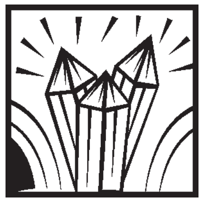


Chapter 5: Mineral Resources of the South Central US

What is a mineral?

A **mineral** is a naturally occurring solid with a definite chemical composition and crystalline structure. Minerals provide the foundation of our everyday world. Not only do they make up the rocks we see around us in the South Central, they are also used in nearly every aspect of our lives. The minerals found in the rocks of the South Central are used in industry, construction, machinery, technology, food, makeup, jewelry, and even the paper on which these words are printed.

Elements: The Building Blocks of Minerals

Elements are the building blocks of minerals. The mineral quartz, for example, is made of the elements silicon and oxygen, and, in turn, is also a major component of many rocks. Most minerals present in nature are not composed of a single element, though there are exceptions such as gold. Elements such as copper (Cu), lead (Pb), zinc (Zn), and even silver (Ag), gold (Au), and diamond (C) are not rare, but they are usually widely dispersed in rocks and occur at very low average concentrations. Eight elements make up (by weight) 99% of the Earth's crust, with oxygen being the most abundant (46.4%). The remaining elements in the Earth's crust occur in very small amounts, some in concentrations of only a fraction of one percent (*Figure 5.1*). Since silicon (Si) and oxygen (O) are the most abundant elements in the crust by mass, it makes sense for silicates (e.g., feldspar, quartz, and garnet) to be some of the most common minerals in the Earth's crust and to therefore be found throughout the South Central.

Minerals provide the building blocks for rocks. For example, **granite**, an **igneous rock**, is typically made up of crystals of the minerals **feldspar**, **quartz**, **mica**, and **amphibole**. In contrast, **sandstone** may be made of **cemented** grains of feldspar, quartz, and mica. The minerals and the bonds between the crystals define a rock's color and resistance to **weathering**.

granite • *a common and widely occurring type of igneous rock.*

igneous rocks • *rocks derived from the cooling of magma underground or molten lava on the Earth's surface.*

feldspar • *an extremely common, rock-forming mineral found in igneous, metamorphic and sedimentary rocks.*

quartz • *the second most abundant mineral in the Earth's continental crust (after feldspar), made up of silicon and oxygen (SiO_2).*

mica • *a large group of sheetlike silicate minerals.*

amphibole • *a group of dark colored silicate minerals, or either igneous or metamorphic origin.*

CHAPTER AUTHOR

Allen Macfarlane

5 Mineral Resources

Review

silica • a chemical compound also known as silicon dioxide (SiO_2).

carbonate rocks • rocks formed by accumulation of calcium carbonate, often made of the skeletons of aquatic organisms.

calcium carbonate • a chemical compound with the formula $CaCO_3$, commonly found in rocks in the mineral forms calcite and aragonite, as well as the shells and skeletons of marine organisms.

gold • a soft, yellow, corrosion-resistant element (Au), which is the most malleable and ductile metal on Earth.

sulfur • a bright yellow chemical element (S) that is essential to life.

salt • a mineral composed primarily of sodium chloride (NaCl).

crust • the uppermost, rigid outer layer of the Earth, composed of tectonic plates.

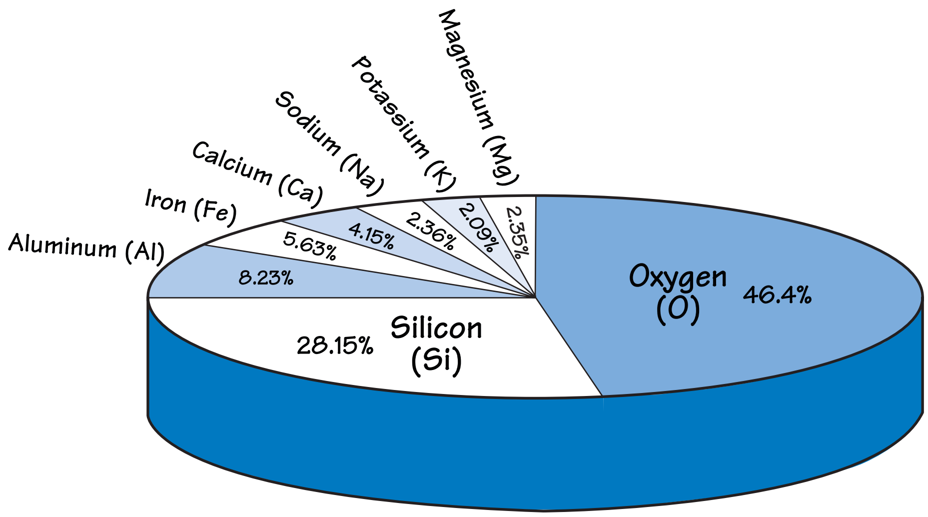


Figure 5.1: Mineral percentage by mass in the Earth's crust.

Several thousand minerals have been discovered and classified according to their chemical composition. Most of them are **silicates** (representing approximately a thousand different minerals, of which quartz and feldspar are two of the most common and familiar), which are made of silicon and oxygen combined with other elements (with the exception of quartz, SiO_2). **Carbonate rocks** are made of carbon and oxygen combined with a metallic element; **calcium carbonate** ($CaCO_3$) is the most common example, and most of it today originates as skeletal material precipitated by organisms. Other mineral categories include native elements (such as **gold**), oxides and **sulfur**-bearing minerals, and **salts**.

Metallic minerals are vital to the machinery and technology of modern civilization. However, many metals occur in the **crust** in amounts that can only be measured in parts per million (ppm) or parts per billion (ppb). A mineral is called an **ore** when one or more of its elements can be profitably removed, and it is almost always necessary to process ore minerals in order to isolate the useful element. For example, **chalcopyrite** ($CuFeS_2$), which contains **copper**, **iron**, and sulfur, is referred to as a copper ore when the copper can be profitably extracted from the iron and sulfur. Ores are not uniformly distributed in the crust of the Earth, but instead occur in localized areas where they are concentrated in amounts sufficient for being economically extracted by mining.

Non-metallic minerals do not have the flash of a metal, though they may have the brilliance of a **diamond** or the silky appearance of **gypsum** ($CaSO_4{\cdot}2H_2O$). Generally much lighter in color than metals, non-metallic minerals can transmit light, at least along their edges or through small fragments.

Mineral Identification

Although defined by their chemical composition and crystal structure, minerals are identified based on their physical properties. A variety of properties must usually be determined when identifying a mineral, with each such property eliminating possible alternatives.

Hardness is a very useful property for identification, as a given mineral can only exhibit a narrow range of hardnesses, and since it is easily testable, this property can be used to quickly and simply minimize the number of possibilities. Hardness is important because it helps us understand why some rocks are more or less resistant to weathering and **erosion**. Quartz, with a rating of 7 on the **Mohs scale**, is a relatively hard mineral, but **calcite** ($CaCO_3$), rating 3 on the Mohs scale, is significantly softer. Therefore, it should be no surprise that quartz sandstone is much more resistant to erosion and weathering than is **limestone**, which is primarily made of the mineral calcite. Quartz is a very common mineral in the Earth's crust, and it is quite resistant due to its hardness and relative insolubility. Thus, quartz grains are the dominant mineral type in nearly all types of **sand**.

Mohs Scale of Hardness

In 1824, the Austrian mineralogist Friedrich Mohs selected ten minerals to which all other minerals could be compared to determine their relative hardness. The scale became known as the Mohs scale of hardness, and it remains very useful as a means for identifying minerals or for quickly determining their hardness. Everyday items can be used to determine hardness if the minerals in the scale are not available. These include a streak plate or piece of unglazed porcelain (hardness 7), a piece of glass (5), a penny (3), and a fingernail (2).

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

Color is helpful in identifying some minerals such as sulfur, but it is uninformative or even misleading in others such as garnet. **Luster** describes how light is reflected from a mineral's surface and it can range from adamantine, seen in diamonds, to dull or earthy (effectively no luster), such as in **kaolinite**. **Crystal form**, if visible, can also be diagnostic. For example, **fluorite** and calcite may appear superficially similar, but fluorite forms cubic crystals while calcite forms trigonal-rhombohedral crystals. Relatedly, crystals may have planes of weakness that cause them to break in characteristic ways, called **cleavage**. Or they may not, but instead display **fracture** when broken. Mica and **graphite** have very strong cleavage, allowing them to easily be broken into thin sheets, while quartz and glass (the latter not being a mineral) have no cleavage,

Review

erosion • *the transport of weathered materials.*

calcite • *a carbonate mineral, consisting of calcium carbonate ($CaCO_3$).*

limestone • *a sedimentary rock composed of calcium carbonate ($CaCO_3$).*

sand • *rock material in the form of loose, rounded, or angular grains, and formed as a result of the weathering and decomposition of rocks.*

kaolinite • *a silicate clay mineral, also known as china clay.*

fluorite • *the mineral form of calcium fluoride (CaF_2).*

fracture • *a physical property of minerals, formed when a mineral crystal breaks.*

graphite • *a mineral, and the most stable form of carbon.*

5 Mineral Resources

Review

density • *a physical property of minerals, describing the mineral's mass per volume.*

streak • *a physical property of minerals, obtained by dragging the mineral across a porcelain plate and effectively powdering it.*

luminescence • *the emis-sion of light.*

radioactivity • *the process by which an unstable atom loses energy by emitting radiation.*

effervesce • *to foam or fizz while releasing gas.*

gem • *a mineral that has been cut and polished for use as an ornament.*

dimension stone • *the commercial term applied to quarried blocks of rock cut to specific dimensions.*

marble • *a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite.*

instead displaying a distinctive curved fracture form known as conchoidal. The **density** of a mineral may also aid in identifying it (e.g., metals tend to be very dense). Finding the exact density is straightforward, but it does require measuring the volume of the sample. Placing an unknown mineral in water (or other liquid) to find its volume by displacement can be a risky undertaking since several minerals react violently with water, and many more break down with exposure. A mineral's **streak** is obtained by dragging it across a porcelain plate, effectively powdering it. The color of the powder eliminates conflating variables of external weathering, crystal habit, impurities, etc. Some minerals are **magnetic** (affected by magnetic fields), while a few are natural magnets (capable of producing a magnetic field).

