacial erratics.

METHODS USED IN IDENTIFYING MINERALS

Over 4,000 minerals are known to man, and these minerals are identified by their physical properties. The physical properties of minerals are determined by the atomic structure and crystal chemistry of the minerals. The most common physical properties are crystal form, color, hardness, cleavage, and specific gravity.

Crystals

One of the best aids in the identification of a mineral is its crystal form (external shape). A crystal is defined as a homogenous solid possessing a three-dimensional internal order defined by the lattice structure.

Crystals developed under favorable conditions often exhibit characteristic geometric forms (which are outward expressions of the internal arrangements of atoms), crystal class, and cleavage. Large, well-developed crystals are not common because of unfavorable growth conditions, but small crystals recognizable with a hand lens or microscope are common. Minerals that show no external crystal form but possess an internal crystalline structure are said to be massive. A few minerals, such as limonite and opal, have no orderly arrangement of atoms and are said to be amorphous.

Crystals are divided into six major classes based on their geometric form: isometric, tetragonal, hexagonal, orthorhombic, monoclinic, and triclinic (Fig. 10). The hexagonal system also has a rhombohedral subdivision, which applies mainly to carbonates.

Cleavage and Fracture

After minerals are formed, they have a tendency to split or break along definite planes of weakness. This property is called cleavage. These planes of weakness are closely related to the internal structure of the mineral, and are usually, but not always, parallel to crystal faces or possible crystal faces. Minerals may have one, two, three, four, or six directions of cleavage. These cleavage forms are (1) cubic, (2) octahedral, (3) dodecahedral, (4) rhombohedral, (5) prismatic, and (6) pinacoidal. Minerals that break easily along these lines of weakness yield shiny surfaces. Fluorite and calcite are two common minerals having distinct or perfect cleavage. Fluorite has good octahedral cleavage, which causes it to cleave into octagons; calcite also cleaves preferentially along rhombohedral planes, which determines its external form.

Many crystals do not cleave, but fracture or break instead. Quartz, for example, forms well-developed crystal faces but does not cleave at all; instead it fractures or breaks randomly with a conchoidal fracture.

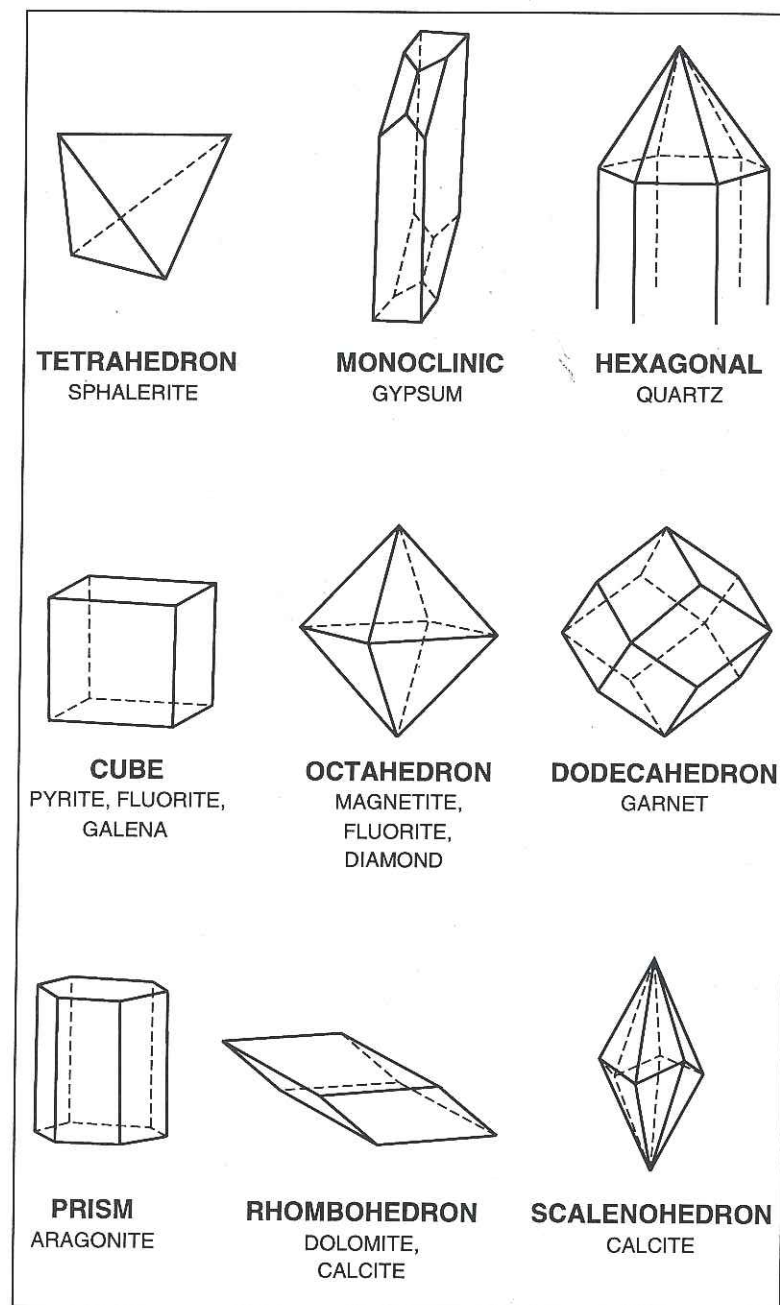


Figure 10. Shapes of the six crystal classes of minerals.

Color

The color of a mineral is the most important identifying characteristic for the amateur mineralogist. Many minerals exhibit various colors; the varieties are mainly due to impurities or a slight change in chemical composition. For example, calcite can be white, blue, yellow, pink, or fluorescent. Surface tarnish may have changed the color of the specimen; therefore, a fresh surface should be examined.

Hardness

The hardness (scratchability) of a mineral can be measured by its resistance to scratching or abrasion. Mohs scale is a set of 10 common minerals chosen for comparative hardness. The minerals are arranged in order of increasing hardness; each mineral will scratch all that precede it, and be scratched by all that follow it. Mohs scale is as follows:

- | | |
|-------------|---------------|
| 1. talc | 6. orthoclase |
| 2. gypsum | 7. quartz |
| 3. calcite | 8. topaz |
| 4. fluorite | 9. corundum |
| 5. apatite | 10. diamond |

A generalized scale using the following common objects can be used to determine relative hardness of minerals that are less than 7:

<i>If a mineral can be scratched by a ...</i>	<i>then its hardness is ...</i>
fingernail	up to 2.5
penny	2.5–3.5
knifeblade	up to 5.5
windowglass	5.5
steel file	up to 7.0

Streak

The streak of a mineral is the color of the powder produced when the mineral is rubbed against an unglazed porcelain plate or other

fine-grained, hard, abrasive surface. The color of a particular mineral may vary, but the streak is generally constant. The streak may be the same color as the mineral or an entirely different color, but the streak of all white minerals, including calcite, is white.

Luster

Luster refers to the brightness of light reflected from the mineral's surface. The main types of luster are metallic and nonmetallic. Some of the more important nonmetallic lusters are:

Adamantine: brilliant, like that of a diamond.

Earthy: dull, like kaolin.

Silky: having the sheen of silk, like satin spar, a variety of gypsum.

Greasy: oily appearance.

Resinous: waxy appearance, like sphalerite.

Vitreous: the appearance of broken glass, like quartz.

Nacreous (pearly): like mother of pearl; for example, pearly luster on fossil gastropods and cephalopods.

Specific Gravity

The specific gravity (relative density) of a mineral is its weight compared to the weight of an equal volume of water; thus, a mineral with a specific gravity of 4 is four times heavier than water. Special instruments are needed to measure the specific gravity.

Tenacity

Tenacity is the measure of a mineral's cohesiveness or toughness. Tenacity terms are:

Brittle: breaks or powders easily; for example, pyrite or marcasite.

Ductile: can be drawn into a wire; for example, copper.

Elastic: bends and resumes its original position or shape when pressure is released; for example, biotite or muscovite.

Malleable: can be hammered into thin plates or sheets; for example, gold or copper.

Sectile: can be cut or shaved with a knife; for example, gypsum or galena.

Acid Test

When carbonates (especially calcite) are treated with cold, dilute hydrochloric acid, they will effervesce, foam, and bubble, and give off carbon dioxide gas (CO_2). When sulfides, such as galena, pyrite, and sphalerite, are treated with dilute hydrochloric acid, they will give off the rotten-egg odor of hydrogen sulfide.

Magnetism

A few minerals, such as magnetite and pyrrhotite, are attracted by a magnet and are said to be magnetic. Magnetic minerals are rare in Kentucky, but do occur in the kimberlite in Elliott County. If you find a large piece of highly magnetic material, it may be a meteorite or a furnace product.

Fluorescence

Some minerals, such as calcite, gypsum, halite, uranium minerals, and fluorite, will fluoresce in brilliant colors when viewed with an ultraviolet (UV) light. UV light is not normally visible to the human eye, and you should avoid looking directly at the UV source as it can damage eyesight.

MINERALS

Most minerals are chemically classified as native elements, sulfides, sulfates, oxides, silicates, carbonates, phosphates, halides, nitrates, tungstates, molybdates, arsenates, or vanadates. Unless otherwise noted, most of the minerals mentioned occur in Kentucky.

Descriptions

This section describes most of the minerals that occur in the State using the classification system established by Dana (Palache and others, 1955; Hurlbut, 1971). This classification is based on chemical composition and the chemical name for each mineral. Each description provides some basic information on crystallography, physical properties, other diagnostic features, uses, and mode of occurrence.

Native Elements

Native elements are minerals composed of only one element, such as copper, sulfur, gold, silver, and diamonds. These native elements are not common in Kentucky, but are mentioned because of their collector appeal.

DIAMOND, C

Crystal system: isometric. Cleavage: perfect octahedral. Color: colorless, pale shades of yellow, orange, or blue. Hardness: 10. Specific gravity: 3.5. Uses: jewelry, saws, polishing equipment.

Diamonds, the hardest of any naturally formed mineral, are also highly refractive, which causes light to be split into a spectrum of colors commonly called *play of colors*. Because of its high specific gravity, it is easily concentrated in alluvial gravels, where it can be mined. This is one of the main mining methods used in South Africa, where most of the world's diamonds originate. The source rock of diamonds is the igneous rock, kimberlite, also referred to as diamond pipe. A non-gem variety of diamond is called *bort*.

Kentucky has kimberlites in Elliott County in eastern Kentucky and Crittenden and Livingston Counties in western Kentucky, but no diamonds have ever been discovered or authenticated in these rocks. A diamond was found in Adair County, but it was determined to have been brought in from somewhere else.

SULFUR, S

Crystal system: orthorhombic. Fracture: uneven. Color: yellow. Hardness 1–2. Specific gravity: 2. Sulfur smell, burns easily.

Sulfur crystals occur in geodes and nodules in the Borden–Ft. Payne Formation in south-central Kentucky.

PRECIOUS METALS

Gold, Au (Silver, Ag; Platinum, Pt)

Crystal system: isometric. Cleavage: octahedral. Color: brilliant yellow, paler if it has high silver content. Hardness: 2.5–3. Luster: metallic. Specific gravity: 19.3. Tenacity: malleable and ductile. Uses: jewelry, coins.

Gold (Plate 4) is not common in Kentucky, but is included here because of its appeal. Gold has been of value to mankind for centuries because of its color, weight, and malleability.

Gold commonly occurs in microscopic amounts in the earth and in seawater, and it commonly is found in quartz veins associated with igneous and metamorphic rocks.

Silver (color: gray to silver white; hardness: 2.5–3; specific gravity: 10.5) and platinum (color: steel gray; hardness: 4; specific gravity: 21.5) do not have good cleavage and are not common in Kentucky, but are sometimes associated with gold.

Sulfides

Sulfides are elements combined with sulfur, such as sphalerite, galena, pyrite, and millerite.

GALENA, PbS

Crystal system: isometric. Cleavage: perfect cubic, although octahedrons are common as truncations to the cube. Color: silver to lead gray. Hardness: 2.5. Streak: grayish black. Luster: bright metallic. Specific gravity: 7.5. Tenacity: sectile. Uses: batteries, gasoline, type metal, solder, low-fusion alloys, telephone and telegraph cable coverings, protective shieldings against radiation.

Galena (Plate 5) is the chief ore of lead. It is recovered as a by-product of the fluorspar industry in western Kentucky. It has been recovered from the Columbia Mines in Crittenden County and Silver and Royal Mines in Livingston County. It also occurs to a limited extent in the central Kentucky vein system, where it used to be mined near Gratz in Owen County, and in vein deposits in Scott and Franklin Counties. In both of these areas galena crystals can be found with barite and sphalerite crystals. Galena also occurs with calcite, dolomite, fluorite, and pyrite.

PYRITE, FeS₂ (CHALCOPYRITE, CuFeS₂; BORNITE, Cu₅FeS₄; MARCASITE, FeS₂)

Crystal system: isometric. Cleavage: when present, crystals usually cube-shaped; crystal faces commonly marked by parallel lines called *striations*. Color: pale brass yellow to golden yellow. Hardness: 6.0–6.5. Streak: brown to black. Luster: metallic. Specific gravity: 5.0. Tenacity: very brittle. Uses: sulfuric acid.

Because of its brassy-yellow color, pyrite (Plates 6–8) is often mistaken for gold; hence its common name, “fool’s gold.” In Kentucky, pyrite and marcasite are very common in several different rock types and in geodes, especially in strata associated with coal

beds and in the Chattanooga Shale. Cubic pyrite and pyritohedrons (Plate 8) can be collected from coal mines, and pyrite cubes occur with millerite at Halls Gap in Lincoln County. Pyrite can be massive with no crystals visible, or it can have euhedral cubic crystals. In some states pyrite can be mined, but there are no deposits large enough to be mined in Kentucky.

Pyrite occurs frequently with chalcopyrite (CuFeS₂), bornite (Cu₅FeS₄), and marcasite (FeS₂). Chalcopyrite, also known as fool’s gold, is commonly tarnished and iridescent. Bornite is known as “peacock ore” because it is very iridescent and produces a pleochroic array of colors.

Marcasite crystals have a pale-bronze color, hardness of 6.0 to 6.5, and a tabular cleavage that resembles cockscombs or spearheads. Marcasite, also called white iron pyrite, readily tarnishes yellow to brown and decomposes to a white powder. Immersion in epoxy will retard the decomposition process.

MILLERITE, NiS (HONESSITE, NiS·H₂O)

Crystal system: hexagonal; individual crystals can be twisted, spiraled, or offset along the crystal axis. Cleavage: usually does not occur in cleavable masses. Color: brass yellow. Hardness: 3.5. Luster: metallic. Specific gravity: 5.5.

Millerite (Plates 9–10) is an acicular (needle-like) mineral that occurs in interwoven groups of radiating crystals, usually in geodes and cavities. Millerite hydrates (water is incorporated into its chemical composition) to honessite (NiS·H₂O) (Plate 11), which has the same mode of occurrence as millerite, but is commonly green to brown and acicular. Capillary pyrite has also been associated with millerite.

Since the early 1960’s, millerite from Halls Gap (Fig. 11) near Stanford in Lincoln County has been a prized collector’s item. Most mineral books have pictures of millerite (Plates 9–10), honessite (Plates 11–12), and capillary pyrite collected from the Halls Gap locality. Millerite and honessite occur in the Wildie Member of the Borden Formation. Anatase (TiO₂) has also been reported (Alan Goldstein, 1992, personal communication) in the upper section of the Halls Gap locality. Most millerite geodes are small, but some are as big as softballs.

The photograph of very small calcite crystals attached to an acicular millerite crystal in Plate 13 was taken using a powerful mi-

croscope. Pyrite cubes were also observed attached to millerite hairs (Plate 14), and a pyrite ring was observed in one geode (Plate 15).

SPHALERITE, ZnS (GREENOCKITE, CdS)

Crystal system: isometric. Color: yellowish brown to black. Hardness: 3.5–4.0. Streak: pale yellowish brown. Luster: resinous to adamantine. Specific gravity: 4.0. Tenacity: brittle. Uses: galvanizing iron, brass, die castings; associated cadmium used for batteries and in the electronics industry; associated germanium and gallium used to produce transistors, diodes, and rectifiers.

Sphalerite (Plates 16–17), is also called zinc blende or blackjack and is a common vein-forming mineral in numerous mines in central and western Kentucky, where it has been mined. It is predominantly associated with galena, but also occurs with barite, fluorite, calcite, pyrite, and chalcopyrite.

Sphalerite has been mined from the Hutson Mine in Livingston County, and the Lexington Quarry Company has mined sphalerite from a vein deposit in Jessamine County for several years, produc-



Figure 11. Halls Gap locality and roadcut, Halls Gap, Kentucky.

ing very fine, dark-brown to black, tetrahedral crystals (Plate 17). The sphalerite there is associated with calcite, barite, and gypsum.

Cadmium (Cd), a trace element commonly found in sphalerite, forms the mineral greenockite (CdS). Greenockite occurs as orange or yellow crystals or coatings associated with sphalerite. Germanium and gallium, also trace elements in sphalerite, are produced as by-products of sphalerite in the fluorspar area in western Kentucky.

Sulfates

Sulfates are elements combined with both sulfur and oxygen, such as gypsum, barite, and anglesite.

BARITE, BaSO₄

Crystal system: orthorhombic. Cleavage: often in groups of platy or tabular crystals. Color: usually white, but may be light shades of blue, brown, yellow, or red. Hardness: 3.0–3.5. Streak: white. Luster: vitreous to pearly. Specific gravity: 4.5. Tenacity: brittle. Uses: in heavy muds in oil-well drilling, to increase brilliance in glass-making industry, as filler for paper, cosmetics, textiles, linoleum, rubber goods, paints.

Barite (Plates 18–20) generally occurs in the white massive variety (often appearing earthy when weathered), although some clear to bluish, bladed barite crystals (Plate 18) have been observed in several vein deposits in central Kentucky, and various nodular zones have been observed in Silurian-Devonian rocks in east-central Kentucky. Rosettes (Plate 19) are common in many Kentucky mineral veins. Feathery barite is shown in Plate 20, as it appears under a petrographic microscope.

Barite is extremely insoluble in acid and water and is therefore chemically inert. It is the principal source of the element barium. Barite is the most abundant of the semi-commercial vein-forming minerals in central Kentucky. Until World War I, barite was mined along with fluorite and sphalerite in Jessamine, Woodford, and Fayette Counties. Limited barite mining was attempted during the 1960's in Lincoln and Boyle Counties. Commercial barite was recovered as a by-product of the fluorspar industry in western Kentucky during World War II and during the 1960's.

More detailed information on barite in vein deposits is discussed under the section, "Vein Mineral Deposits." A comprehensive report

on the vein and barite deposits of Kentucky (Anderson and others, 1982) is available from the Kentucky Geological Survey.

CELESTITE, SrSO_4

Crystal system: orthorhombic. Cleavage: tabular or prismatic. Color: generally white, but may be tinted blue or pink. Hardness: 3.0–3.5. Streak: white. Luster: glassy to pearly. Specific gravity: 3.9. Tenacity: brittle. Uses: fireworks, flares, tracer bullets, refining sugar beets, ceramic and glass industries, caustic soda solutions.

Celestite occurs as a solid-solution series with barite and is the principal ore of strontium. It is not common in Kentucky, but is sometimes found in vein deposits and lining cavities in limestones. Good celestite crystals have been found in nodules and geodes in Ordovician rocks in Woodford and Jessamine Counties, Silurian rocks in Montgomery County, and Mississippian rocks in Rockcastle and Lincoln Counties. The geodes are generally composed of an outer shell of siliceous material, such as chalcedony, and the inner parts are filled with celestite and associated minerals such as calcite, fluorite, barite, gypsum, and quartz.

GYPSUM, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (ANHYDRITE, CaSO_4)

Crystal system: monoclinic. Color: colorless when pure, but often stained gray to yellow. Hardness: 2.0. Streak: white. Luster: glassy. Specific gravity: 2.32. Uses: plaster, wallboard, pottery molds, orthopedic and dental plasters, portland cement.

Gypsum (Fig. 12, Plates 21–23) usually occurs as a massive variety, although crystals are common. A fibrous variety is called satin spar; it has a silky luster and is found as vein fillings and as thin layers in shales and limestones. Selenite is a transparent crystalline variety (Plates 21–22). Excellent selenite specimens and curved gypsum (Fig. 12) have been collected from the Lexington Quarry Company, where foot-long crystals have been discovered. The New Providence Formation in northwestern Marion County also has good gypsum crystals. The gypsum occurs as diamond-shaped crystals that often grow together to form "swallowtail twins." Numerous "gypsum flowers" (Plate 23) adorn the walls of many caves in Kentucky.

From a commercial standpoint, rock gypsum is the most important variety. It is an aggregate of crystals that range from less than 0.1 mm to more than 2.0 mm in diameter. Bedded rock-gypsum de-

posits associated with anhydrite occur deep underground in the St. Louis Limestone in northwestern Kentucky and at moderate depths southwest of Louisville.

Anhydrite (crystal system: orthorhombic; color: white, gray, or bluish; hardness: 3.5; streak: white; luster: vitreous; specific gravity: 3.0) usually hydrates to gypsum. Anhydrite crystals have been found in well cuttings of deep oil wells, in nodules in Wayne County, and in some vein deposits.

SECONDARY SULFATES, SO_4

Many other sulfates occur in lesser amounts in various parts of Kentucky. They are fragile, fibrous, granular or powdery, clear to white masses (except for copiapite). These minerals occur in coal beds, coal mines, and the black shale.

Most of these minerals are difficult for the experienced collector to distinguish, and some may require analysis for correct identification. These minerals are humidity-sensitive and their chemistry may change when they are dehydrated.

Epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) is white and occurs as delicate encrustations. Melanterite ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) is a white powdery mineral with glassy luster. Alunite ($\text{KAl}_3(\text{OH})_6(\text{SO}_4)_2$) is white and massive, and is distinguished from limestone and dolomite by not effervescing in an acid test. Copiapite ($(\text{Fe}, \text{Mg})\text{Fe}_4(\text{SO}_4)_6(\text{OH})_2 \cdot 20\text{H}_2\text{O}$) occurs as a loose crust with a distinctive yellow color. Mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) forms white, massive crusts. Halotrichite

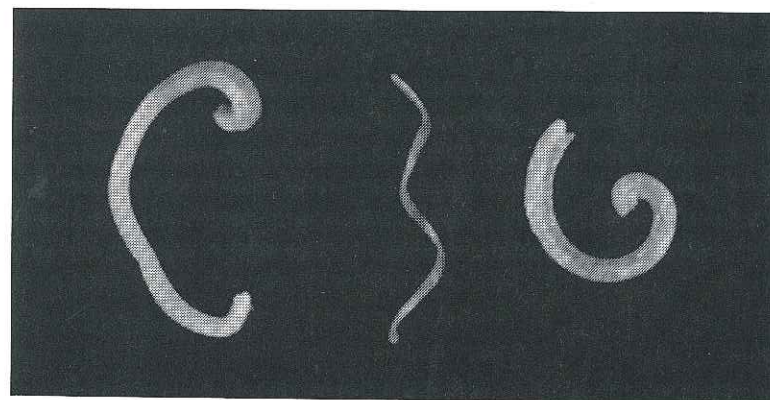


Figure 12. Curved gypsum and selenite crystals. Center crystal is 3 inches long.

($\text{FeAl}_2(\text{SO}_4)_4 \cdot 22\text{H}_2\text{O}$) and pickeringite ($\text{MgAl}_2(\text{SO}_4)_4 \cdot 22\text{H}_2\text{O}$) are massive and white, with silky luster and astringent taste.

Goslarite ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) is a rare secondary zinc mineral that has been reported (Richardson, 1925) in the Western Kentucky Fluorspar District. It may be white to reddish, with good cleavage, and forms in acicular, orthorhombic crystals.

Anglesite (PbSO_4) is white and soft, has a hardness of 3, and heavy specific gravity of 6.4. It is also rare but can be found in oxidized lead deposits.

Oxides

Oxides are elements combined with oxygen, such as hematite, magnetite, rutile, water, and ice.

GOETHITE, HFeO_2

Crystal system: orthorhombic. Color: yellowish brown to dark brown. Hardness: 5.0–5.5. Streak: brownish yellow. Luster: dull to adamantine. Specific gravity: 4.37.

Goethite usually occurs in massive, stalactitic, fibrous, or botryoidal (grape-like) forms, and exhibits radial growth. Goethite weathers from pre-existing iron minerals. In western Kentucky, goethite is associated with limonite in porous earthy masses called bog iron ore. Goethite is an ore of iron in some areas; it is noncommercial in Kentucky.

HEMATITE, Fe_2O_3

Crystal system: hexagonal. Cleavage: indistinct. Color: brownish red, steel gray, or black. Hardness: 5.5–6.0. Streak: cherry red. Luster: dull to metallic, opaque. Specific gravity: 5.2.

Hematite (Plate 24) occurs in platy, compact, granular, or earthy masses. When individual grains are red and about the size and roundness of fish eggs, the mineral is called oolitic hematite; when it occurs in plates or scales as mica does and is steel gray it is called micaceous or specular hematite; and when it occurs as a fine powder that can be mixed with oil and used as a paint pigment, it is called red ocher. Hematite is often the red cementing material in sandstones, and is found to a lesser extent in red clays and shales. It is readily distinguished from all other minerals by its cherry red streak.

Hematite is the most important ore of iron, and also the most important metallic mineral in the world. The value of the pig iron and steel manufactured from it every year exceeds the value of any other metal.

During the late nineteenth century, oolitic hematite was mined in Bath County in northeastern Kentucky. In this area, hematite is found in the Brassfield Dolomite of Silurian age and the Boyle Limestone of Devonian age. The average thickness of the iron-bearing beds is 3 feet, and the higher grade ore ranges in iron content from 46 to 57 percent. Iron ore of this type occurs in Silurian-age rocks from New York to Alabama. Because of its limited thickness in Kentucky, and because of vast supplies of hematite ore in the Great Lakes region, it became unprofitable to mine in Kentucky.

Hematite crystals have been observed lining the cavities of geodes from Estill County. These crystals are dark brown, bladed, and approximately $\frac{1}{2}$ inch long (Plate 24).

ILMENITE, FeTiO_2

Crystal system: hexagonal. Color: black to brownish black. Hardness: 5.0–6.0. Streak: black to brownish red. Specific gravity: 4.3–5.5. Magnetism: slightly magnetic; more magnetic when heated. Uses: pigment for white paints.

Ilmenite is considered a heavy mineral and commonly occurs with rutile in the McNairy Sands in western Kentucky and in peridotite dikes in eastern and western Kentucky. It commonly occurs in ancient, near-shore sandstone environments. Although the mineral is very noticeable in beach sands as black specks, it is used as a pigment for white paints; the refining process removes traces of iron and other deleterious materials to create a white refined product.