Most minerals can be identified by process of elimination after examining a few of these properties and consulting a mineral identification guide. Mineral testing kits often include several common objects used to test hardness: a porcelain streak plate, a magnet, and a magnifying glass. Some minerals have rare properties, which may be more difficult to test. For example, there are minerals that exhibit **luminescence** of all types, giving off light due to a particular stimulus. Some minerals are **radioactive**, usually due to the inclusion of significant amounts of uranium, thorium, or potassium in their structure. Carbonate minerals will **effervesce** when exposed to hydrochloric acid. **Double refraction** describes the result of light passing through a material that splits it into two polarized sets of rays, doubling images viewed through that material. For example, a single line on a sheet of paper will appear as two parallel lines when viewed through a clear calcite crystal.

There are many more interesting and distinguishing properties that minerals may possess, and there are many more elaborate and precise means for identifying them. The branch of geology that studies the chemical and physical properties and formation of minerals is called *mineralogy*.

What Are Minerals Used For?

Mineral resources fall into many different categories, including industrial minerals, construction materials, **gemstones**, and metallic and non-metallic ores. Some minerals and rocks are abundant and are used in the construction industry or in the manufacturing of many of the products we commonly find in stores. Construction materials include **dimension stone** (e.g., sandstone, limestone, and granite), which is used for the exterior or interior of structures.

Minerals used in manufacturing include kaolinite for ceramics, gypsum for wallboard, fluorite for the fluoride in toothpaste, and halite for common table and rock salt. We also seek out specific rock types and sediment to use in the construction of buildings, highways, and bridges. Many of the statues in museums are commonly made of **marble**, **jade**, or **soapstone**. Granite, travertine, and other decorative stones are increasingly used to beautify our home interiors and to make art, in addition to being used in public buildings.

Mineral Resources 5

What distinguishes a regular mineral from a gem?

Minerals are assigned to the category of gemstones based primarily on our interpretation of what has value. Typically, the beauty, durability, and rarity of a mineral qualify it as a gemstone. Beauty refers to the luster, color, transparency, and brilliance of the mineral, though to some degree it is dependent on the skillfulness of the cut. Not all gems are prized for these reasons; for example, scarcity may be artificially inflated, or a mineral may be valued for its unusual color.

Gemstones can be further categorized as precious or semi-precious stones. Precious stones, including diamond, topaz, and sapphire, are rare and translucent to light. They are more durable because they are hard, making them scratch resistant. On the Mohs scale of hardness, the majority of precious gemstones have values greater than 7. Semi-precious stones are generally softer, with hardness scale values between 5 and 7. The minerals, peridot, jade, garnet, amethyst, citrine, rose quartz, tourmaline, and turquoise are examples of semi-precious stones that can be cut and used in jewelry.

Gems may have common names that differ from their geological ones, and these names may be dependent on mineral color. For example, the mineral *beryl* is also referred to as emerald, aquamarine, or morganite depending on its color. *Corundum* can also be called sapphire or ruby, and peridot is another name for olivine.

Some minerals are considered to be precious or semi-precious and are used in jewelry, including diamond and some crystalline forms of quartz.

Metallic minerals have many applications and are used to manufacture many of the items we see and use every day. For example, iron comes from **hematite** and **magnetite**, and from it we make steel. **Lead**, from the mineral **galena**, is used in the manufacture of batteries and in the solder found in electronic devices. **Titanium**, from the mineral **ilmenite**, is used in airplanes, spacecraft, and even white nail polish. **Aluminum** comes from **bauxite** and is known for being both lightweight and strong—many of the parts that make up today's automobiles are made of this metal. Copper comes from a variety of copper-bearing minerals, including chalcopyrite, and is used to make electrical wire, tubing, and pipe.

Review

hematite • *a mineral form of iron oxide (Fe_2O_3), with vivid red pigments that make it valuable as a commercial pigment.*

magnetite • *a mineral form of iron oxide (Fe_3O_4) with naturally occurring magnetic properties.*

lead • *a metallic chemical element (Pb).*

galena • *an abundant sulfide mineral with cubic crystals.*

titanium • *a metallic chemical element (Ti) that is important because of its lightweight nature, strength and resistance to corrosion.*

ilmenite • *an ore of titanium, produced for use as a white pigment in paint.*

bauxite • *a whitish, grayish, brown, yellow, or reddish-brown rock composed of hydrous aluminum oxides and aluminum hydroxides.*

5 Mineral Resources

Mineral Formation

Economically recoverable mineral deposits are formed by geologic processes that can selectively concentrate desirable elements in a relatively small area. These processes may be physical or chemical, and they fall into four categories:

Magmatic processes separate minor elements of **magma** from the major elements and concentrate them in a small volume of rock. This may involve the early crystallization of ore minerals from the magma while most other components remain molten, or late crystallization after most other components have crystallized. Magmatic processes responsible for the formation of mineral deposits are usually associated with igneous **intrusions** (formed during mountain building events, **rifting**, and **volcanic** activity), which can range in composition from granite (**felsic**) to **gabbro** (**mafic**). **Metamorphism** may also cause **recrystallization** of minerals and concentration of rare elements. Under conditions of extreme high-temperature metamorphism, minerals with the lowest melting temperatures in the crust may melt to form small quantities of **pegmatite** magmas.

Hydrothermal processes involve **hydrothermal solutions** that dissolve minor elements dispersed through large volumes of rock, transport them to a new location, and precipitate them in a small area at a much higher concentration. Hydrothermal solutions are commonly salty, acidic, and range in temperature from over 600°C (~1100°F) to less than 60°C (140°F). Some of these fluids may travel very long distances through **permeable sedimentary rock**. Eventually, the hydrothermal fluids precipitate their highly dissolved load of elements, creating concentrated deposits.

Sedimentary processes gather elements dispersed through large volumes of water and precipitate them in a sedimentary environment, such as in sedimentary layers on the ocean floor or on lakebeds. Sedimentary mineral deposits form by direct precipitation from the water.

Weathering and erosion break down large volumes of rock by physical and chemical means and gather previously dispersed elements or minerals into highly concentrated deposits. **Residual weathering deposits** are mineral deposits formed through the concentration of a weather-resistant mineral, as a result of surrounding minerals being eroded and dissolved. In contrast, mineral deposits formed by the concentration of minerals in moving waters are called **placer deposits**.

A mineral is not necessarily restricted to one method of concentration or environment of formation. For example, economically important deposits of gypsum may form as a precipitate from evaporating water. However, gypsum formation may also be associated with volcanic regions where limestone and sulfur gases from the volcano have interacted, or from other areas as a product of the chemical weathering of pyrite.

Review

magma • *molten rock located below the surface of the Earth.*

intrusive rock • *a plutonic igneous rock formed when magma from within the Earth's crust escapes into spaces in the overlying strata.*

rift • *a break or crack in the crust that can be caused by tensional stress as a landmass breaks apart into separate plates.*

volcanism • *the eruption of molten rock onto the surface of the crust.*

felsic • *igneous rocks with high silica content and low iron and magnesium content.*

gabbro • *a usually coarse-grained, mafic and intrusive igneous rock.*

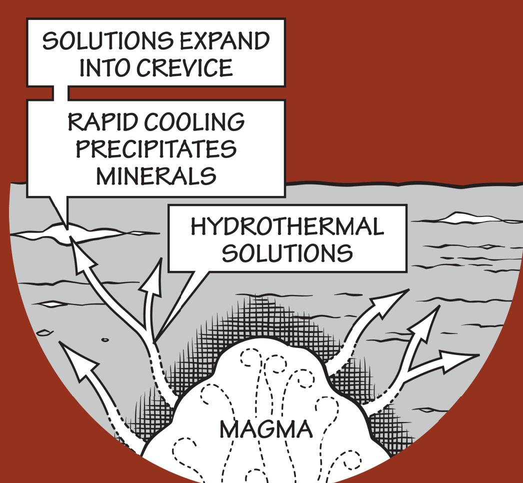
mafic • *igneous rocks that contain a group of dark-colored minerals, with relatively high concentrations of magnesium and iron.*

What are hydrothermal solutions?

Hot water enriched in salts such as sodium chloride (NaCl), potassium chloride (KCl), and calcium chloride ($CaCl_2$) is called a hydrothermal solution, or simply "brine." Brine is as salty or even saltier than seawater, and may contain minute bits of dissolved minerals such as gold, lead, copper, and zinc. The presence of salt in the water stops the metallic minerals from precipitating out of the brine because the chlorides in the salt preferentially bond with the metals. Additionally, because the brine is hot, the minerals are more easily dissolved, just as hot tea dissolves sugar more easily than cold tea does.

Hot water brines can have varying origins. Most bodies of magma contain mineral-enriched, superheated water, which is released into the surrounding rock as the magma cools. Rainwater can become a hydrothermal solution as it filters through rocks and picks up soluble materials along its path. Seawater, which is already enriched in salt, often becomes a hydrothermal solution in the vicinity of volcanic activity on the ocean floor where tectonic *plates* are pulling apart.

Hydrothermal solutions move away from their source of heating through cracks, faults, and solution channels into the adjacent cooler rocks. While the water moves quickly through fractures and openings in the rock (where it experiences changes in pressure or composition and dilution with groundwater), it can cool rapidly. This rapid cooling over short distances allows concentrations of minerals to be deposited. When a hydrothermal solution cools sufficiently, the dissolved salts form a precipitate, leaving behind minerals in a vein or strata-bound deposit.



Review

metamorphic rocks • *rocks formed by the recrystallization and realignment of minerals in pre-existing sedimentary, igneous, and metamorphic rocks when exposed to high enough temperature and/or pressure.*

recrystallization • *the change in structure of mineral crystals that make up rocks, or the formation of new mineral crystals within the rock.*

pegmatite • *a very coarse-grained igneous rock that formed below the surface.*

permeability • *a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.*

sedimentary rock • *formed through the accumulation and consolidation of grains of broken rock, crystals, skeletal fragments, and organic matter.*

plates • *large, rigid pieces of the Earth's crust and upper mantle, which move and interact with one another at their boundaries.*

5 Mineral Resources

Region 1

Minerals in the South Central

Throughout the South Central, the deposition of sediment has left behind an abundance of deposits useful for construction materials. River systems and **glaciers** deposited sand and **gravel**, while ancient seas that spread across the area also left behind thick deposits of halite and gypsum. The advance of **inland seas** and the subsequent deposition of marine detritus also made possible the widespread existence of **energy** resources (**fossil fuels**) throughout the area, most notably **oil**, **natural gas**, and **coal**. Some of the natural gas produced in the South Central also contains **helium** in sufficient concentrations to be profitably extracted—it originates from the decay of radioactive elements in the source rocks of accumulated natural gas.

See Chapter 7: Energy to learn more about fossil fuel resources in the South Central.