LIMONITE, $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$

Crystal system: amorphous. Color: rusty brown, yellow, to black. Hardness: 1.0–5.5. Streak: yellowish brown. Luster: dull, submetallic. Specific gravity: 3.6–4.0. Uses: iron ore, pigment ingredient.

Limonite is commonly earthy and porous. It results from weathering of previously existing iron minerals, and is associated with goethite, hematite, and siderite. Small amounts of limonite give a yellow color to clays, limestone, sandstone, and soil.

In Kentucky, limonite, sometimes called brown iron ore, was mined in Trigg, Lyon, Livingston, and Crittenden Counties in the

mid-1800's, but it has little commercial value today. It occurs at the erosional contact between the Mississippian limestones and the Cretaceous gravels. It is very low-grade ore and contains numerous impurities. Yellow ocher, a form of limonite, is an ingredient in certain pigments.

PYROLUSITE, MnO_2

Crystal system: tetragonal. Color: black. Hardness: 2–6.

Pyrolusite (Plate 25) is commonly found as a secondary mineral and forms in a black, dendritic pattern in sedimentary rocks. It is commonly called *wad*. The black, soft, sooty mineral is associated with hematite, siderite, and limonite, and is found in the Givens Vein in the Western Kentucky Fluorspar District and in sandstones in eastern Kentucky.

RUTILE, TiO_2

Crystal system: tetragonal. Color: red to black. Hardness: 6. Streak: yellow or brown. Specific gravity: 4.3. Uses: source of titanium.

Rutile generally occurs with ilmenite and has been noted in the peridotite dikes in eastern and western Kentucky. Rutile also occurs in the McNairy Sands in the Jackson Purchase Region and has been mined in Tennessee, Florida, and parts of the East Coast.

URANIUM MINERALS (URANINITE, UO_2)

Crystal system: isometric. Color: black to dark gray. Hardness: 5–6. Specific gravity: 9–10.

Some radioactive minerals have been reported in the black shale that crops out around the Blue Grass Region. Other occurrences of uranium minerals have been reported in eastern Kentucky, including one at Bell Falls in Menifee County. These radioactive minerals are detected by Geiger counter or scintillometer, since usually the minerals themselves are too small to see with the naked eye.

Uraninite generally occurs as massive, botryoidal, or banded coatings. The microcrystalline variety of uraninite is called pitchblende. Because of the rapid oxidation, radioactive decay process, and numerous hydrous phases, uraninite can have many chemical variations.

Silicates

Silicates are arrangements of the elements silicon and oxygen with a wide variety of other elements. The most common silicates are quartz and feldspars. Quartz is abundant in Kentucky, and some of the feldspars occur as very fine grains in sandstones in Kentucky.

CALAMINE-HEMIMORPHITE, $ZnSiO_3$

Crystal system: orthorhombic. Cleavage: tabular. Color: clear to white, with yellow or red iron staining common. Hardness: 4.5–5. Luster: vitreous. Specific gravity: 3.4.

Calamine is an older name for the rare mineral hemimorphite. It forms in oxidized zinc deposits. Hemimorphite is commonly associated with smithsonite and cerussite, and occurs in clusters of radiating, acicular crystals (Plate 26). A massive variety shows worm-like shapes. Hemimorphite occurs in zinc-bearing vein deposits in the Western Kentucky Fluorspar District in Crittenden and Livingston Counties.

FELDSPAR GROUP (DIVERSE SILICATE)

Crystal system: monoclinic and triclinic. Cleavage: good at 90° angle. Hardness: 6.

The feldspars are an important rock-forming group of minerals, but their occurrence in Kentucky is limited to very small detrital fragments of sandstones and cement that are only visible with microscopes.

GARNET (DIVERSE SILICATE)

Crystal system: isometric. Color: various colors. Hardness: 6.5–7.5. Luster: vitreous. Specific gravity: 3.5–4.3. Uses: semi-precious stone, industrial abrasive saws, polishing tools.

The garnet group of silicates has a diverse chemical composition consisting of calcium, aluminum, magnesium, and chromium silicates. Some minerals included in the garnet class are pyrope (red to black), almandine (red), grossularite (green yellow), and uvarovite (green). It is translucent to transparent.

Pyrope and almandine occur abundantly in ultramafic dikes in Elliott County, and many can be obtained by panning in the alluvial sediments near the dikes. Garnets can also be found in some glacial erratics in northern Kentucky and in metamorphic rocks in the Appalachian Mountains in Virginia and North Carolina.

MICA GROUP, COMPLEX $\text{KAISi}_3\text{O}_{10}$ (BIOTITE, MUSCOVITE, PHLOGOPITE)

Crystal system: monoclinic. Cleavage: cleaves into sheets; flexible when bent. Color: dark gray to black (biotite), white to light brown (muscovite). Hardness: 2.5 (biotite)–3.0 (muscovite). Specific gravity: 2.7 (muscovite)–3.0 (biotite).

Muscovite and biotite generally occur in igneous and metamorphic rocks, but in Kentucky they are commonly found as detrital sediment in sandstones, shales, and clays. Mica minerals are commonly mistaken for gold because of their golden color and cleavage, which causes light to be reflected easily. The magnesium-rich phlogopite has similar physical characteristics as biotite and muscovite, and is found in kimberlite dikes in Elliott County.

OLIVINE, MgFeSiO_2

Crystal system: orthorhombic. Fracture: conchoidal. Color: green. Hardness: 6.5–7. Luster: glassy. Specific gravity: 3.3–4.3.

Olivine is a common igneous rock-forming mineral and occurs in both basaltic rocks and the kimberlite dike in Elliott County. Transparent gem-quality varieties are known as peridots. Olivine alters readily to serpentine.

PEROVSKITE, CaTiO_2

Fracture: uneven. Color: black to dark brown. Hardness: 5.5. Luster: metallic. Specific gravity: 4.

Perovskite can occur as cubic crystals and massive or reniform (kidney-shaped) masses. It is found in ultramafic rocks and in the peridotite dikes in eastern and western Kentucky.

QUARTZ, SiO_2

Crystal system: hexagonal. Fracture: conchoidal. Color: colorless or white, but may be tinted various colors (e.g., purple, amethyst). Hardness: 7.0. Streak: colorless. Luster: glassy. Specific gravity: 2.65. Uses: jewelry; prehistoric arrowheads, knives (flint); gravel (chert).

Quartz (Plate 27) is the hardest, most resistant mineral found in abundance in Kentucky. It is the main constituent in sandstones and geodes, and also occurs as vein quartz. Crystals usually consist of six-sided hexagonal prisms capped by pyramids on one or

both ends. Quartz crystals are found in geodes that occur in several different rock types, particularly limestone. In south-central Kentucky, valleys and stream beds downslope from the Warsaw-Salem Formation are filled with geodes, some containing amethyst.

Several cryptocrystalline (microscopic crystals) varieties of quartz occur in Kentucky. They are commonly recognized on the basis of their fibrous texture and granularity. The fibrous varieties include chalcedony, agate, onyx, and jasper, and granular varieties include chert and flint.

Agate (Plates 28–29, front cover) has delicate and varying shades of color arranged in layers. In the typical occurrence the bands are irregular, curved, or in concentric patterns. Agate is used as an ornamental material or in semi-precious jewelry. The color banding is usually related to chemical impurities; for example, iron gives a red or orange color and manganese or calcium give black or blue colors.

For the past decade, beautiful specimens of red, black, yellow, and gray banded agate (Plates 28–29) have been discovered in Estill, Jackson, Powell, Madison, and Rockcastle Counties. These Kentucky agates are derived from the Renfro-Borden Formation of Early Mississippian age and can be collected along some river drainages where the Borden is exposed to weathering. Many of these agates are displayed at local rock shows.

Flint is dark brown to black and breaks with a conchoidal fracture into fragments with sharp cutting edges. It is found in limestones or in soils derived from limestones.

Chert and flint are cryptocrystalline varieties of quartz. Chert is usually gray to white; flint is dark brown to black. Chert and flint are very hard and break with a splintery fracture. Chert is usually associated with dolostone and limestone and occurs as lenses, irregular layers, and nodules, but some rock units are composed almost entirely of chert. Chert abounds in the upper St. Louis Limestone in south-central Kentucky between Glasgow and Somerset. The Boyle Dolomite of Silurian age also contains abundant gray, blue, and black chert. Any roadcuts or active or abandoned quarries in this region in the St. Louis Limestone or Boyle Dolomite would contain numerous chert nodules. Chert and flint were the most common silicate minerals used by early Native Americans for

making arrowheads (Plate 30). Because chert and flint have a conchoidal fracture, they are easily shaped into arrowheads.

Jasper is an impure variety of quartz that has been colored some shade of red by iron oxide inclusions. The name "Jasper" may also be used for some silicious agate material that has replaced organic material in petrified wood. It is used as an ornamental stone and in jewelry.

Opal is an amorphous, massive silicate that exhibits a conchoidal fracture and has a characteristic play of colors caused by its water content. Opal is not common in Kentucky, but may occur in some silicious fossils, particularly in the black shale, and in microscopic amounts in cherts and chalcedony. Opal is not a stable mineral, and in geologic time alters to other silicate minerals.

SERPENTINE, $\text{MgFeSiO}_2(\text{OH})_4$

Crystal system: monoclinic. Color: green. Hardness: 3–5. Luster: greasy, wax-like. Specific gravity: 2.5. Uses: asbestos.

Serpentine occurs in both a platy and a fibrous variety. The most common variety is chrysotile, which is the chief source of asbestos. In Kentucky, serpentine occurs in peridotite dikes. A light-green serpentine fracture fill is shown in a peridotite in Plate 2.

CLAY MINERALS

Clay minerals are a subgroup of silicates that comprise the various claystones, such as ball clay, flint clay, and fuller's earth.

Illite, $\text{KAl}_4\text{SiO}_2(\text{OH})_4$

Illite is the constituent of many shales and is an intermediate clay between montmorillonite and muscovite. It has more potassium than montmorillonite, but is not expandable or absorptive. It is structurally similar to chlorite ($\text{MgFeAlSi}_3\text{O}_{10}(\text{OH})_8$), but chemically different.

Glauconite, $\text{K}(\text{Fe,Mg,Al})_2\text{AlSiO}_{10}(\text{OH})_2$

Crystal system: amorphous. Color: green. Streak: colorless or greenish, but lighter than the grains themselves. Luster: earthy to dull. Specific gravity: 2.3. Tenacity: brittle. Uses: fertilizer, soil conditioner.

Glauconite, a variety of illite, occurs disseminated in shales, sandstones, and limestones, and is commonly associated with phosphate pebbles and iron sulfides. The Floyds Knob Bed of the Borden Formation (Mississippian) is a glauconitic siltstone that crops out in a semicircle around the Outer Blue Grass.

Kaolinite, $\text{Al}_2\text{Si}_2\text{O}_4(\text{OH})_4$

Crystal system: monoclinic. Hardness: 2–2.5. Luster: earthy. Specific gravity: 2.6.

Kaolinite is the chief component of ball clay and flint clay. It has a sheet structure, and is therefore not as absorbant as montmorillonite.

Halloysite is a hydrated variety of kaolinite (crystal system: amorphous; fracture: conchoidal; color: white, yellowish white, gray, to green; hardness: 1.5; streak: white; luster: earthy to pearly; specific gravity: 2.1; tenacity: brittle) with little or no plasticity. Halloysite has a distinctive tube-like structural appearance.

Montmorillonite, $(\text{AlMgFe})_2\text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot \text{H}_2\text{O}$

Crystal system: monoclinic. Hardness: 1–1.5. Specific gravity: 2.5.

Montmorillonite is very fine grained, and visible only with powerful microscopes. It is the main mineral in bentonite and fuller's earth (see "Sedimentary Rocks"). Montmorillonite is called an expanding clay because the arrangement of its crystal lattice allows frequent and extensive substitution of additional minerals; actual composition may vary depending on iron, magnesium, zinc, aluminum, and silicate ratios.

Vermiculite is a related montmorillonite clay mineral that has the absorbant but not the expandable characteristics of typical montmorillonite.

Carbonates

Carbonates are minerals combined with carbon and oxygen, including calcite, dolomite, smithsonite, malachite, and cerussite.

CALCITE, CaCO_3 (ARAGONITE, CaCO_3 ; TRAVERTINE, CaCO_3)

Crystal system: hexagonal. Cleavage: three-directional in rhombohedron-shaped fragments. Color: usually white, but may be tinted various colors by impurities. Hardness: 3.0. Luster: glassy. Specific

gravity: 2.71. Acid test: effervesces strongly when treated with dilute hydrochloric acid. Uses: in the form of limestone, as aggregate for road surfacing and concrete, agricultural lime, flux, building stone, sulfur sorbents, and in cement; in the form of Iceland spar in optical instruments to obtain polarized light.

Calcite (Plates 31–33) is one of the most abundant and widespread minerals in Kentucky. It may occur in a multitude of crystal forms, of which scalenohedrons and rhombohedrons are the most common; it may also be granular, massive, earthy, or fibrous. Calcite is the chief mineral in limestone, where it is generally in the form of small, broken fragments of fossil shells. Large, well-developed crystals are generally found in veins, commonly associated with faults. Numerous quarries throughout the State contain various nodules and geodes with calcite crystals. The Lexington Quarry Company in Nicholasville and the Caldwell Stone Company in Danville have discovered numerous scalenohedral calcite crystals along veins in the quarries. Vein calcite (back cover) is usually associated with fluorite, barite, galena, and sphalerite (Plate 17). The calcites in Plate 31 were collected from cave openings in mineral veins in central Kentucky. Plate 32 shows the various colors and forms of calcite in Kentucky. Calcite often appears as twinned crystals (Plate 33).

Iceland spar, a clear, pure, colorless variety of calcite (lower left in Plate 32, Fig. 13), has been found at the Twin Chimneys Mine in Mercer County; other localities near Mundys Landing and the Chinn Mine might contain optical calcite as well.

Aragonite (Plate 34) is a polymorph of calcite and is distinguished from calcite by a higher specific gravity (2.95) and hardness (3.5 to 4), and a lack of rhombohedral cleavage. Aragonite usually occurs as radiating crystals and is commonly found in reniform, columnar, and stalactitic forms. The aragonite in Plate 34 was found near Pulaski County.

Travertine, often called *cave onyx*, has properties similar to calcite. It is usually a shade of yellow or brown, and exhibits banding because of intermittent deposition and iron oxide impurities. Travertine is redeposited calcium carbonate. The best known deposits in Kentucky are in caves near the Mammoth Cave region (Fig. 14). It also occurs as a surface deposit associated with ground-water seeps and springs, and may be collected around crevices in most limestone quarries. An attractive deposit of travertine may be seen

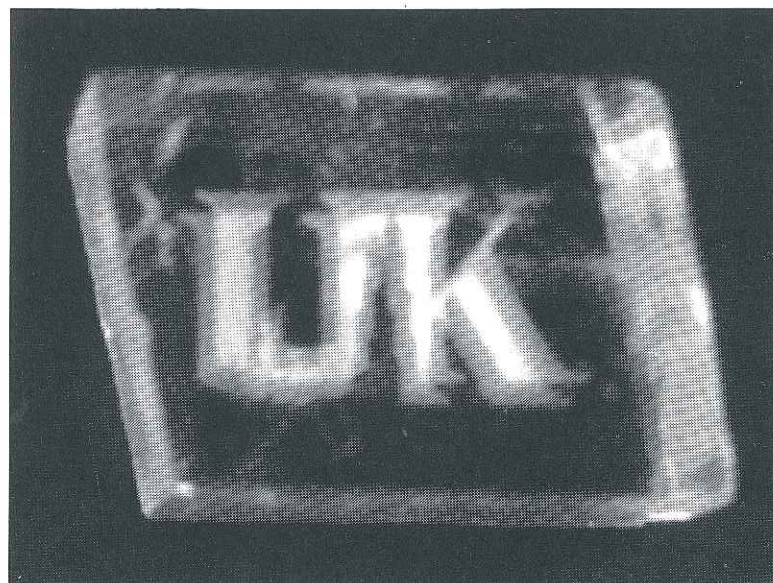


Figure 13. Iceland spar, optical variety of calcite, Twin Chimneys Mine, Mercer County. Optical calcite refracts light so that a double image is seen through the calcite crystal.

at Elk Lick Falls in Fayette County, where it forms the impressive Petrified Falls. Travertine may be found in stalactitic, stalagmitic, columnar, nodular, encrusting, and many other forms. Travertine is the chief scenic attraction of caves and it should not be destroyed, because it grows very slowly.

DOLOMITE, $\text{CaMg}(\text{CO}_3)_2$ (ANKERITE, $\text{FeMg}(\text{CO}_3)_2$; BARYTOCALCITE, $\text{BaCa}(\text{CO}_3)_2$)

Crystal system: hexagonal. Cleavage: rhombohedral with curved or saddle-shaped faces. Color: white or pink, rarely gray, green, yellow, or black. Hardness: 3.5–4.0. Streak: colorless. Luster: glassy or pearly. Specific gravity: 2.85. Acid test: effervesces slowly in cold dilute hydrochloric acid.

Dolomite (Plate 35) is associated with calcite, galena, sphalerite, barite, and fluorite. It is found in nodules or geodes in some limestone quarries and in some of the vein deposits in the State.

Iron substitutes for magnesium to form ankerite (cleavage: rhombohedral; color: yellowish brown; hardness: 3.5; specific gravity: 2.9), and barium substitutes for magnesium to form barytocal-



Figure 14. Travertine occurring as flowstone in Mammoth Cave.

cite (crystal system: monoclinic; color: white to greenish; hardness: 4; specific gravity: 3.67). Barytocalcite is a polymorph of alstonite ($\text{CaBa}(\text{CO}_3)_2$) and may fluoresce under ultraviolet light. Its high specific gravity makes it feel heavy, and it may resemble "heavy calcite." Barytocalcite has been observed in some mineral veins in Cumberland County.

CERUSSITE, PbCO_3

Crystal system: orthorhombic. Cleavage: orthorhombic crystals are commonly tabular, prismatic, and pyramids; good cleavage in four directions. Color: white when pure, but often gray to very pale blue. Hardness: 3.25. Streak: white. Luster: resinous to adamantine. Specific gravity: 6.5. Tenacity: brittle. Acid test: effervesces in nitric acid. Uses: lead ore.

Cerussite is distinguished from other carbonates by its high specific gravity; it is distinguished from anglesite (PbSO_4) by effervescing in nitric acid and by its crystal form. It also occurs in fibrous, granular, and earthy forms. It was formed by the reaction of carbonated water on galena. It occurs in noncommercial quantities near the Big Four Mines and Dike Eaton area in the Western Kentucky Fluorspar District. Cerussite has also been observed in vein deposits in north-central Kentucky. It is associated with galena, sphalerite, anglesite, limonite, and smithsonite.

MALACHITE, $\text{Cu}_2\text{CO}_3(\text{OH})_2$ (AZURITE, $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$)

Crystal system: monoclinic. Cleavage: perfect, but commonly massive. Color: green (malachite), blue (azurite). Hardness: 3.5–4.

Malachite is rare in Kentucky, but does occur as microscopic grains or green coatings as a weathering/oxidation product of chalcopyrite in some vein deposits in central and western Kentucky. Azurite is extremely rare in Kentucky, although it could have the same mode of occurrence as malachite.

Aurichalcite, $(\text{Zn}, \text{Cu})_5(\text{CO}_3)_2(\text{OH})_6$, a zinc-copper carbonate associated with smithsonite, also occurs in oxidized zinc/copper deposits with malachite and azurite. It is distinct because of its acicular blue crystals. The photomicrograph of aurichalcite (Plate 36) from a deep well in western Kentucky represents the only known occurrence of the mineral in Kentucky. It was formed from the oxidation of drill steel in cuttings from the well.

IRON CARBONATES**Siderite, FeCO_3**

Crystal system: hexagonal. Cleavage: frequently rhombohedral crystals with curved faces, similar to dolomite. Color: light to dark brown. Hardness: 3.5–4. Luster: vitreous. Specific gravity: 3.96. Acid test: soluble in hot hydrochloric acid.

Siderite is a common mineral associated with geodes, nodules, and ironstone banding. Siderite is very common in the coal fields, where it occurs as a reddish-brown mineral in shale layers, nodules, concretions, and fossil burrows. Commonly, a siderite nodule will have a nucleus of another mineral such as pyrite, sphalerite, or chert. Siderite also occurs in geodes with dolomite and calcite. Siderite becomes magnetic on heating, and alters readily to limonite and goethite.

Smithsonite, ZnCO_3 (Hydrozincite, $\text{Zn}_5(\text{OH})_6(\text{CO}_3)_2$)

Crystal system: hexagonal. Cleavage: perfect. Fracture: uneven. Color: white to greenish brown. Hardness: 5.0. Streak: white. Luster: glassy. Specific gravity: 4.37. Acid test: effervesces rapidly in dilute hydrochloric acid.

Smithsonite (Plates 37–38) occurs usually in reniform, botryoidal, and stalactitic forms and as crystalline encrustations. It is formed by the reaction of carbonated water on sphalerite (ZnS), and occurs in calcareous rocks associated with galena, sphalerite, cerussite, limonite, fluorite, and calcite. It is distinguished from most other carbonates by its greater hardness and weight (it is distinctly harder than cerussite, but lighter in weight).

Another zinc carbonate, hydrozincite ($\text{Zn}_5(\text{OH})_6(\text{CO}_3)_2$) (crystal system: monoclinic; color: white to gray; hardness: 2.5; specific gravity: 3.5), is a massive mineral that forms as earthy, compact crusts in oxidized zinc deposits. It commonly will luminesce blue under ultraviolet light.

One of the better occurrences of smithsonite and hydrozincite is at the Old Jim Mine in Crittenden County, where the deposit is associated with an igneous intrusive dike. Smithsonite can be found at numerous mine sites in western Kentucky and has been observed at the Shrylock Ferry Vein in Woodford County in central Kentucky.

Strontianite, SrCO_3

Crystal system: orthorhombic. Cleavage: good. Color: white to gray to green. Hardness: 3.5. Luster: vitreous. Specific gravity: 3.7. Acid test: effervesces in dilute hydrochloric acid. Uses: fireworks, flares, rockets.

Strontianite (Plate 39) generally occurs as tufts and radiating acicular crystals. It also occurs as columnar or fibrous crystals. It gives off a crimson flame on ignition, and occurs in hydrothermal veins with barite and celestite. It is found in the north-central part of the Central Kentucky Mineral District in Franklin and Scott Counties. Strontianite balls have been observed in the Caldwell Stone Company Quarry.

Witherite, BaCO_3

Crystal system: orthorhombic. Cleavage: indistinct. Fracture: uneven. Color: white to pale yellow. Hardness: 3.5. Streak: white. Luster: glassy. Specific gravity: 4.3. Tenacity: brittle. Acid test: effervesces rapidly in dilute hydrochloric acid.

Witherite is a relatively rare mineral, but is found in central and western Kentucky, where it occurs in veins associated with barite and galena. Elsewhere a minor source of barium, it is noncommercial in Kentucky.

Phosphates

Phosphates, arsenates, and vanadates are minerals that are combined with phosphorus, arsenic, vanadium, and oxygen, such as apatite, vanadinite, amblygonite, and wavellite. Apatite is common in various places in Kentucky, and wavellite has been observed.

APATITE, $\text{Ca}_5\text{F}(\text{PO}_4)_3$

Crystal system: hexagonal. Fracture: conchoidal. Color: red, brown, white. Hardness: 5.0. Luster: opaque or semitransparent. Specific gravity: 3.1.

Apatite, also called collophane, occurs in peridotites in eastern and western Kentucky. A microcrystalline variety of collophane found in central Kentucky is dark reddish brown, porous, and occurs in phosphatic beds, lenses, and nodules in the Tanglewood Member of the Lexington Limestone in northern Woodford County. Some fossils in the Tanglewood Member are coated with phos-

phate. Beds are generally very thin, but occasionally several feet thick. The Woodford County phosphate beds were mined during the early 1900's (see "Other Mineral Deposits—Phosphate").

VIVIANITE, $\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$

Crystal system: monoclinic. Color: blue. Hardness: 2. Specific gravity: 2.68.

Vivianite commonly occurs in radiating small aggregates or earthy masses. It is rare, although Richardson (1925) reported it in Floyd County. It is possible that this mineral could occur in geodes, nodules, or fossil cavities in the phosphate beds of central Kentucky.

PYROMORPHITE, $\text{Pb}_5(\text{PO}_4, \text{AsO}_4)_3\text{Cl}$

Crystal system: hexagonal. Cleavage: occurs in rounded or barrel-shaped crystals. Color: light green to brown. Hardness: 4. Specific gravity: 7.0.

Pyromorphite (Plate 40) is a rare lead phosphate that can occur in oxidized lead deposits and has been reported (Richardson, 1925; Hardin and Trace, 1959) at the Big Four Mines and Dike Eaton areas in the Western Kentucky Fluorspar District.

Tungstates and Molybdates

Although no tungstate or molybdate minerals occur in Kentucky, some molybdenum salts have been noted in Menifee County, and chemical analysis shows some trace of molybdenum in deep oil wells in western Kentucky.

Halides

Halides, nitrates, and borates are minerals that combine with the halogen elements, nitrogen, and boron. Examples include halite (salt), sylvite, fluorite, niter (saltpeter), borax, and kernite. Fluorite is very common in central and western Kentucky, whereas the borate minerals are not common in Kentucky.

FLUORITE, CaF_2

Crystal system: isometric with cubic crystals, more often massive. Cleavage: excellent octahedral cleavage; may be broken into triangular-faced fragments. Color: white, purple, green, yellow, brown.

Hardness: 4.0. Streak: colorless. Luster: glassy. Specific gravity: 3.18. Uses: flux, hydrofluoric acid, enamel and glass industries, refrigerating fluids, portland cement, insecticides, to retard tooth decay.

Fluorite (Plates 41–50) is often called spar or fluorspar. Massive fluorite may resemble calcite, but it is heavier and does not effervesce when treated with hydrochloric acid. It is distinguished from gypsum and quartz by its hardness.

The Kentucky–Illinois fluorspar area once was ranked first in the United States in the production of fluorite. In Kentucky, commercial deposits occur in Caldwell, Crittenden, and Livingston Counties. A small amount of noncommercial fluorite occurs in veins in the Central Kentucky Mineral District. Numerous mines and mine dumps along the Tabb and Commodore Faults in western Kentucky contain fluorite, and several mines near Mundys Landing in southern Woodford and northern Mercer County have produced nice fluorite specimens. Most of these mines are now closed. Many old uncovered shafts exist in the vicinity of old mines, so caution should be used when collecting near these areas because of open shafts.

Numerous publications on fluorite are listed in the References. Published guidebooks on the fluorspar district are especially useful in locating areas where fluorite may be collected.