Periods of igneous activity commonly produce metals. However, some sources of metals in sedimentary rocks resulted not from igneous activity, but rather from **chemical reactions** that took place within rocks either as they formed or at some time after their formation—the hydrothermal precipitation of minerals is one such example. Igneous activity also contributes to the occurrence of non-metallic minerals and gemstones. For example, diamonds form near the Earth's **mantle**, but are often carried toward the surface by explosive volcanic eruptions.

Mineral Resources of the Central Lowland

Region 1

Mineral resources in the Central Lowland have accumulated primarily due to the deposition of sediment (*Figure 5.2*). The region's surface rocks are sedimentary strata from the **Pennsylvanian** and Permian, covered by glacial, river, and **wind**-blown deposits from the **Quaternary** and **Holocene**. Sources of non-organic sediment (sand and finer-grained materials) are derived from erosion, while organic carbonate sediment accumulated in shallow seas to form limestone. Ancient forests produced layers of organic debris that eventually formed coal. All of these depositional patterns have also been influenced by cyclical fluctuations in sea level, producing **cyclothems**: repeated sequences of terrestrial **shale**, sandstone, and coal layered with marine shale and limestone (*Figure 5.3*). Episodes of Quaternary glaciation and erosion in northeast Kansas and northern Missouri left behind discontinuous patches of glacial deposits consisting of **till** interspersed with sand and gravel **outwash**. As a result of all these processes, sand, gravel, stone, limestone, and **clay** occur abundantly throughout the Central Lowland, and all are quarried for use in construction. Industrial sand is mined at several locations in Oklahoma and Texas, primarily for use in glassmaking.

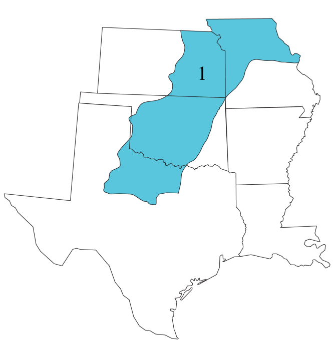
gravel • *unconsolidated, semi-rounded rock fragments larger than 2 millimeters (0.08 inches) and smaller than 75 millimeters (3 inches).*

inland sea • *a shallow sea covering the central area of a continent during periods of high sea level.*

energy • *the power derived from the use of physical or chemical resources.*

Quaternary • *a geologic time period that extends from 2.6 million years ago to the present.*

Holocene • *the most recent portion of the Quaternary, beginning about 11,700 years ago and continuing to the present.*



Mineral Resources 5

Region 1

Mining

Mining is a profit-focused undertaking. The profitability of mining minerals or rocks depends on a number of factors, including the concentrations of recoverable elements or material contained in the deposit; the anticipated amount of the deposit that can be mined; its accessibility using current mining methods and technologies; its marketability; and lastly the cost of returning the site to its original state once the extraction phase of mining has ended (reclamation). All these factors determine the choice of mining method. Types of mining include underground (tunnel or shaft), surface (open pit or quarry), hydraulic operations (placer), solution using hot water, and seawater evaporation ponds. Once a mineral resource has been removed from the ground, the next step is to process it in order to recover its useful elements or to transform it so that it can be used in manufacturing or other industrial processes.

Modern mining is accomplished in three phases: exploration, extraction, and reclamation. Exploration is performed to determine the extent of the mineral resource and usually involves extensive use of drilling and geophysical techniques to determine the shape, size, and quality of the resource. Extraction involves removing the mineral resource from the ground. Reclamation is done when mining ceases and is designed to restore the land to a condition where it can be used for other purposes. This last phase usually involves removing sources of contamination, which can be considerable depending on the scope of the mining activity. A good example of the need for an extensive and expensive cleanup of past activity is in the Tri-State mining district in southeast Kansas, northeast Oklahoma, and southwest Missouri, where lead and zinc deposits were actively mined for many decades in the late 19th and early 20th centuries.

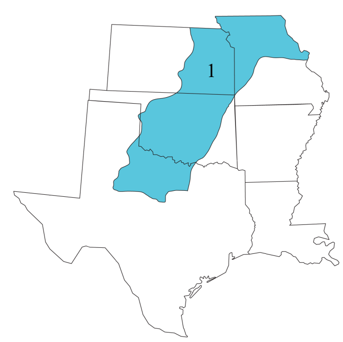
oil • *See petroleum: a naturally occurring, flammable liquid found in geologic formations beneath the Earth's surface and consisting primarily of hydrocarbons*

natural gas • *a hydrocarbon gas mixture composed primarily of methane (CH4), but also small quantites of hydrocarbons such as ethane and propane.*

coal • *a combustible, compact black or dark-brown carbonaceous rock formed by the compaction of layers of partially decomposed vegetation.*

mantle • *the layer of the Earth between the crust and core.*

Pennsylvanian • *a subperiod of the Carboniferous, spanning from 323 to 299 million years ago.*



5 Mineral Resources

Region 1

Pangaea • *supercontinent, meaning "all Earth," which formed over 250 million years ago and lasted for almost 100 million years.*

Carboniferous • *a geologic time period that extends from 359 to 299 million years ago.*

climate • *a description of the average temperature, range of temperature, humidity, precipitation, and other atmospheric/hydrospheric conditions a region experiences over a period of many years (usually more than 30).*

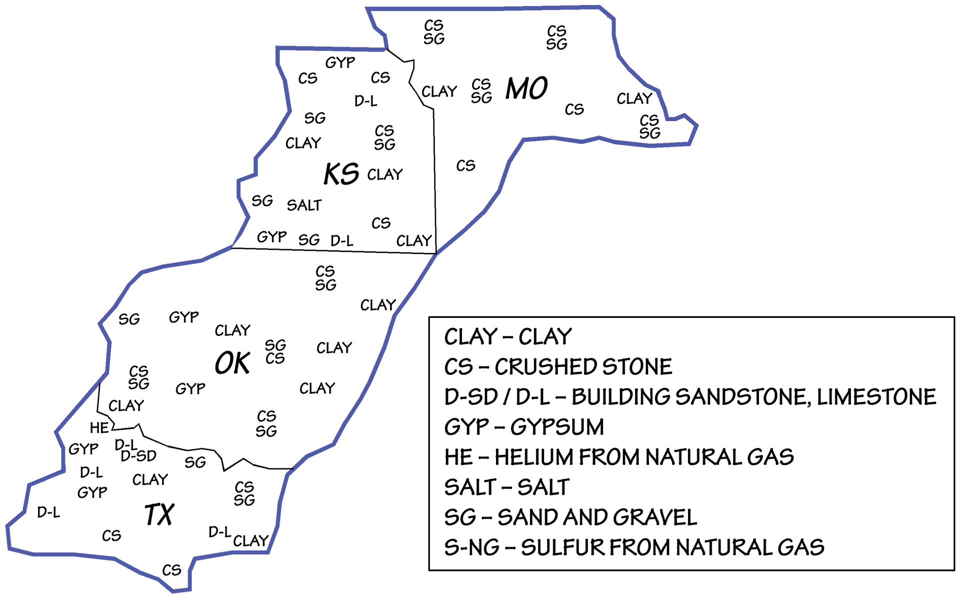


Figure 5.2: Principal mineral resources of the Central Lowland.

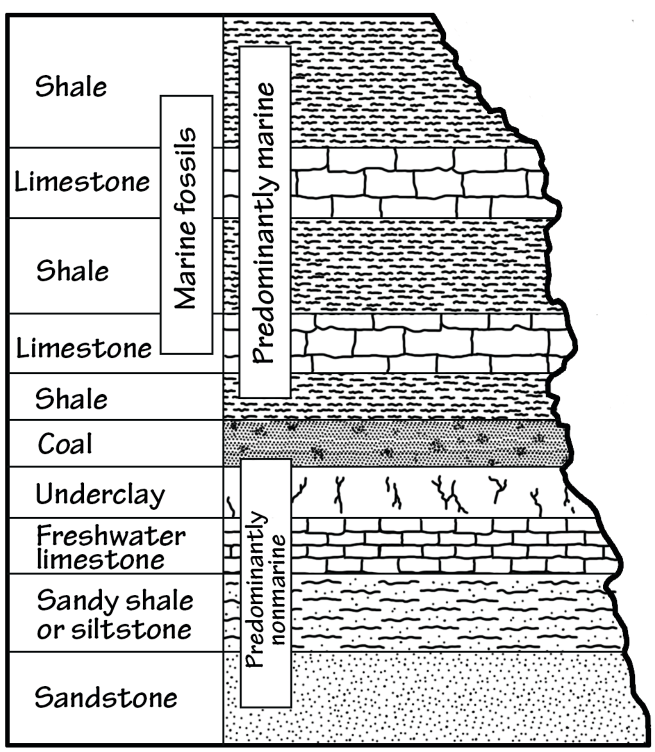
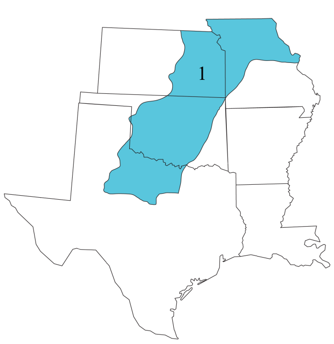


Figure 5.3: An example of a cyclothem.



Mineral Resources

5

Region 1

During and after the formation of **Pangaea**, the humid and tropical **Carboniferous** environment transitioned to the hot and arid **climate** of the Permian. These arid conditions led to the formation of **hypersaline**, shallow seas with restricted circulation, and layers of **evaporite** minerals were deposited as these seas evaporated. Today, Permian evaporite beds in Kansas, Oklahoma, and Texas are mined for halite and gypsum.

See Chapter 1: Geologic History for more detail on the formation of Pangaea.

Halite is mined in two ways. When deposited in thick beds, salt can be excavated by mechanically carving and blasting it out. This method, called "room and pillar" mining, usually requires that pillars of salt be left at regular intervals to prevent the mine from collapsing (*Figure 5.4*). Another method, called **solution mining**, involves drilling a well into a layer of salt. In some cases, the salt exists as part of a brine that can then be pumped to the surface and the water then removed, leaving the salt behind. In others, fresh water is pumped down to dissolve the salt, and the solution is brought back to the surface where the salt is removed (*Figure 5.5*).