One of the most outstanding collections of fluorite is the Clement fluorite collection, located in Marion, Kentucky. This collection consists of various specimens of fluorite collected by Mr. Ben Clement while he worked in the fluorspar district. Since most of the mines are now closed, a visit to this collection is the best way to view the beautiful colored fluorites.

HALITE, NaCl

Crystal system: isometric. Cleavage: commonly in cubes. Color: white. Hardness: 2.5. Streak: white. Luster: vitreous. Specific gravity: 2.25.

Halite, also known as common table salt, has a strong salty taste, which is the most diagnostic tool for identification. Although not common in Kentucky, it does occur in brine waters, salt springs, and salt licks. It can be formed as encrustations and small crystals at salt licks. Prehistoric animals walked miles to salt springs and licks to obtain this chemical. Pleistocene mammals have been preserved, trapped in mud, at a salt lick at Big Bone Lick in Boone

County, northern Kentucky. Salt was obtained by early pioneers by boiling down water from salt springs, and it was a major item of trade for Native Americans and pioneers. The locations of salt springs were considered of strategic importance.

Nitrates

Nitrates usually occur as massive but delicate crusts on walls, roofs, and floors in caves, although some fine acicular crystals may also be found. These minerals are biogenic deposits. Nitrates were used as explosives, and several caves in Kentucky were mined for their saltpeter compound during the Civil War.

SODA NITER, NaNO_3

Crystal system: crystals rare, but may be found in hexagonal form. Color: colorless to white, gray, or reddish brown. Hardness: 1–2.

Soda niter is very soluble in water. Because it is so soluble, when taken out of a cave environment it may decompose (deliquesce) upon exposure to humidity in the atmosphere.

NITER, KNO_3

Color: white. Hardness: 2.

Niter, commonly called saltpeter, is a massive, encrusting mineral found on the surfaces and floors of caves. Like soda niter, niter is very soluble in water. Tufts of acicular crystals, similar to aragonite, may be found, and niter will not deliquesce.

Borates

Borates such as kernite, borax, and ulexite are a source of borax, but these minerals do not occur in Kentucky. The most popular collecting locality for these minerals is in the Mojave Desert, California, where several of the minerals were first described.

Minor Minerals

Numerous minerals occur in Kentucky rocks in small quantities or to a limited extent, or are only observable under a microscope. Among these minerals are albite, orthoclase feldspar, zircon, and epidote, which make up some of the small constituents of sandstones in eastern Kentucky. Pyroxene (diopside), hornblende, en-

statite, and chromite are a few additional microscopic minerals that have been noted in the igneous dikes of Kentucky.

Gold and Silver

Gold and silver are commonly found in areas where igneous and metamorphic activity has occurred and are generally associated with silicic types of intrusives and Precambrian metamorphic rocks. When gold-bearing rocks weather, the liberated gold, because of its higher specific gravity, is mechanically separated from the accompanying lighter material and concentrated in the stream bottoms in the valleys. This type of mineral concentration is called *placer*.

In Kentucky, the geology is not favorable for the natural occurrence of gold or silver. Most of the surface and near-surface rocks are sedimentary, and there has not been any igneous, metamorphic, or tectonic event to allow the gold or precious metal to be concentrated in economic quantities.

The most common mineral mistaken for gold is pyrite, an iron sulfide, commonly referred to as "fool's gold." Another mineral that often confuses an amateur rockhound is muscovite, often called white mica. It is nonmetallic, but has a shiny luster, and when weathered it turns brownish gold. Small flakes of muscovite occur disseminated throughout some shales and sandstones in Kentucky. It is remotely possible that minute, noncommercial amounts of gold could be found in glacial outwash deposits along the Ohio River Valley. Some gold has been recovered from glacial debris in southern Ohio near the Kentucky border. If this gold exists in Kentucky, it was derived from sediments in the northeastern part of the United States.

Some silver was recovered from galena concentrates in the Western Kentucky Fluorspar District in the 1960's, but the amount was very small and uneconomic. The silver occurred in the crystal lattice structure of the galena.

The Kentucky Geological Survey has responded to numerous requests for evaluation or confirmation of reported gold and silver mines in various parts of Kentucky, particularly Lawrence, Elliott, Wolfe, Pike, Harlan, Bell, Powell, Menifee, Jackson, Estill, Marion, and Floyd Counties. Results of these investigations show that no major gold anomalies have been found and the potential is very small. Analysis for gold in samples collected in Kentucky indicate that values range from less than 0.02 to 0.05 parts per million

(ppm). Background values for gold in limestone are 0.005 to 0.009 ppm, and in sandstones, 0.03 ppm. Gold values in seawater are less than 0.00001 ppm. This means that any gold concentrated in Kentucky rock falls within an acceptable "background concentration," and you could expect to find this value anywhere in the earth's crust.

Jonathon Swift Silver Mines

The legend of the Jonathon Swift Silver Mines is well known in Kentucky. Thousands of Kentuckians have spent time and money in search of this legend. Numerous books, maps, and interpretations of the Swift legend have been studied by amateur prospectors, hobbyists, and folklorists in search of the lost mines. Versions of the Swift maps are probably in the hundreds, and based on the ambiguous descriptions, every county in eastern Kentucky could probably claim to be the location of the Swift Mines.

The Swift legend reports that a vein of pure silver ore existed in eastern Kentucky and was mined by an Englishman named Jonathon Swift during the late 1700's. Some ore was supposedly smelted into coins and taken to Virginia, while the remainder of the ore and coins was hidden in caves in the vicinity of the mines.

Reported maps and journals of the mine and travels of Swift were first chronicled by John Filson, a noted early Kentucky historian, surveyor, and biographer of Daniel Boone and Jonathon Swift. Filson was an eloquent, creative writer; but he apparently had some personal and financial interest in the promotion of these mines, which calls into question his motivation for extensive writings and glamorous promotions of the reported Jonathon Swift Silver Mines (Walton, 1956). It is very unlikely that there is any natural occurrence of gold, silver, or any precious metals in the Paleozoic rocks of eastern Kentucky. Based on geologic studies, the surface rocks in eastern Kentucky are not a favorable site for gold or silver exploration. The Kentucky Geological Survey has had hundreds of inquiries on the Swift Silver Mines from every county in eastern Kentucky, and our investigations of these claims found nothing to substantiate this legend.

Vein Mineral Deposits

In Kentucky, many economic minerals occur in tabular or lenticular bodies known as veins. The mineralization is commonly localized in faults, fractures, and joints. A fault is defined as a fracture or break in the continuity of a body of rock along which observable displacement or movement has occurred parallel to the plane of fracture. In many instances, faults of large displacement are accompanied by many small faults spread over a wide area. This type of complex faulting is referred to as a fault zone. Because of the resistance to movement of one large rock mass against another, much of the material along a fault is crushed or ground into a fine-grained, clay-like mass called *fault gouge*, or broken into larger angular fragments called *fault breccia*.

In the Central Kentucky Mineral District (Fig. 15) and the Western Kentucky Fluorspar District, minerals occur in veins (Plate 51) associated with the fault zones (Figs. 16–18). These minerals in central Kentucky veins are barite, sphalerite, fluorite, galena, celestite, dolomite, and calcite. Occasionally, some secondary minerals such as smithsonite, cerussite, and anglesite may be observed. Some witherite has also been observed in central Kentucky veins. Several veins in northeastern Kentucky in Owen and Henry Counties (Fig. 17) have been mined, and numerous specimens of barite, galena, and sphalerite can be collected from the mine dumps and along the trace of the vein itself. In the Lexington Quarry vein, two different forms of gypsum were discovered: large, clear, fish-tailed selenite crystals and curved, fibrous varieties. In addition to gypsum, excellent sphalerite and calcite crystals have also been discovered at this location, where a vein deposit has been mined out, as shown in Plate 52. The Caldwell Stone Company Quarry, located in Danville, also intersected one of these veins, and excellent specimens of fluorite, sphalerite, calcite, and barite were collected from this location. Some strontianite has also been observed in nodular occurrence at this quarry (Anderson and others, 1994). Vulcan Materials' Central Rock Quarry and the Boonesboro Quarry have also intersected these mineral veins, and nice mineral specimens are available in these veins. The Kentucky Stone Company Quarry at Flemingsburg has also produced nice specimens of calcite.

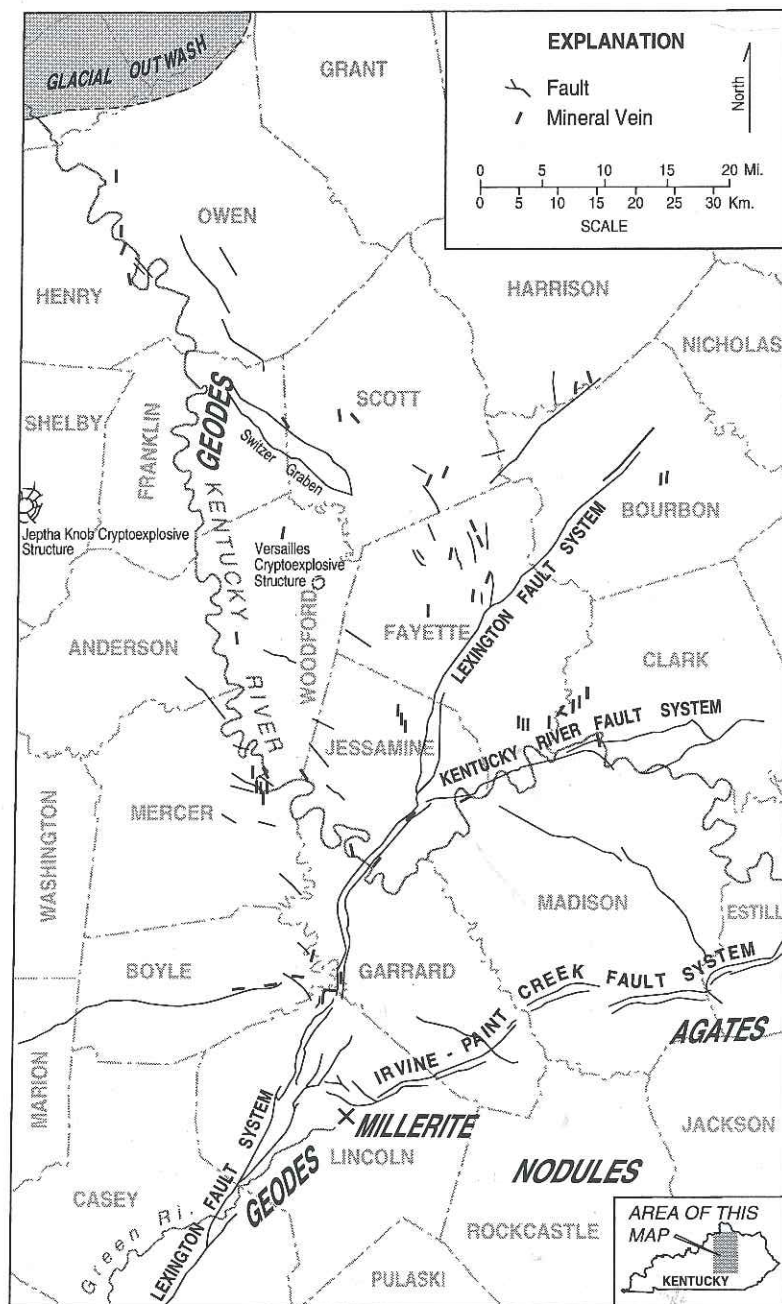


Figure 15. Locations of mineral veins in central Kentucky.

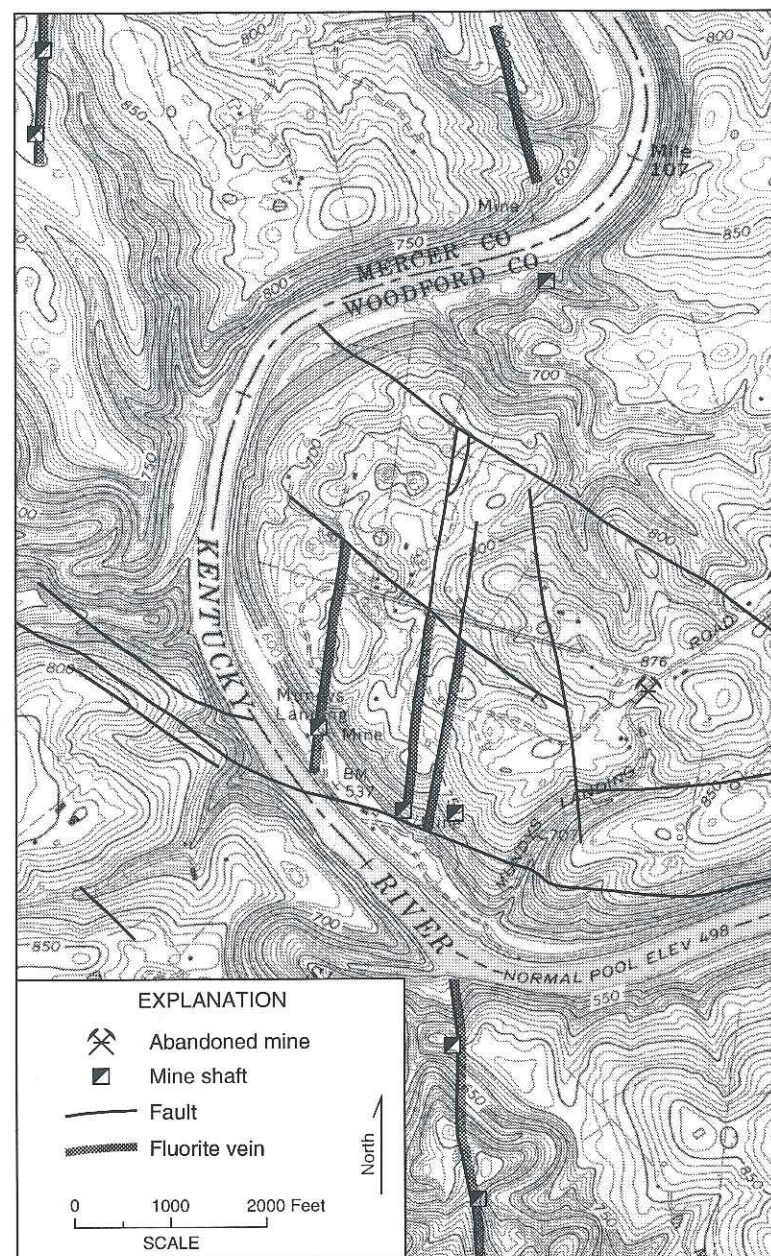


Figure 16. Portion of Harrodsburg topographic quadrangle map showing locations of old mines and mine dumps.

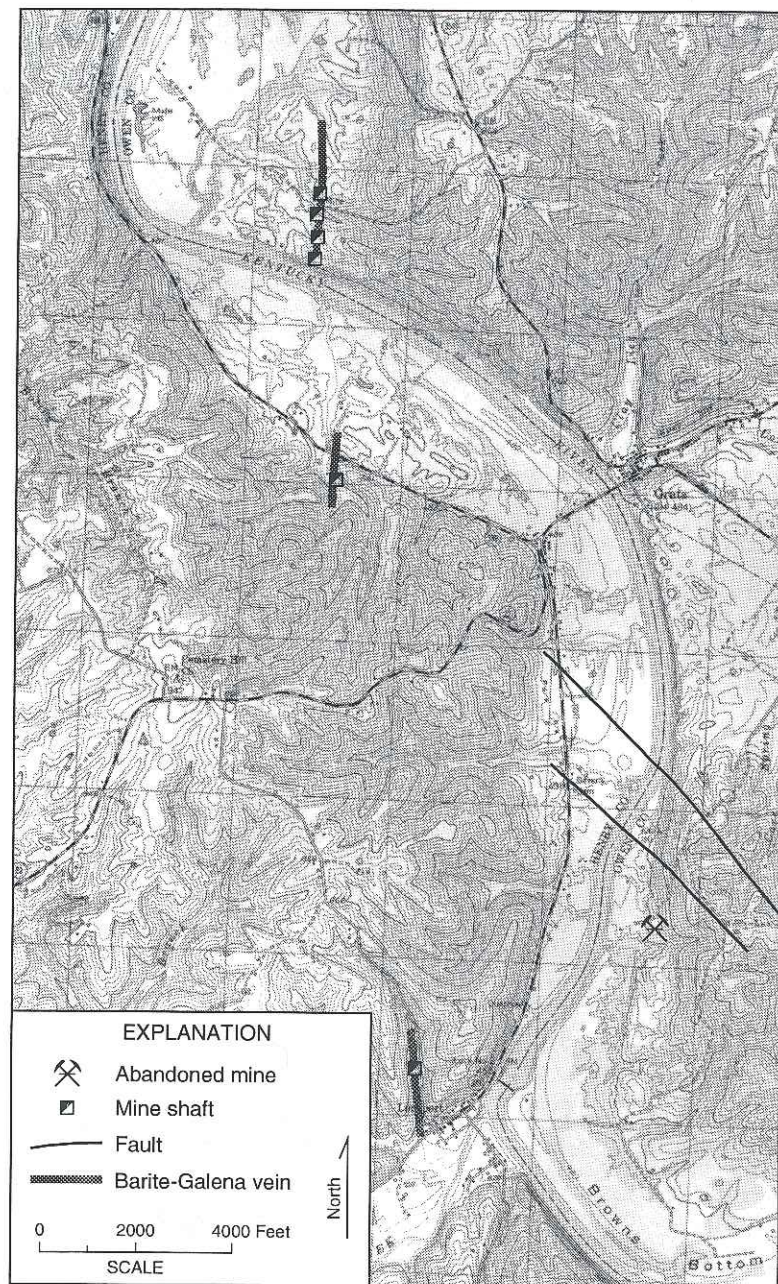


Figure 17. Portion of Gratz topographic quadrangle map showing location of Gratz, Union, and Lockport Mines.

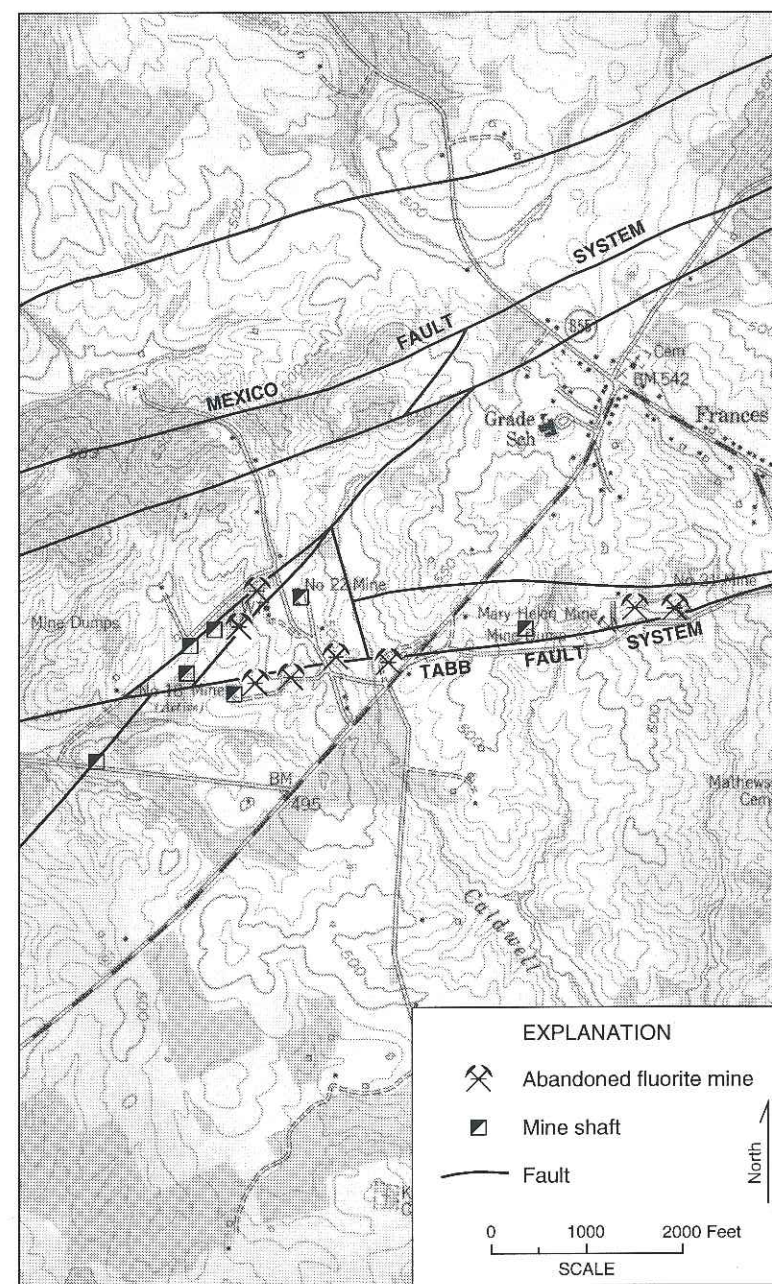


Figure 18. Map of Tabb and Mexico Faults, showing old mines and adits in the Western Kentucky Fluorspar District.

A recent report on the Central Kentucky Mineral District and Western Kentucky Fluorspar District (Anderson and others, 1982) discusses the vein deposits of central and western Kentucky and has a map that shows the locations of most of the mineral veins in central Kentucky. Another report (Trace and Amos, 1984) also discusses the Western Kentucky Fluorspar District, which has many old mines (Fig. 18). Mines located along the Tabb, Mexico, Crittenden Springs, and Dyer Hill Faults (Figs. 18–19) have numerous dumps that are a source of minerals. Numerous secondary minerals such as smithsonite, cerussite, hemimorphite, and greenockite are also obtained from some of the mines, particularly the Old Jim Mine (Fig. 19). Traces of malachite are visible in both central and western Kentucky.

Other Mineral Deposits

Iron

Iron deposits near Owingsville in Bath, Powell, and Estill Counties were mined as late as the 1900's. These iron ores occur in an oolitic limestone in the Brassfield Formation of Silurian age. Specimens of limonite and hematite may also be found in this area. Iron ore was also mined in northeastern Kentucky in Greenup, Boyd, and Carter Counties, where iron ore occurs in the Upper Mississippian and Lower Pennsylvanian rocks. Siderite and limonite nodules also occur at this locality. Some iron ore occurs in the Tertiary gravels of western Kentucky, and they were mined at one time. Numerous ferruginous nodules, concretions, and irregular bodies occur in the sandstones of eastern Kentucky. These are mainly massive ironstone bodies with few or no crystals visible.

Most mining of these iron deposits was halted in the early 1900's with the discovery of the massive iron deposits in the Lake Superior region.

Phosphate

Phosphate deposits consisting dominantly of microcrystalline apatite were mined from the Lexington Limestone in central Kentucky in Woodford, Fayette, Franklin, and Jessamine Counties in the early 1900's. These phosphates are thin bedded and weather easily in streams to form soft, dark-colored phosphate sands. Any cave or outcrop in the phosphatic portion of the Tanglewood Mem-

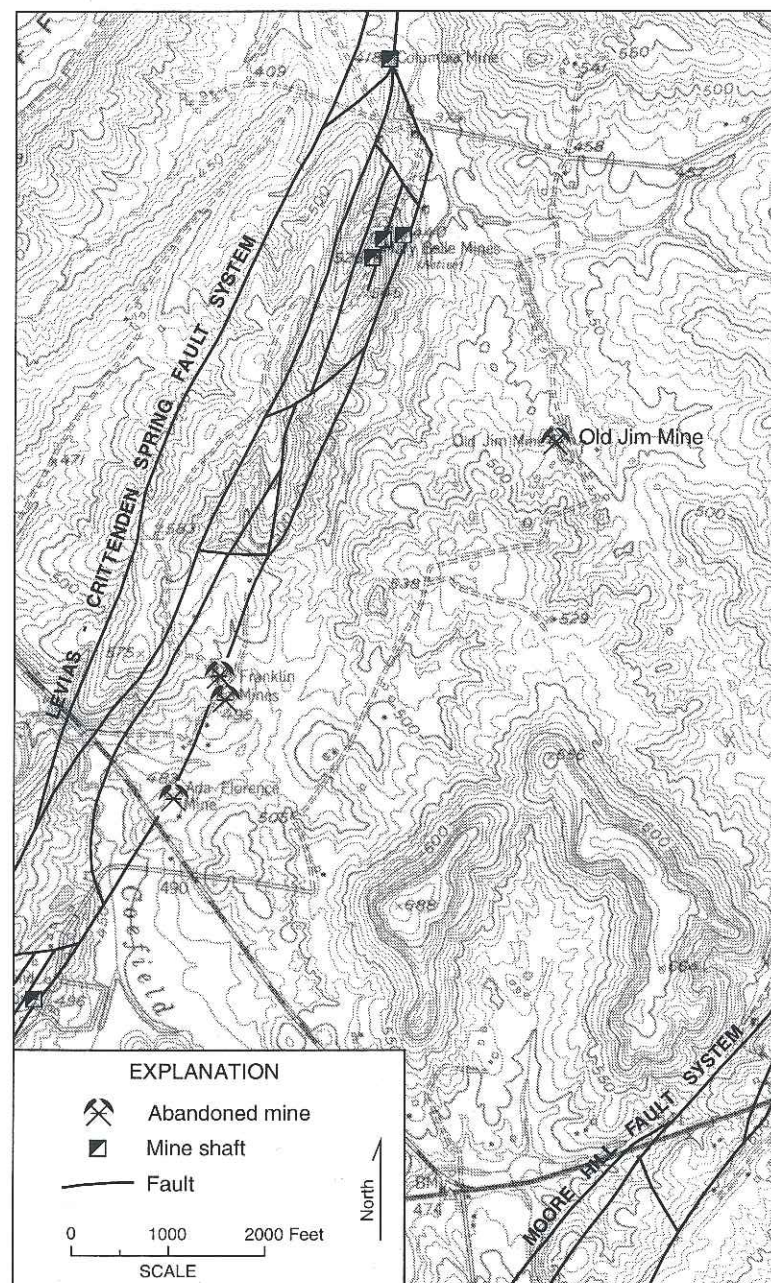


Figure 19. Map of Crittenden Springs Fault System, showing locations of old mines.

ber would yield specimens of collaphane. It is possible that some nodules or geodes might contain crystals of some phosphate minerals. Phosphate is commonly used as a fertilizer; thus, the exceptional fertility of some Blue Grass soils.

Geodes

Geodes are defined as spherical or oblong bodies filled or partially filled with layered mineral matter, some with crystals projecting inward (Fig. 20). Their sizes range from less than an inch to several feet in diameter. Most geodes have an outer shell of chalcedony, and an interior lined with quartz crystals projecting inward. Less commonly, calcite or dolomite crystals are found on the inside, either alone or associated with bitumen, barite, galena, fluorite, quartz, limonite, sphalerite, pyrite, selenite, or celestite.