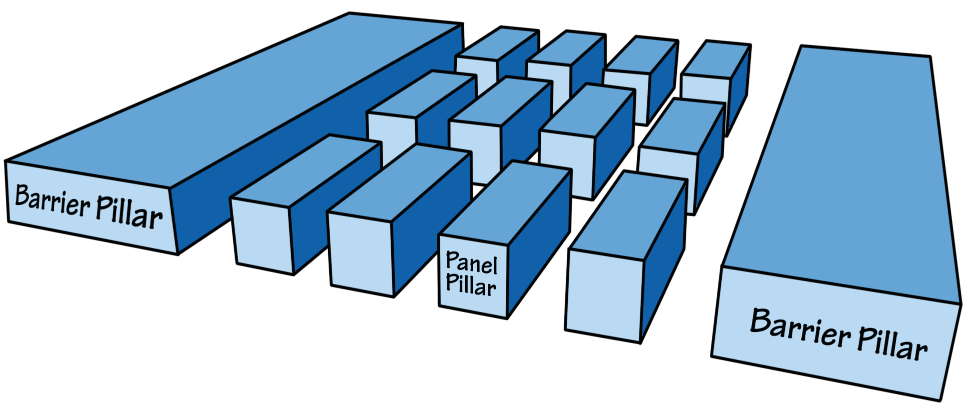


Figure 5.4: In pillar and room mining, the mine is divided up into smaller areas called "panels." Groups of panels are separated from one another by extra-large (barrier) pillars that are designed to prevent total mine collapse in the event of the failure of one or more regular-sized (panel) pillars.

Selenite, a variety of gypsum, is commonly found where Permian rocks appear at the surface, most notably in the Salt Plains of Oklahoma. In many locations, crystals of selenite are impregnated with sand and clay and are often referred to as "sand crystals." In Salt Plains National Wildlife Refuge, groundwater seeping through salt- and gypsum-saturated sand becomes concentrated with these minerals, spurring the formation of selenite crystals with a distinctive hourglass-shaped sand inclusion (*Figure 5.6*). The Salt Plains are the only place in the world where this phenomenon occurs. **Barite** roses can also be found at the surface in central Oklahoma (*Figure 5.7*). Due to their attractive form, sand crystals and barite roses are often sought after as collectibles.

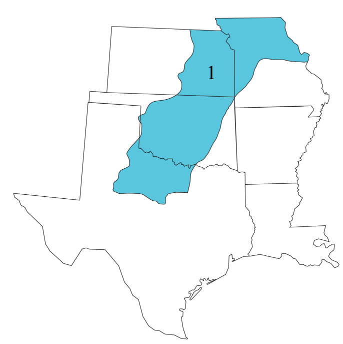
hypersaline • *of high salinity.*

evaporite • *a sedimentary rock created by the precipitation of minerals directly from seawater, including gypsum, carbonate, and halite.*

solution mining • *the extraction of soluble minerals from subsurface strata by the injection of fluids.*

selenite • *a variety of the mineral gypsum that is most often colorless.*

barite • *a usually white, clear, or yellow mineral ($BaSO_4$) found in limestone, clay-rich rocks, and sandstones.*



Mineral Resources

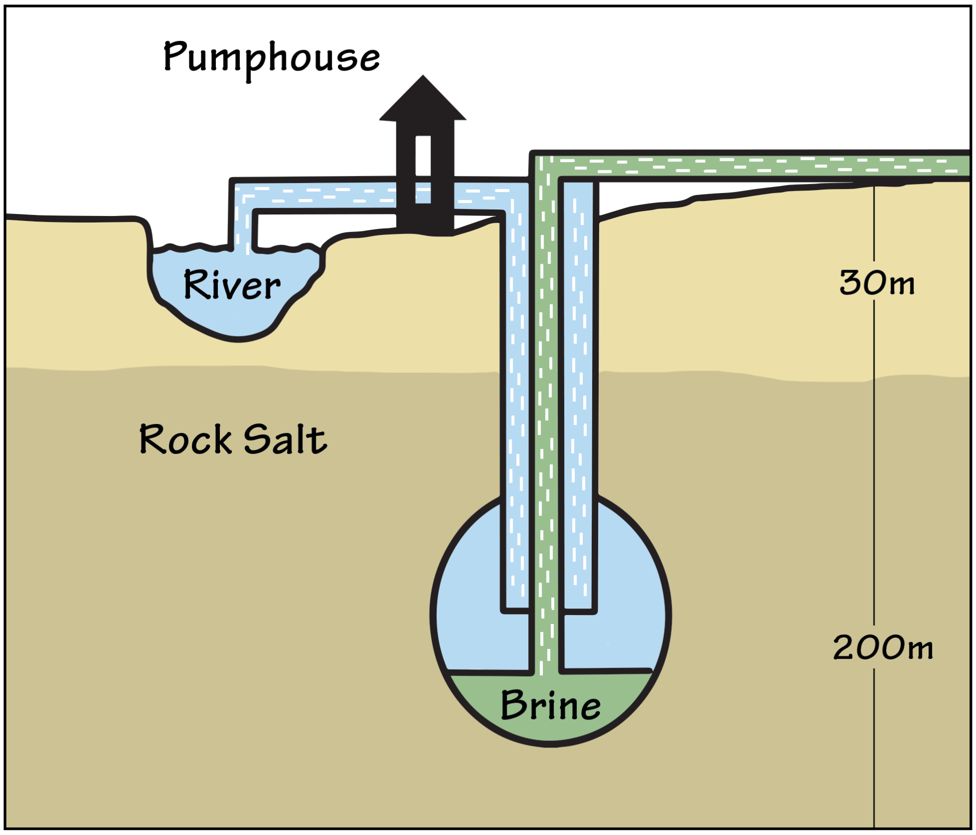


Figure 5.5: An example of solution mining that involves the pumping of fresh water through a borehole drilled into a subterranean salt deposit.

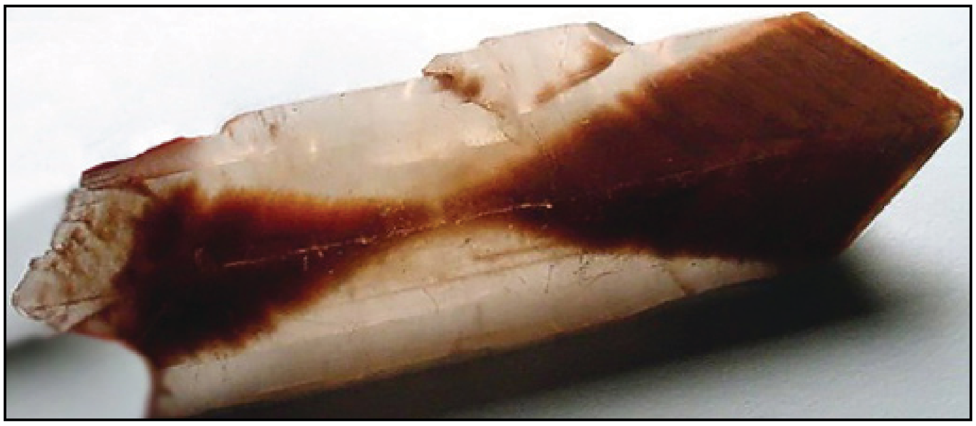


Figure 5.6: A selenite crystal from Salt Plains National Wildlife Refuge, Oklahoma with distinctive hourglass-shaped sand inclusion. Individual crystals up to 18 centimeters (7 inches) long have been found at this locality.

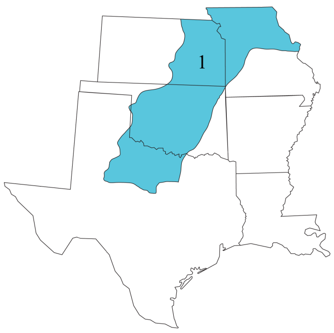


Figure 5.7: A barite rose from Cleveland County, Oklahoma. Each rosette measures over 4 centimeters (1.6 inches) across.

Igneous activity has also contributed to the formation of minerals found in the Central Lowland. During the late **Cretaceous**, eastern Kansas experienced episodes of volcanism. Some magma solidified in the necks of erupting volcanoes, eventually becoming kimberlite. These deposits, exposed by erosion at several locations in northeastern Kansas, yield small garnets. In southeastern Kansas, igneous intrusions led to the formation of **lamproite** sills and pipes. The lamproite contains shiny flakes of mica (*Figure 5.8*), which, when first observed in the 1870s, led to reports of **silver** and the formation of a mining town called Silver City. Although the lamproite does not actually contain silver, it is still mined today for its mica (used in polymers, coatings, and construction). In addition, the lamproite itself is ground and used as a mineral supplement in cattle feed.

Ancient sedimentation patterns and tectonic activity have favored the placement of widespread fossil fuel resources in the Central Lowland. Processing plants in Texas and Kansas recover commercial quantities of helium gas, an important byproduct of natural gas extraction. Non-commercial deposits of **asphalt**, formed by the breakdown of petroleum in the underlying rock, are also common in eastern Oklahoma.

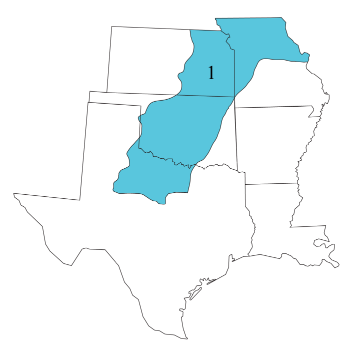
The Central Lowland does not contain economically viable metal deposits. However, copper-bearing minerals can be found in the Permian rocks of southern Kansas, parts of Oklahoma, and north-central Texas.

***Cretaceous** • a geologic time period spanning from 144 to 66 million years ago.*

***lamproite** • an ultramafic volcanic (extrusive) rock with high levels of potassium and magnesium that contains coarse crystals.*

***silver** • a metallic chemical element (Ag).*

***asphalt** • a black, sticky, semi-solid and viscous form of petroleum.*



5 Mineral Resources

Regions 1–2

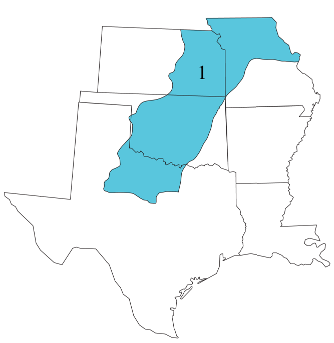
uplift • *upward movement of the crust due to compression, subduction, or mountain building.*

Paleozoic • *a geologic time interval that extends from 541 to 252 million years ago.*

dolomite • *a carbonate mineral, consisting of calcium magnesium carbonate ($CaMg(CO_3)_2$).*

Precambrian • *a geologic time period that spans from the formation of Earth (4.6 billion years ago) to the beginning of the Cambrian (541 million years ago).*

nodule • *a small, irregular or rounded mineral deposit that has a different composition from the sedimentary rock that encloses it.*



5.8: A piece of lamproite containing abundant mica flakes.

Mineral Resources of the Interior Highlands
Region 2

The Interior Highlands region consists of two areas of **uplifted** rock—the Ozark Uplift and the Ouachita Mountains—which have existed since the formation of Pangaea. Thick sequences of **Paleozoic** limestone and **dolomite**, with lesser thicknesses of sandstone and shale, underlie the area occupied by the Ozarks, except in the St. Francois Mountains (where erosion has stripped away the sedimentary cover and exposed **Precambrian** granite). **Nodules** of **chert** are present and often abundant in most of the limestone and dolomite. The weathering and erosion of these rocks has produced the chert gravels that mantle much of the Ozark Uplift.

See Chapter 4: Topography to learn more about the Ozark Uplift and Ouachita Mountains.

Mineral Resources

5

Region 2

The Interior Highlands is a source of several industrial minerals, primarily from sedimentary rocks. Episodes of marine **transgression** have left behind considerable resources for construction materials, including clay, limestone, sandstone, and granite (*Figure 5.9*). Deposits of **tripoli** (porous, weathered limestone mixed with silica) and novaculite (a form of chert) are mined in Missouri, Arkansas, and Oklahoma for use as abrasives. Tripoli is also used as filler in plastics, rubber, paint, and even toothpaste! Novaculite has been mined since prehistoric times; Native Americans used it to make arrow and spear points (*Figure 5.10*), and it has been quarried for use as whetstones since the 1800s.

See Chapter 2: Rocks to learn more about novaculite.

Metals have also generated a historically important mining industry in the Interior Highlands. Lead, **zinc**, copper, and silver are all found in significant

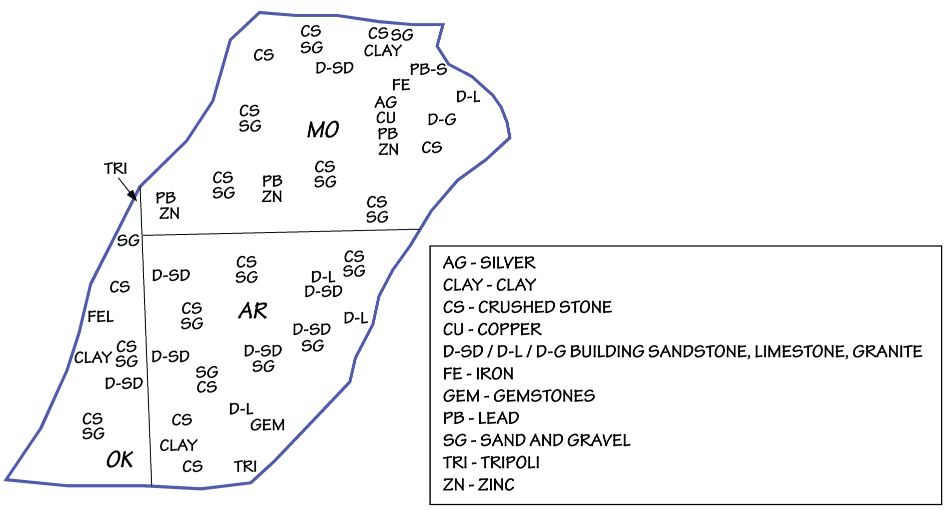


Figure 5.9: Principal mineral resources of the Interior Highlands.

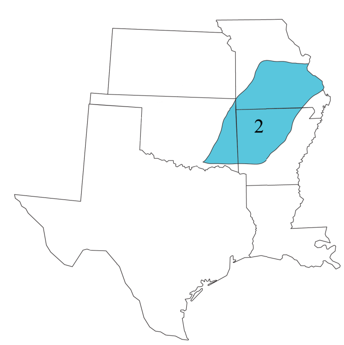
Figure 5.10: A novaculite arrowhead found in the Ozark Mountains.

chert • *a sedimentary rock composed of microcrystaline quartz.*

transgression • *a relative rise in sea level in a particular area, through global sea level rise or subsidence of land.*

tripoli • *a porous, usually brittle, siliceous sedimentary rock that is commonly used as filler for paints, plastics, and rubber.*

zinc • *a metallic chemical element (Zn, atomic number 30).*



quantities, and are thought to have precipitated from hydrothermal solutions during the Carboniferous and Permian. Lead mining first began in southeastern Missouri around 1720, and it has continued into the present. There are three mining districts in the Missouri portion of the Ozark Uplift: the Southeast Lead District, the Tri-State, and the Central (*Figure 5.11*). The Southeast Lead District includes the Old Lead Belt on the eastern side of the St. Francois Mountains and the New Lead Belt on the western side. Smaller, localized deposits of lead ores are located in northern Arkansas and southeastern Oklahoma. The Southeast Lead District contains the highest known concentration of galena, a lead-bearing ore, in the world (*Figure 5.12*). More than 17 million tons of lead have been produced in Missouri since mining began there, valued at more than 5 billion dollars. The Southeast Lead District produces about 70% of the US lead supply, most of which is used in the manufacture of batteries and ammunition.

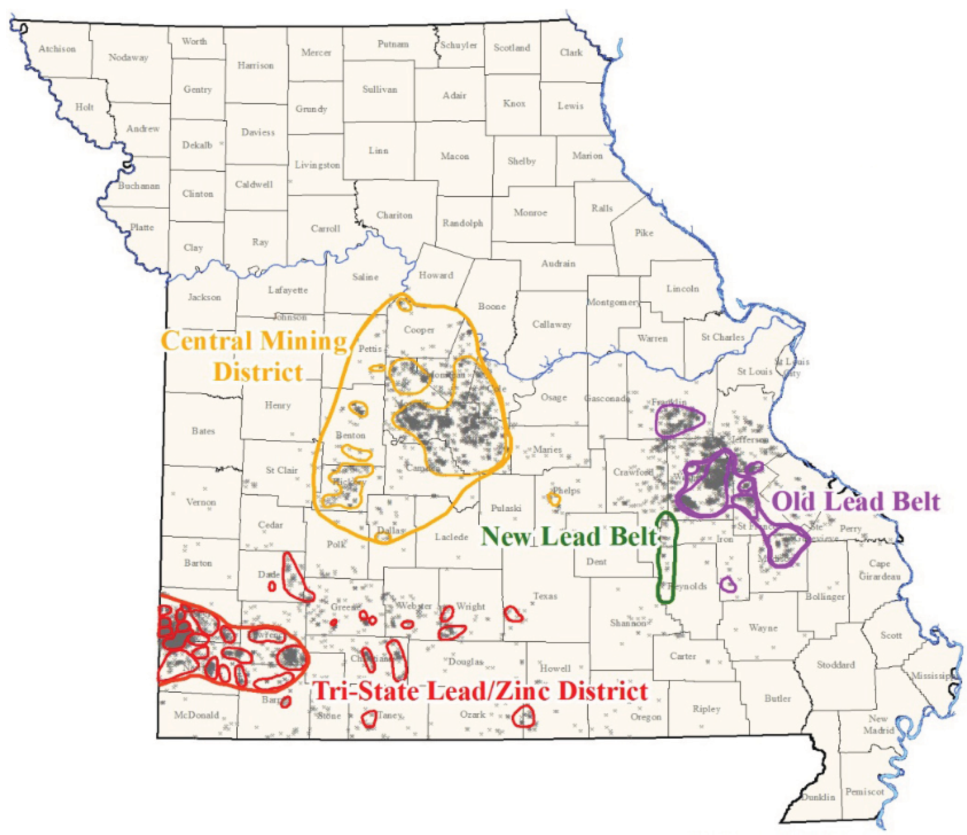
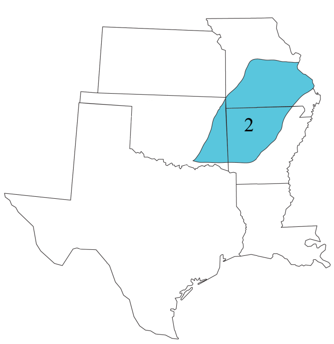


Figure 5.11: Locations of Missouri's mining districts. (See TFG website for full-color version.)

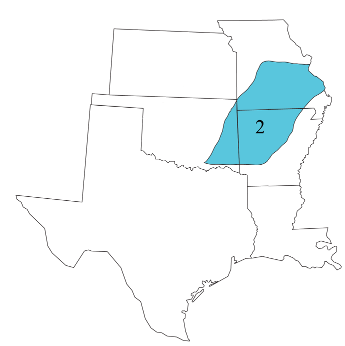


Of Missouri's three mining districts, perhaps the most famous is the Tri-State, which includes southwest Missouri around Joplin, and adjacent areas in southeast Kansas and northeast Oklahoma (*Figure 5.13*). The discovery of *aquifer* • a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.

Figure 5.12: A cubic galena crystal sitting atop a bed of calcite, from Reynolds County, Missouri. Specimen is 5.5 centimeters (2 inches) wide.

ore in Joplin occurred in 1838, and mining reached full swing by the beginning of the Civil War. Both sides fought over the mines, each trying to secure a source of lead for the war effort. This conflict resulted in the suspension of most mining operations until after the war's end. Lead mining resumed after the war, and zinc production began in the early 1870s. In the western part of the Tri-State District, the ore bodies are deeper, and mining was conducted underground, but in the east the ore bodies are shallower and were mined using pits. Production of metals from the district fluctuated with the economic fortunes of the country and the need for wartime supplies. Production began dropping after World War II, and the last mine closed in 1970. During the district's life, 4000 mines produced 23 million tons of zinc concentrates and 4 million tons of lead concentrates, accounting for 50% of the zinc and 10% of the lead used in the US. Today, some of the Tri-State's mines have become Superfund sites due to the quantities of toxic waste left behind after the closure of the mines. The Tar Creek Superfund site, located near the towns of Picher and Cardin in Oklahoma, was originally a major lead-zinc mining area. After its closure, the mine left behind about 75 million tons of chat, or lead-contaminated dust

A Superfund site is a heavily polluted location, designated by the government to receive a long-term clean-up response in order to remove environmental hazards and contamination.