Geodes differ from concretions in that they are hollow and the crystals grow inward from an outer shell; concretions are solid, grow from the center outward, and are generally noncrystalline, although some crystals have been observed.



Figure 20. Geode showing multilevel crystal growth, Estill County.

The Fort Payne and Warsaw-Salem Formations of Mississippian age, which crop out in a general semicircle around the Outer Blue Grass and southward into Tennessee, are noted for their abundant geodes. In many places, creeks that drain these formations are filled with geodes, and several mineral varieties can be collected, particularly during low-water stages. Other locations for geode collecting include the tributaries of the Green River in south-central Kentucky (Fig. 21) and along ancient terraces of the Kentucky River. The Green River has produced some very large geodes (2 feet in diameter) and countless smaller ones. The terraces along the Kentucky River are usually situated near the present course of the river and their locations can be found on geologic quadrangle maps.

Concretions and Nodules

Concretions are generally lens shaped, although some have irregular, complex forms. Concretions are formed by the deposition of distinct minerals, different from the surrounding rock, very firmly cemented around a nucleus. The most common cementing materi-



Figure 21. Geodes in stream bed, Lincoln County.

als are calcite, siderite, and silica. Parts of plants and animals may serve as nuclei, and well-preserved fossils may be found in concretions. In Kentucky, large concretions of siderite and calcite, which used to be called ironstones, are found in shales associated with coal beds.

Nodules are another type of irregularly shaped minerals that occur in sedimentary rocks. The most common minerals that occur in nodules are siderite, gypsum, calcite, quartz, and barite/celestite. Siderite nodules, concretions, and liesegang (iron-stained) banding are a very common type of mineralization found in eastern and western Kentucky sandstones.

Meteorites

A meteorite is a fragment of stony or metallic interplanetary rock thought to have formed in the asteroid belts billions of years ago when the earth and solar system were first formed. The most common are the stony meteorites, which are composed of silicate minerals (mainly olivene) and the iron meteorites (siderites) composed of iron, nickel, and accessory minerals. Miller (1919) reported 14 locations in Kentucky where meteorites had been recovered, including Bath, Bullitt, Livingston, Franklin, Allen, Carroll, Grant, and McCreary Counties. Another unconfirmed report of a meteorite has come from Lewis County.

Once a large meteorite strikes a planet, the energy and shock waves eject rock material and brecciate other strata, forming the circular structures associated with meteorite impact structures. The deformation caused by the meteor impact is a very rapid geological process. These impact structures are also called *astroblemes*. Kentucky has three and possibly four meteorite impact structures. Jephtha Knob in Shelby County, the Versailles structure in Woodford County, and the Middlesboro structure in Bell County are all circular, faulted structures that have some shatter breccia. The Muldraugh Dome or Knob structure in Hardin County may also be an impact structure. Because the earth has weathered and erosion is ongoing, traces of impact structures are uncommon. Approximately 200 impact structures are known on the earth.

Some minerals or unusual rocks may be found near these impact structures, namely part of the meteorite itself, brecciated rocks struck by the meteorite, and possibly some iron, nickel, or sphalerite minerals formed during or after the impact.

COLLECTING SITES

Any new and some old rock cuts, construction sites, or quarry operations have the potential to uncover pockets of nice specimens, such as the pink dolomites found at the Hickman Creek Sewage Treatment Plant construction several years ago (Sam Van, personal communication, 1988). Purple fluorites were discovered in Fayette County when Man O' War Boulevard was constructed near Higbee Mill Road, and more recently barite and sphalerite crystals were discovered on Interstate Highway 64 near Mount Sterling. Fluorite, gypsum, and dolomite were discovered at the Versailles exit on the Bluegrass Parkway (Dan Wells, personal communication, 1992).

Fault zones are good places for minerals, mainly calcite, to occur, but occasionally dolomite, barite, fluorite, sphalerite, and galeana also occur. Strip mines and quarries have uncovered several nice specimens of pyrite/marcasite crystals, numerous secondary sulfates, and occasionally some limestone and sphalerite nodules. Rivers continually renew the geode supplies along the Green River and agate material along tributaries in Estill County.

ACKNOWLEDGMENTS

All rocks and minerals photographed in this report belong to the author or staff of the Kentucky Geological Survey unless otherwise noted. Appreciation is extended to the following individuals who contributed their time, skills, and specimens: Sam Van, Roland McIntosh, Dan Wells, Mike Plagett, Kirtley Settles, and Garland Dever, Jr. Appreciation is also extended to Dan Matulionis, former President of the Bluegrass Rock and Mineral Club, for use of photographs of the red/black Kentucky agate and strontionite, and to Alan Goldstein, for use of his photograph of hemimorphite. Thanks go to Robert Holladay for assistance in photography of specimens and to Stephen Greb for use of rock specimens and for his sketches. Thanks also to Pete Helton for his earlier work on Kentucky's rocks and minerals.

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KENTUCKY MUSEUMS THAT DISPLAY ROCKS AND MINERALS

Berea College, Department of Geology, Berea

Clement Collection, Marion, Kentucky

Eastern Kentucky University, Richmond

Georgetown College, Georgetown

Museum of Natural History, Louisville

Morehead State University, Morehead

Murray State University, Murray

Transylvania University, Lexington

University of Kentucky, Department of Geosciences, Lexington

University of Kentucky, Kentucky Geological Survey, Lexington

Western Kentucky University, Bowling Green



Plate 1. Quartz sandstone with ferruginous (iron) bands, from eastern Kentucky. Actual specimen is 4 inches wide.

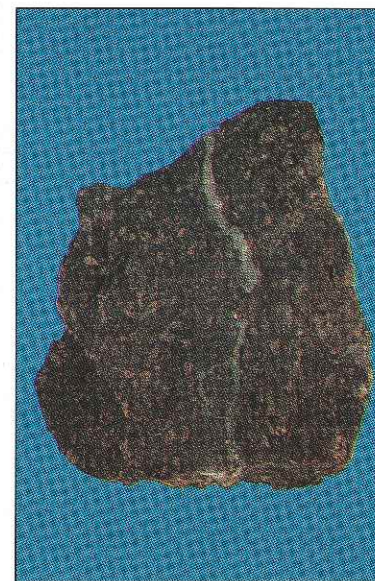


Plate 2. Specimen from kimberlite dike with a serpentine fracture fill, Elliott County. Actual specimen is 4 inches wide at base.

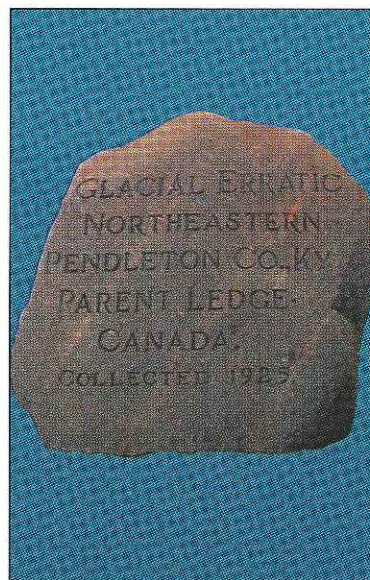


Plate 3. Glacial erratic, from Pendleton County. Actual specimen is 18 inches wide.

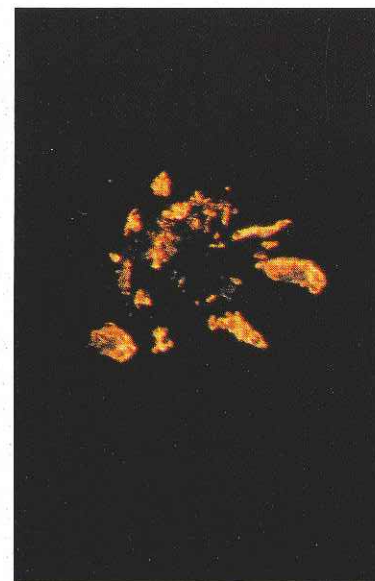


Plate 4. Gold nuggets (not from Kentucky).



Plate 5. Galena, from Western Kentucky Fluorspar District. Actual specimen is 2 inches wide.



Plate 6. Massive pyrite, commonly called fool's gold, from Perry County. Specimen is 6 inches long.



Plate 7. Various forms of pyrite.

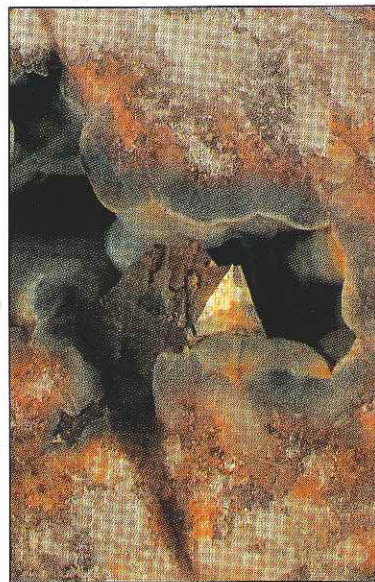


Plate 8. Pyritohedron crystal in geode, from Halls Gap. Geode is 2 inches in diameter.



Plate 9. Millerite crystals in small, dime-size geode, from Halls Gap.



Plate 10. Millerite in softball-size geode, from Halls Gap.



Plate 11. Honessite crystals in small geode, Halls Gap.



Plate 12. Honessite from Halls Gap. Magnified 70 times (70X).

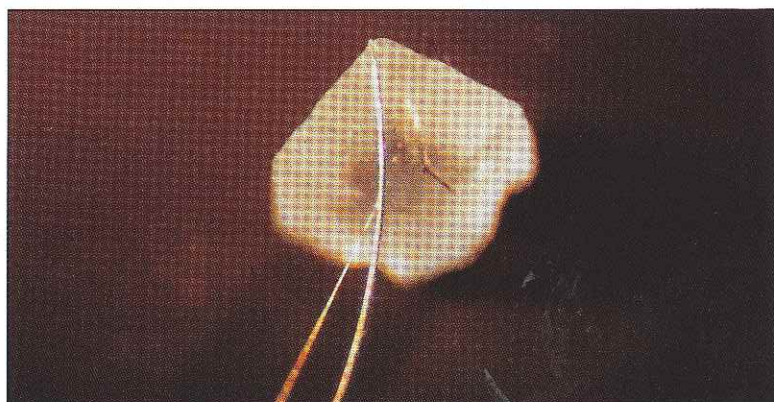


Plate 13. Calcite rhombohedron on acicular millerite crystal, 70X.

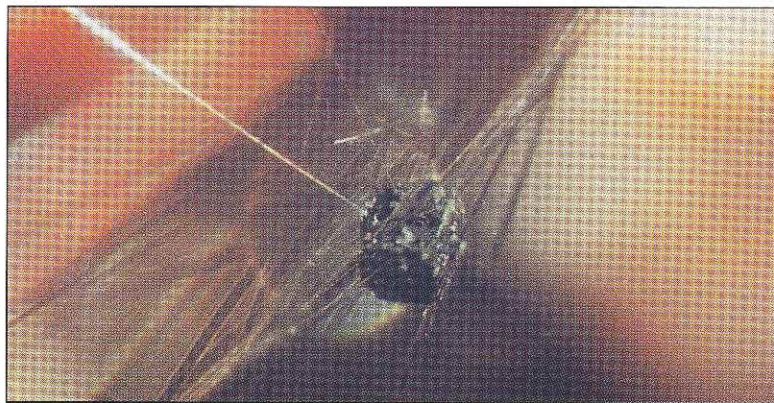


Plate 14. Pyrite cube on millerite crystals. 70 X.

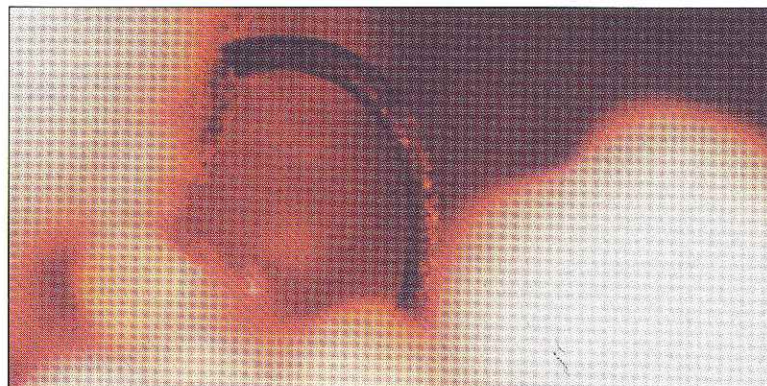


Plate 15. Pyrite ring from Halls Gap. 70X.



Plate 16. Sphalerite crystals with white barite rosettes. Actual specimen is 3 inches wide.

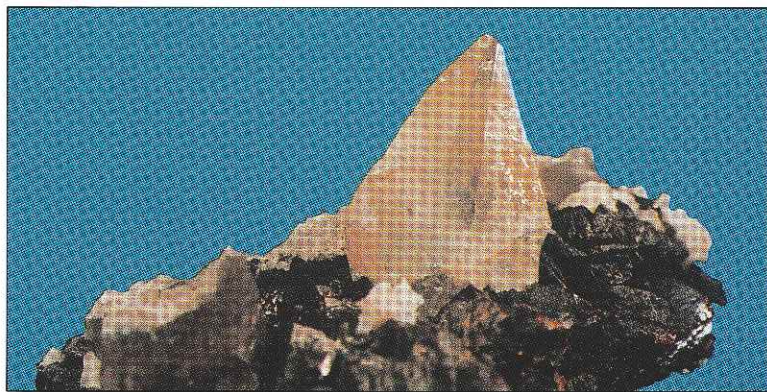


Plate 17. Calcite scalenohedron on sphalerite crystals.