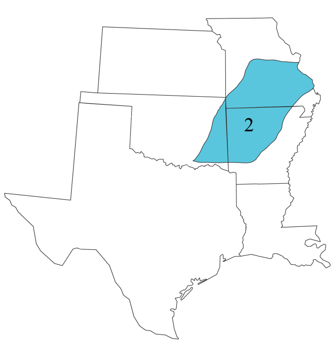
nickel *• a ductile, silvery-white metallic element (Ni) generally found in combination with iron.*

pyrite *• the iron sulfide mineral (FeS2) with a superficial resemblance to gold, known commpnly as "fool's gold."*

delta *• a typically wedge-shaped deposit formed as sediment is eroded from mountains and transported by streams across lower elevations.*

interglacial *• a period of geologic time between two successive glacial stages.*

Cenozoic *• the geologic time period spanning from 66 million years ago to the present.*



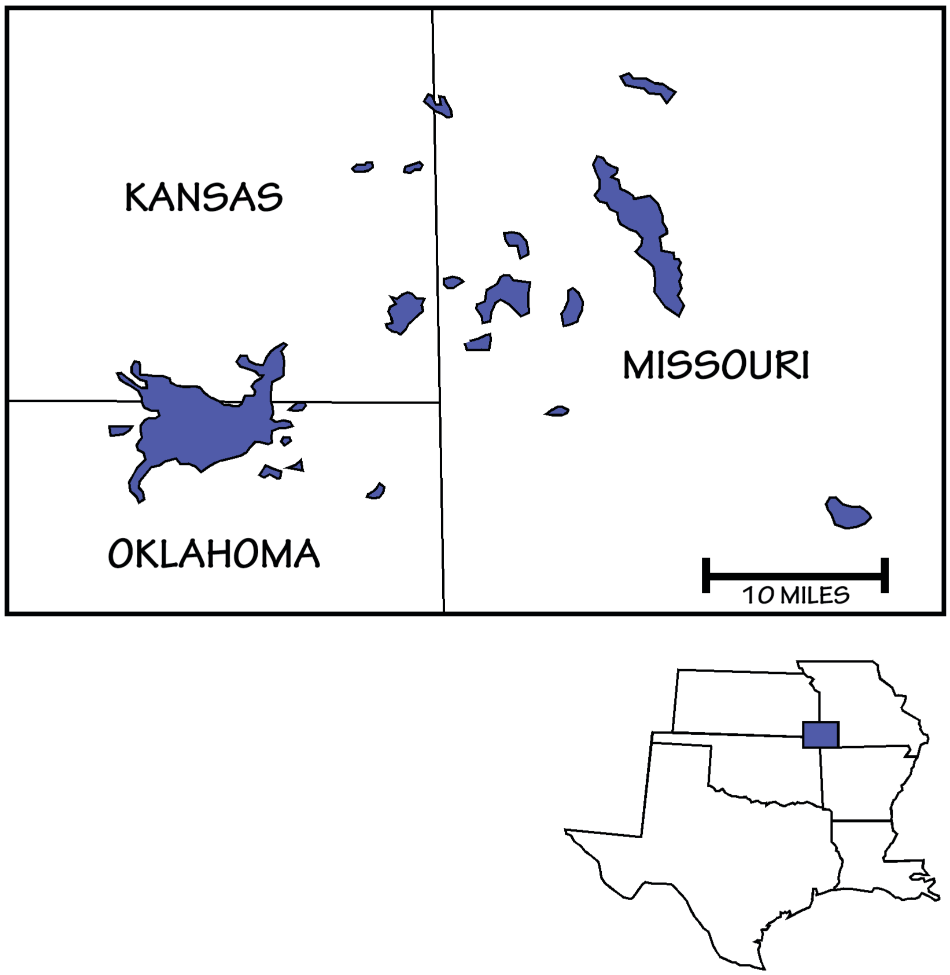


Figure 5.13: Locations of deposits of lead and zinc in the Tri-State mining district.

(*Figure 5.14*). Waste materials, acids, and heavy metals have seeped into the groundwater, contaminating local **aquifers** and other freshwater sources. The severe environmental and health impacts of Tar Creek's mining waste have lead the EPA to declare Picher, Oklahoma as one of the most toxic places in the US.

In addition to lead and zinc, mines in the Interior Highlands have also produced significant quantities of silver and copper. Other metallic elements are also present, including cadmium, **nickel**, and cobalt. **Pyrite**, calcite, dolomite, and quartz specimens from the region are highly prized by collectors.

Mining for iron ore began in Missouri in the mid-19th century, and has been intermittent since 2000. The ores precipitated from hydrothermal solutions, filling sinkholes and fractures in limestone, dolomite, and the Precambrian rocks of the St. Francois Mountains. The Interior Highlands' iron mines produce hematite and magnetite, unique among the iron ores for its magnetic properties.

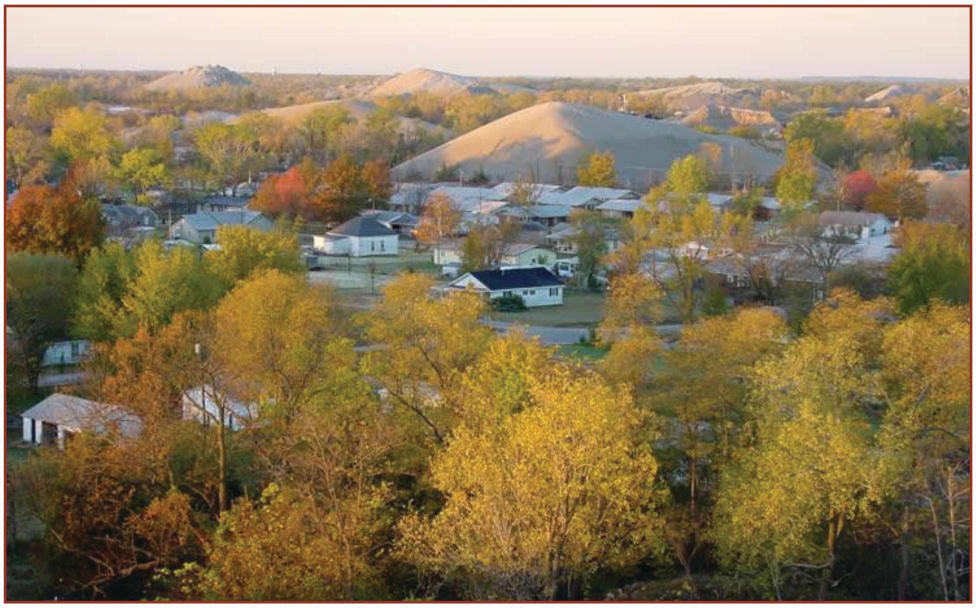


Figure 5.14: Residential area in Ottawa County, Oklahoma near the Tar Creek site. Note the proximity of several large lead-contaminated chat piles.

Mineral Resources of the Coastal Plain
Region 3

The Coastal Plain is underlain by thousands of feet of sedimentary rock and sediments that were deposited in both marine and terrestrial environments. Strata underlying this region consist of limestones, shales, and sandstones that were deposited in river valleys as well as in shallow seas, **deltas**, bays, and beaches. Cycles of deposition, erosion, and stability are tied to changes in sea level, which in turn have been influenced by Quaternary glacial and **interglacial** periods. Throughout the **Cenozoic**, the Mississippi River has continually deposited sediment in its **alluvial** plain, contributing to its evolving delta **system**. Offshore, Louisiana and Texas continue to experience the deposition of sediment from rivers emptying into the Gulf of Mexico.

See Chapter 4: Topograpny for more about the Mississippi River Delta.

Mineral resources in the Coastal Plain have accumulated primarily as a result of sedimentary processes (*Figure 5.15*). Sand and gravel, limestone for cement, crushed stone, and clay are mined throughout the region. Halite, gypsum, and industrial sand are produced in Texas and Louisiana, and **bromine** is extracted from brine wells located in Arkansas and Texas. Sulfur is produced from sources associated with **salt domes** in the Texas coastal plain, and as a byproduct from the processing of oil and gas. **Zeolites**—porous alumino-silicate minerals with cation-exchange properties that can transform hard water into soft water—are mined in south-central Texas.

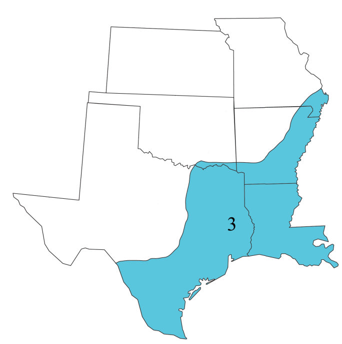
alluvial • *a thick layer of river-deposited sediment.*

system • *a set of connected things or parts forming a complex whole.*

bromine • *a liquid chemical element (Br), with corrosive and toxic properties.*

salt dome • *a largely subsurface geologic structure, consisting of a vertical cylinder of salt embedded in horizontal or inclined sedimentary strata.*

zeolites • *porous alumino-silicate minerals, often formed some time after sedimentary layers have been deposited, or where volcanic rocks and ash react with alkaline groundwater.*



BENT – BENTONITE
BR – BROMINE
BX – BAUXITE
CLAY – CLAY
CS – CRUSHED STONE
DIAM – DIAMOND
D-L – BUILDING LIMESTONE
GEM – GEMSTONES
GYP – GYPSUM
KA – KAOLINITE
SALT – SALT
SG – SAND AND GRAVEL
S-NG – SULFUR FROM NATURAL GAS
S-O – SULFUR FROM OIL
ZEO – ZEOLITE

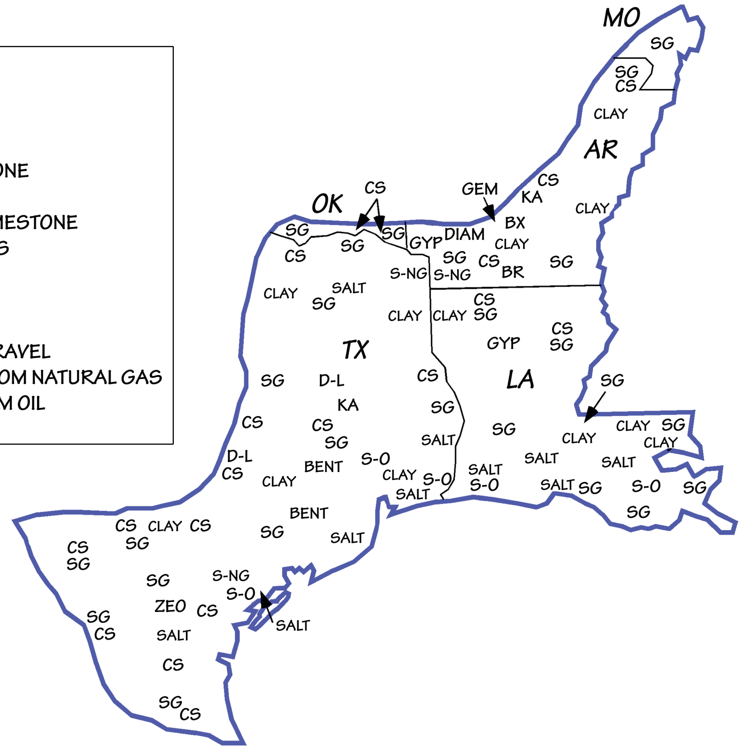


Figure 5.15: Principal mineral resources of the Coastal Plain.

See Chapter 7: Energy to learn how salt domes on the Gulf Coast trap oil and gas.

Although the Coastal Plain is primarily made up of sedimentary strata, small areas of Cretaceous igneous intrusions are located in southwestern Arkansas. Deposits of diamonds and other gemstones do not appear here in commercially viable quantities, but individuals may prospect for and freely remove diamonds and other gemstones they find from the Crater of Diamonds State Park in Pike County, Arkansas. These minerals are found in an ancient volcanic pipe or conduit—the volcano was so explosive that it brought minerals like diamonds,

Coastal Plain clays include fire clay, ball clay, kaolin, and bentonite. Fire clay is used in the production of refractory brick, and ball clay is used to produce ceramic products. Kaolin is used in ceramics, as well as a stabilizing agent or filler in many products. Bentonite is used in drilling muds and can be used as a sealant in instances where it is important to provide a barrier for water flow through rock or sediment.

olivine, and garnet, all of which are formed at great depths, up toward the surface. When the ancient vent exploded, it left behind a crater filled with volcanic material. Today, minerals can be collected from within the weathered crater. Over 75,000 white, brown, and yellow diamonds have been found in the park, including “Uncle Sam,” the largest diamond ever found in the United States, and the Strawn-Wagner Diamond, the world’s only “perfect” diamond (*Figure 5.16*). Other gems and minerals found in the park include amethyst, banded **agate**, **jasper**, peridot, garnet, quartz, calcite, barite, and hematite.

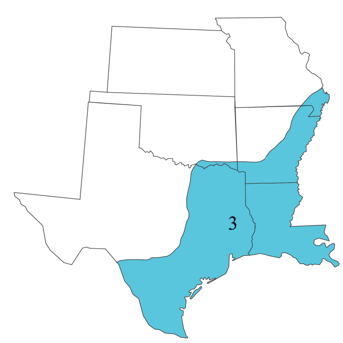
Metals are not currently mined for commercial purposes in the Coastal Plain. While some deposits of metal-bearing minerals do occur in Texas and Arkansas, most of these deposits are either too small or low grade to be profitably mined.

Figure 5.16: The Strawn-Wagner Diamond, found at Crater of Diamonds state Park in 1990, was cut to 1.09 carats and graded “perfect” by the American Gem Society and Gemological Institute of America. It is the only diamond in the world to receive such a grading. Crater of Diamonds State Park purchased the diamond for $34,700, and it is currently on exhibit there.

olivine • *an iron-magnesium silicate mineral* $((Mg,Fe)_2SiO_4)$ *that is a common constituent of magnesium-rich, silica-poor igneous rocks.*

agate • *a crystalline silicate rock with a colorful banded pattern. It is a variety of chalcedony.*

jasper • *a speckled or patterned silicate stone that appears in a wide range of colors.*



5 Mineral Resources

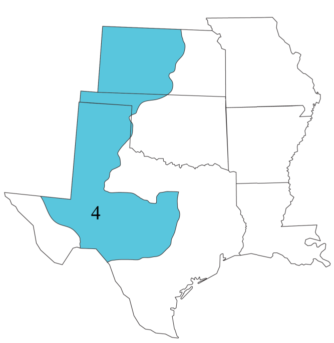
Region 4

Miocene • *a geological time unit extending from 23 to 5 million years ago.*

Pliocene • *a geologic time interval extending from roughly 5 to 2.5 million years ago.*

silt • *fine granular sediment most commonly composed of quartz and feldspar crystals.*

Mesozoic • *a geologic time period that spans from 252 to 66 million years ago.*



Mineral Resources of the Great Plains
Region 4

The near-surface geology and mineral resources of the Great Plains region result from a complex suite of factors (*Figure 5.17*). Marine and terrestrial Cretaceous deposits indicate that several periods of sea level rise and fall were associated with the expansion and contraction of the Western Interior Seaway, which extended from what is now western Illinois to central Utah. Deposition ended with the final retreat of the sea and the uplift of the Rocky Mountains. Uplift in Colorado and New Mexico was renewed in the **Miocene** and **Pliocene**, gently tilting the underlying strata eastward. This tilting is more pronounced in the Texas panhandle than it is in western Kansas. Mountain streams transported and deposited large volumes of eroded sediment onto the plains, resulting in a thick blanket of sand, gravel, **silt**, and clay on top of eroded **Mesozoic** and Permian strata throughout the region. The sands and gravels here are rich in quartz and feldspar from the weathering and erosion of igneous and metamorphic rocks in the Rocky Mountains to the west. Sand, gravel, limestone, and other construction materials are mined throughout the Great Plains, and building stone is quarried from rocks near the Llano Uplift in central Texas.

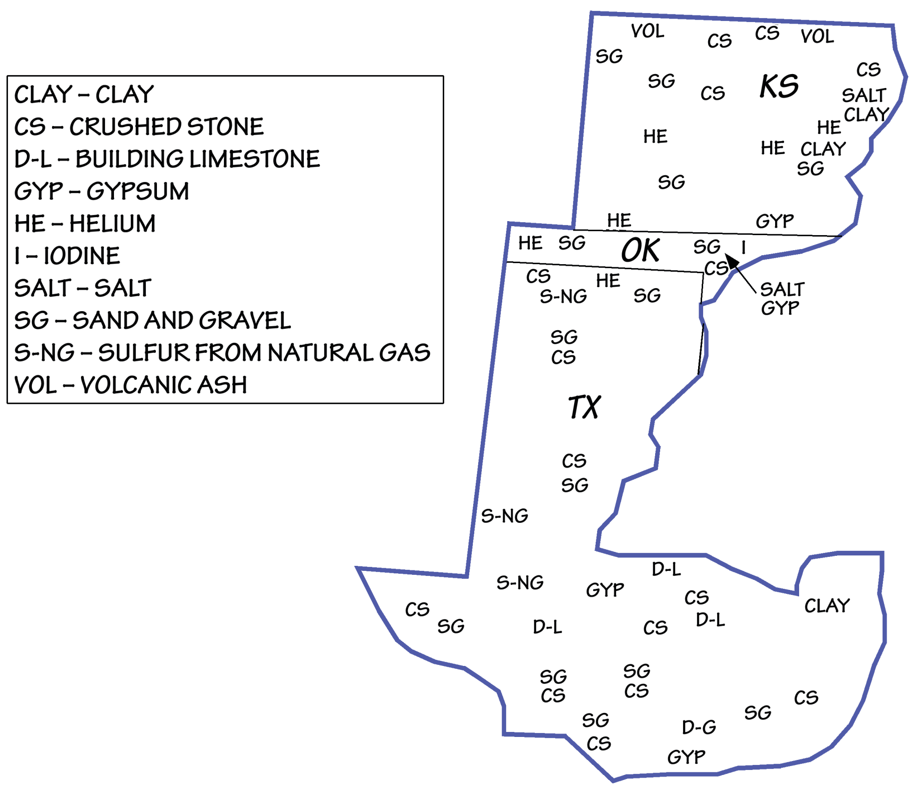


Figure 5.17: Principal mineral resources of the Great Plains.

Cyclical changes in climate during the Quaternary and Holocene initiated episodes of stream erosion, uncovering underlying Permian rocks containing layers of halite and gypsum. In and near river valleys, the movement of groundwater dissolved these soluble minerals, further accelerating the pace of erosion. Sediments were carried and deposited by the wind during drought periods and by streams during wet periods, leading to the development of **soil horizons** rich in deposits of **caliche** *(Figure 5.18)*. Caliche forms when water infiltrates the soil, dissolves soluble material, and evaporates, leaving behind precipitated minerals in the pore space between soil grains. A zone of cemented material forms within the soil if this happens repeatedly. Layers of caliche accumulate to tens of feet in some locations, and multiple layers are commonly found throughout the Great Plains. Caliche is commonly collected for use as an additive in cement.

See Chapter 8: Soils to learn more about caliche and other soils of the Great Plains.

Figure 5.18: A shelf of caliche in central Texas.

Beginning in the Miocene, episodes of volcanism in the Western and Southwestern US produced widespread ashfalls that covered much of the Great Plains. Deposits of silicate **volcanic ash**, as well as sands and gravels derived from the erosion of **basaltic lavas**, are present in the sediments at many locations in the Great Plains, such as the Pearlette Ash Bed in Kansas (*Figure 5.19*). This volcanic ash was mined between the 1930s and 1950s for use in concrete, abrasives, and as a cleaning material.

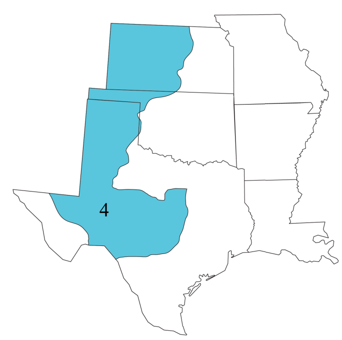
horizons (soil) *• a layer in the soil, usually parallel to the surface, which has physical characteristcs (usually color and texture) that are different from the layers above and below it.*

caliche *• a zone of cemented material within soil, formed when water infiltrates the soil, dissolves soluble materials, and evaporates, leaving behind precipitates in the pore space between soil grains.*

volcanic ash *• fine, unconsolidated pyroclastic grains under 2 mm (0.08 inches) in diameter.*

basalt *• an extrusive igneous rock, and the most common rock type on the surface of the Earth.*

lava *• molten rock located on the Earth's surface.*



5 Mineral Resources

Region 4

__iodine__ • a metallic chemical element (I) that is essential in humans for thyroid hormone production.

__Neogene__ • the geologic time period extending from 23 to 2.6 million years ago.

__fault__ • a fracture in the Earth's crust in which the rock on one side of the fracture moves measurably in relation to the rock on the other side.

__topography__ • the landscape of an area, including the presence or absence of hills and the slopes between high and low areas.

__lithosphere__ • the outermost layer of the Earth, comprising a rigid crust and upper mantle broken up into many plates.

Figure 5.19: The Pearlette Ash deposit in Rice County, Kansas.