Plate 18. Bladed barite crystals, from Boyle County.



Plate 19. White barite with purple fluorite and black sphalerite, from Boyle County. Actual specimen is 4 inches wide.



Plate 20. Photomicrograph of massive, feathery barite, from Fayette County. 25X.

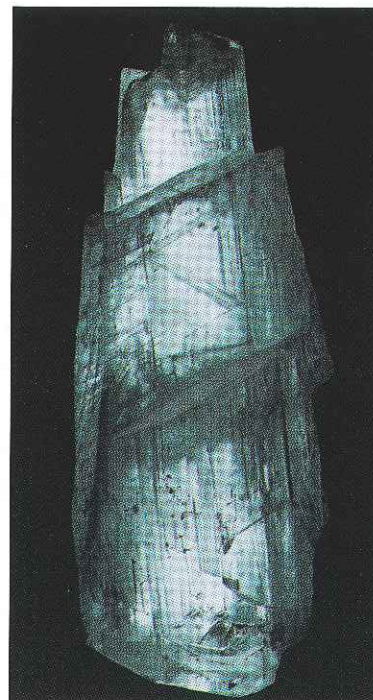


Plate 21. Selenite, backlit. Actual specimen 7 inches long.



Plate 22. Selenite crystals, from Lexington Quarry vein. Actual specimen 5 inches long.



Plate 23. Gypsum flower on calcite, from south-central Kentucky. Actual specimen 2.5 inches wide.

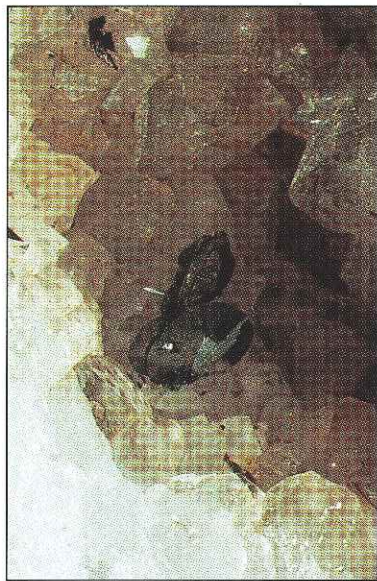


Plate 24. Hematite crystals in geode from Estill County, 25X.

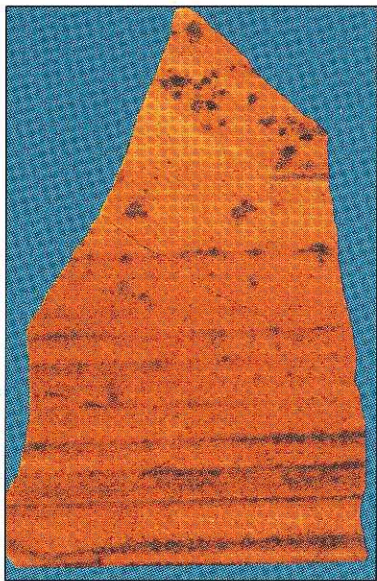


Plate 25. Black, dendritic pyrolusite coatings along bedding planes of quartz sandstone. Actual specimen 4 inches wide at base.



Plate 26. Hemimorphite (photo by A. Goldstein).

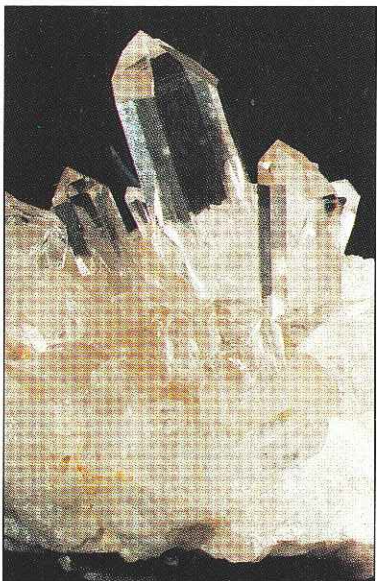


Plate 27. Quartz crystals with hexagonal crystal structure and pyramidal termination.

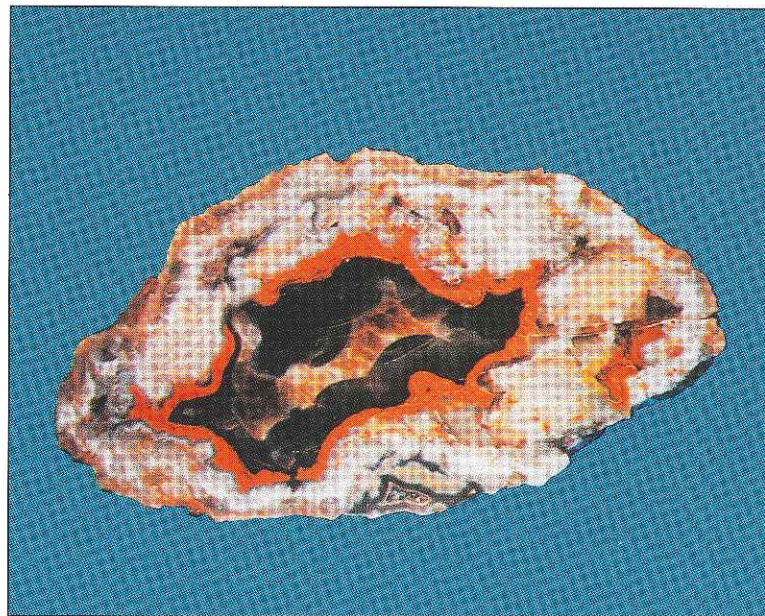


Plate 28. Red and black variety of Kentucky agate (specimen from K. Settles; photo by D. Matulionis).

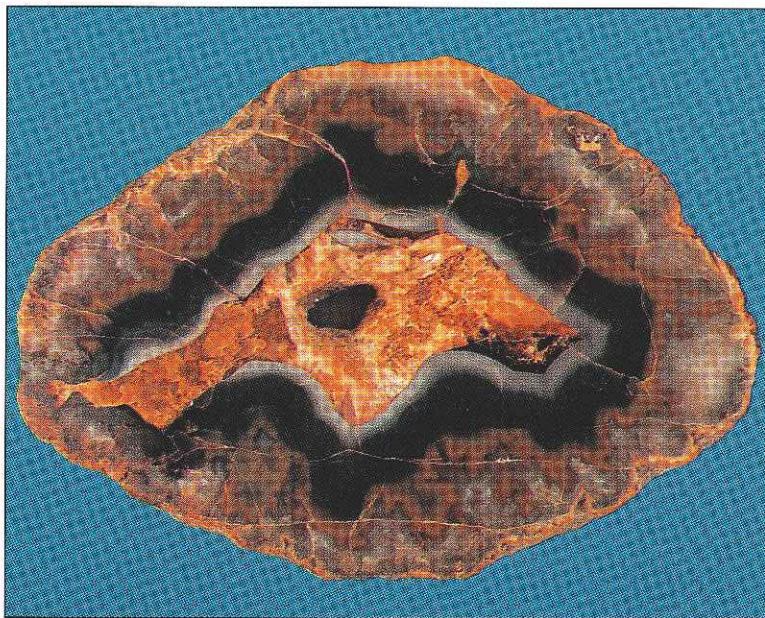


Plate 29. Yellow variety of Kentucky agate, from east-central Kentucky.

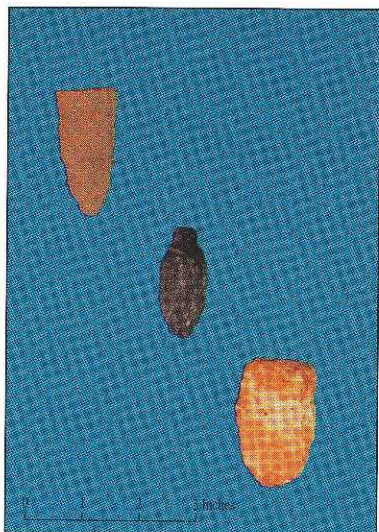


Plate 30. Chert and flint arrowheads.



Plate 31. Calcite scalenohedrons, Lexington Quarry vein, Jessamine County. Actual specimens are 6 inches wide.



Plate 32. Various forms of calcite.

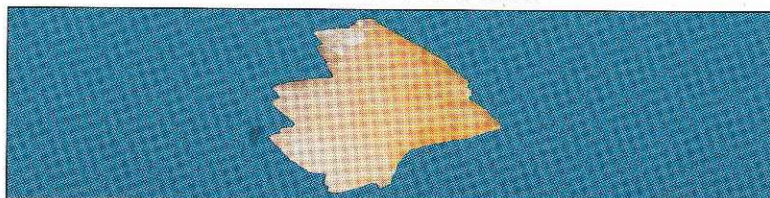


Plate 33. Twinned calcite, from Lexington Quarry vein. Actual specimen 4 inches wide.



Plate 34. Aragonite, from Pulaski County. Actual specimen 5 inches wide.



Plate 35. Dolomite crystals in vug, from Hardin County. Actual specimen 4 inches wide.



Plate 36. Photomicrograph of aurichalcite. 70 X.

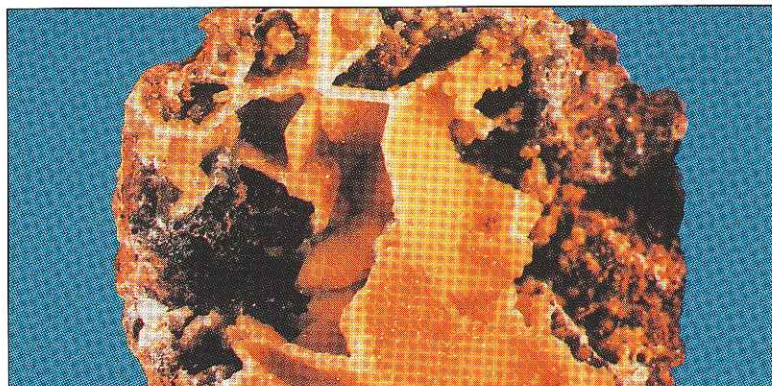


Plate 37. Reticulated smithsonite, from Old Jim Mine, Crittenden County. Actual specimen 3 inches wide.



Plate 38. Botryoidal smithsonite, from Milner Vein, Woodford County. Actual specimen 3 inches wide.



Plate 39. Strontianite balls, from Boyle County. Photo by D. Matulionis.



Plate 40. Pyromorphite from western Kentucky. 70X.



Plate 41. Fluorite octahedrons.



Plate 42. Yellow variety of fluorite in normal, reflected light. Actual specimen 4 inches wide.



Plate 43. Yellow variety of fluorite (backlit).



Plate 44. Purple variety of fluorite. Actual specimen 6 inches wide.



Plate 45. Purple variety of fluorite (backlit).



Plate 46. Fluorite that has grown preferentially along an exterior axis. Actual specimen 4 inches wide.

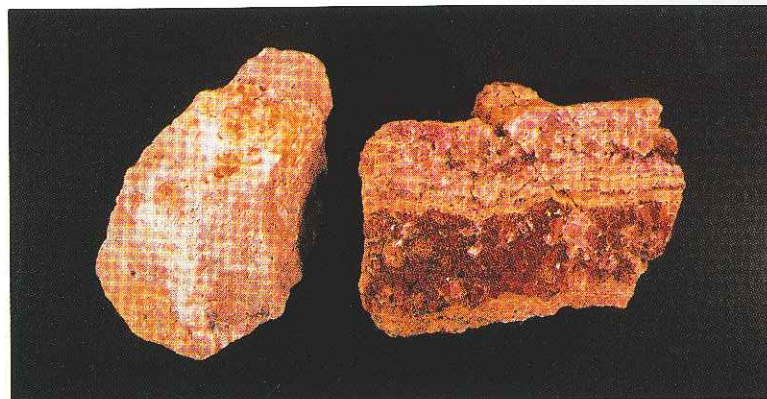


Plate 47. Banded fluorite under normal light. Actual specimen 6 inches wide.



Plate 48. Same specimen as Plate 47 under ultraviolet light.



Plate 49. Cubic fluorite. Cubes are 1.5 inches wide.



Plate 50. Zoned fluorite, with white barite inclusions. Actual specimen 5 inches wide.



Plate 51. Milner Vein, in Woodford County, which contains barite, sphalerite, galena, and smithsonite.

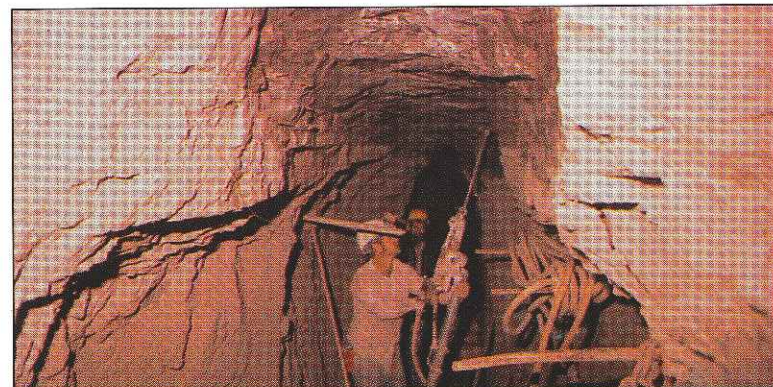


Plate 52. Mined-out mineral vein in Lexington Quarry, Jessamine County (4 feet wide).

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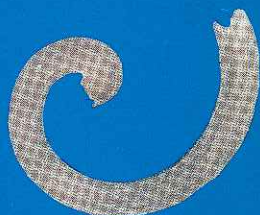
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