Widespread fossil fuel resources in the Great Plains have led to the recovery of several associated elements that are often found alongside gas and oil. Oklahoma is the nation's sole producer of **iodine**, extracted from deeply buried gas brines that occur in the Woodward Trench in northwest Oklahoma. Helium and sulfur are recovered from the Hugoton Gas Field in southwestern Kansas and the panhandles of Oklahoma and Texas. This area contains the largest reserve of helium in the United States; helium collected here is piped to the National Helium Reserve in Amarillo, Texas, for safekeeping and storage (*Figure 5.20*).

Potash is mined commercially from Permian deposits in west Texas. Potash is a name used for a variety of salts containing potassium, with mined potash being primarily potassium chloride. The majority of potash is used as fertilizer, but an increasing amount is being used in a variety of other ways: water softening, snow melting, a variety of industrial processes, as a medicine, and to produce potassium carbonate.

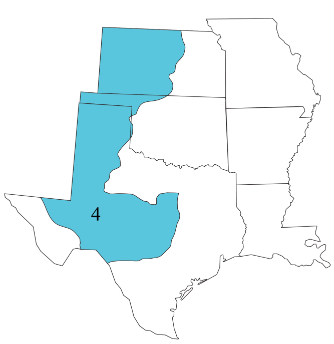


Figure 5.20: The Crude Helium Enrichment Unit located in the Cliffside Gas Field outside Amarillo, Texas.

Mineral Resources of the Basin and Range
Region 5

The Basin and Range province of west Texas is underlain by sedimentary, igneous, and metamorphic rocks ranging in age from Precambrian to **Neogene**. These are exposed in north-south oriented, **fault**-bounded mountain ranges, with considerable amounts of eroded sediment filling the valleys in between ranges (*Figure 5.21*). Taken together, these peaks and valleys (also called horst and graben landscapes) produce basin and range **topography**, formed as a result of stretching and thinning of the **lithosphere** during the **Paleogene**, when crustal extension and faulting led to the formation of almost 400 separate mountain blocks.

See Chapter 4: Topography for more details abou the formation of the Basin and Range.

The mineral resources that are mined commercially in the Basin and Range are limited to **talc** and **bentonite**, industrial minerals used in manufacturing (*Figure 5.22*). Crushed stone, sand, and gravel are quarried as construction materials, and sulfur is extracted from oil at a plant in El Paso County.

Deposits of barite and fluorite have been found in this region, but they are of no commercial value and are not currently mined. Sources of metals (including uranium, tungsten, zinc, tin, iron, **manganese**, lead, silver, **molybdenum**, and mercury) have also been discovered in El Paso County, but these are typically too small to be of commercial value.

Paleogene • *the geologic time period extending from 66 to 23 million years ago.*

talc • *hydrated magnesium silicate, formed during hydrothermal alteration accompanying metamorphism.*

bentonite • *a clay, formed from decomposed volcanic ash, with a high content of the mineral montmorillonite.*

manganese • *a metallic chemical element (Mn).*

molybdenum • *a metallic chemical element (Mo) which has the sixth-highest melting point of any element.*

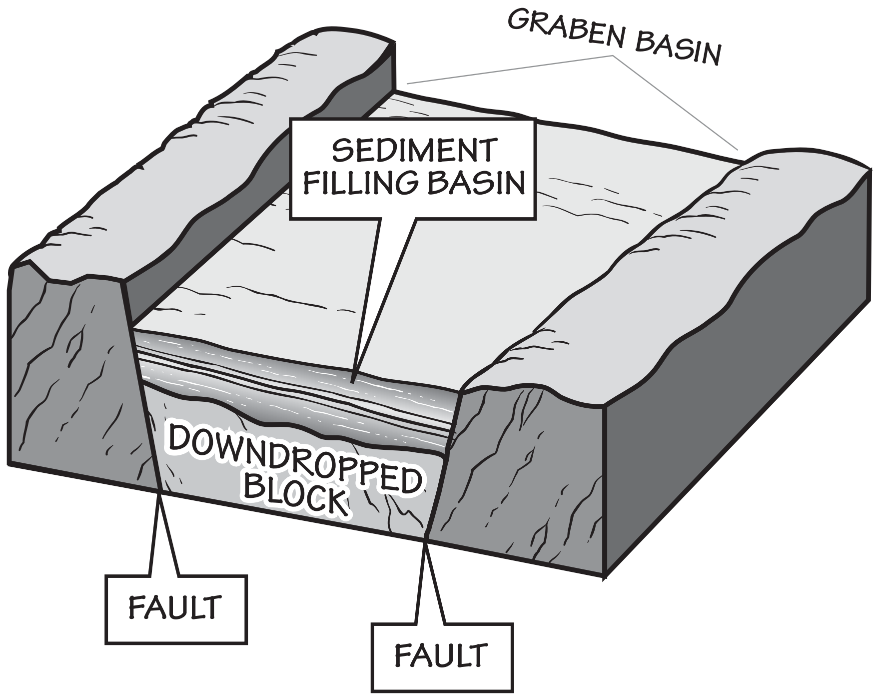


Figure 5.21: An example of basin fill in the Basin and Range.

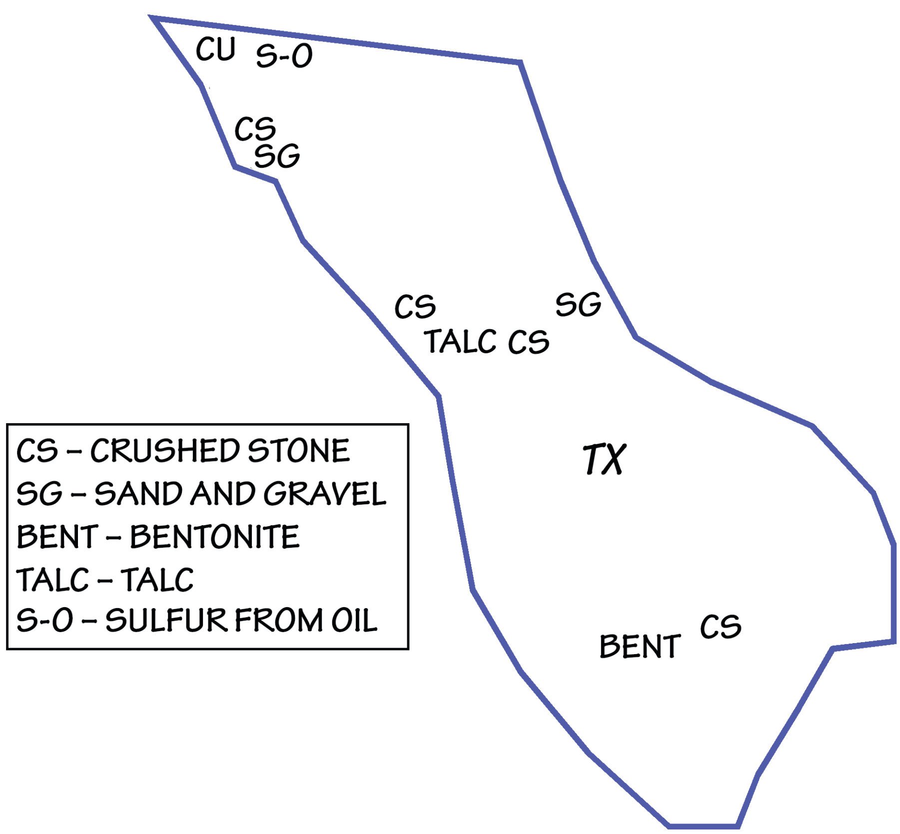


Figure 5.22: Principal mineral resources of the Basin and Range.

Resources

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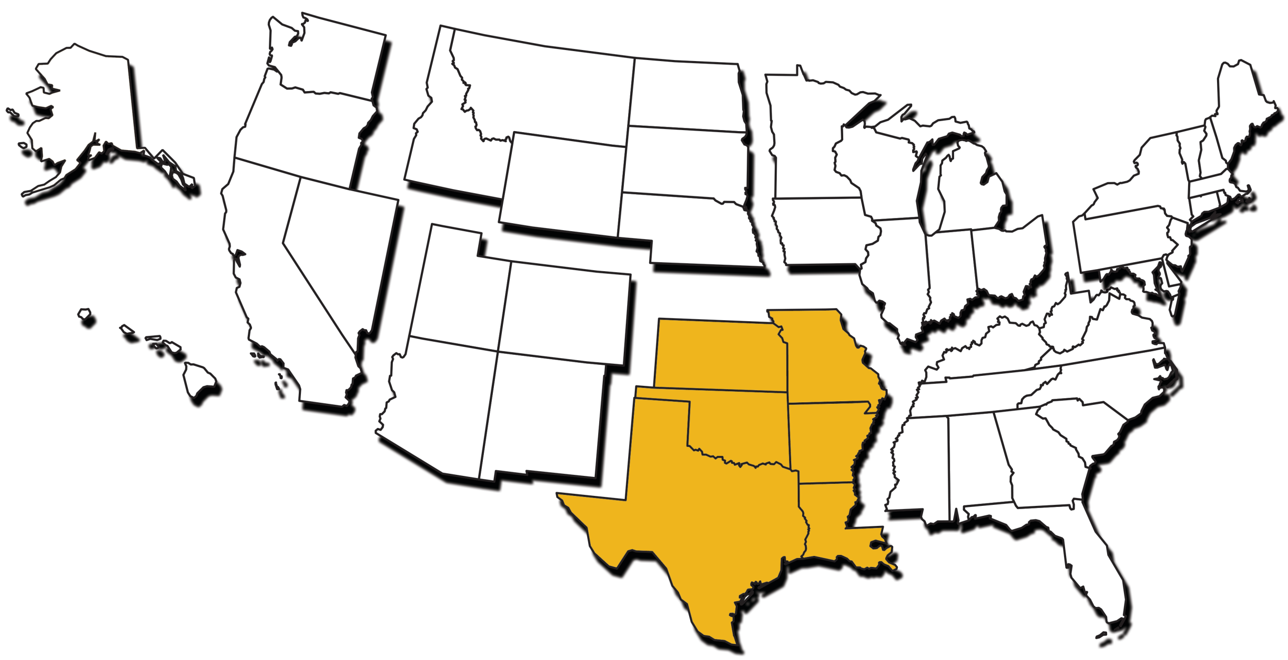
The *Teacher-Friendly* Guide™

to the Earth Science of the South Central US



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On the back cover: Blended geologic and digital elevation map of the South Central US. Each color represents the age of the bedrock at the surface. Adapted from Barton, K. E., D. G. Howell, & J. F. Vigil, *The North America Tapestry of Time and Terrain*, US Geological Survey Geologic Investigations Series I-2781, http://pubs.usgs.gov/imap/i2781.