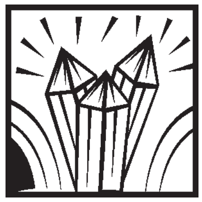

Chapter 5: Mineral Resources of the Northwest Central US

What is a mineral?

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

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**.

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.

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.*

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

sandstone • *sedimentary rock formed by cementing together grains of sand.*

cementation • *the precipitation of minerals that binds together particles of rock, bones, etc., to form a solid mass of sedimentary rock.*

weathering • *the breakdown of rocks by physical or chemical means.*

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

CHAPTER AUTHORS

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Mineral Resources

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

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

copper • *a ductile, malleable, reddish-brown metallic element (Cu).*

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

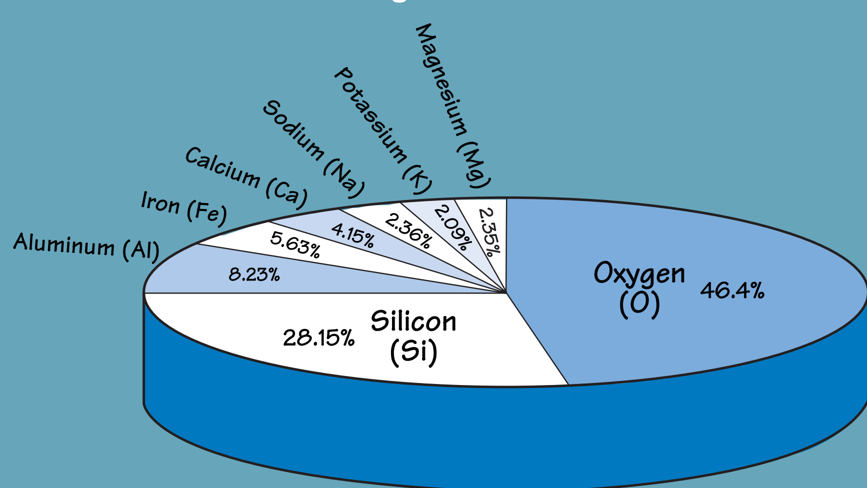
feldspar • *an extremely common, rock-forming mineral found in igneous, metamorphic and sedimentary rocks.*

diamond • *a mineral form of carbon, with the highest hardness of any material.*

gypsum • *a soft sulfate mineral that is widely mined for its use as fertilizer and as a constituent of plaster.*

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 through the 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. 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 Northwest Central.



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** ($CaSO \cdot 2H_2O$). 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 the mineral **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 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 (hardness 5), a penny (hardness 3), and a fingernail (hardness 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. For example, mica

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hardness • *a physical property of minerals, specifying how hard the mineral is.*

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.*

color (mineral) • *a physical property determined by the presence and intensity of certain elements within the mineral.*

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

crystal form • *a physical property of minerals, describing the shape of the mineral's crystal structure.*

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

luminescence • *the emission of light.*

radioactivity • *the emission of radiation by an unstable atom.*

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

double refraction • *the result of light passing through a material that splits it into two polarized sets of rays, doubling images viewed through that material.*

gemstone • *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.*

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

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*.

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

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jade • *a word applied to two green minerals that look similar and have similar properties: jadeite (a kind of pyroxene) and nephrite (a kind of amphibole).*

soapstone • *a metamorphic schistose rock composed mostly of talc.*

beryl • *a white, blue, yellow, green, or pink mineral, found in coarse granites and igneous rocks.*

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

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).*

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.

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 either 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

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*.

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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.*

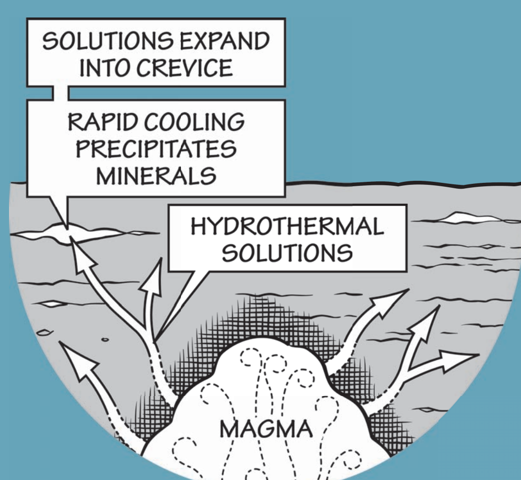
mafic • *igneous rocks that contain a group of dark-colored minerals, with relatively high concentrations of magnesium and iron.*

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." The 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. As 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.



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

pyrite • *the iron sulfide mineral (FeS_2) with a superficial resemblance to gold, known commpnly as "fool's gold."*

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

Regions 1–2

fossil fuels • *fuel for human use that is made from the remains of ancient biomass.*

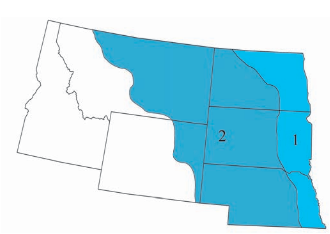
nuclear • *pertaining to a reaction, as in fission, fusion, or radioactive decay, that alters the energy, composition, or structure of an atomic nucleus.*

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

rare earth elements • *a set of 17 heavy, lustrous elements with similar properties, some of which have technological applications.*

wind • *the movement of air from areas of high pressure to areas of low pressure.*

power • *the rate at which energy is transferred, usually measured in watts or, less frequently, horsepower.*



deposits formed through the concentration of a weathering-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**.

Minerals in the Northwest Central

The Northwest Central States are major contributors to the production of mineral resources in the US. In some cases, these states produce the majority of certain minerals used in the US, and they also have the largest deposits of particular mineral types in the world. The Northwest Central provides significant **fossil fuel** resources, along with uranium, which is mined for **nuclear energy**. Several Northwest Central States are also emerging as contributors of **rare earth elements** vital to developing technologies. These valuable metals are useful in a range of technological industries, with applications ranging from manufacturing processes to use in electronics such as HDTVs, computers, hybrid and electric vehicles, solar and **wind power** generators, compact fluorescent lamps, and LEDs.

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

Each region of the Northwest Central US contains significant economic mineral deposits. Mineral resources reflect not only the type of deposit, but also the geological processes that control how and when the minerals were emplaced. Because some geologic events influence more than one region, associated mineral deposits may also cut across regions. In this chapter, the Great Plains and Central Lowland regions have been combined because of similarities in the types of resources found throughout.

Mineral Resources of the Central Lowland and Great Plains

Regions 1 and 2

The Great Plains and Central Lowland compose a **topographically** flat expanse that slopes gently eastward toward the mid-continent. Once partly glaciated, these regions are now characterized by rolling, grassy plains and farmland. The land is interrupted only by river and stream valleys and other erosional features formed during the **Holocene**, with the exception of the Black Hills of Wyoming and South Dakota, and a few outlying **Precambrian** rocks that protrude through the **Quaternary** sedimentary cover. Geologically, the Black Hills are the easternmost outpost of the Rocky Mountains and account for considerable mineral wealth in the Great Plains region (*Figure 5.1*). Beneath the surface cover of **Neogene-** and late Quaternary-aged sediments lies a series of sedimentary and structural basins formed during the **Laramide Orogeny** (about 70 to 40 million years ago) and earlier tectonic events preceding the Laramide.

Mineral Resources 5

Regions 1–2

See Chapter 1: Geologic History to learn about the Laramide Orogeny and other tectonic events that shaped the face of North America.

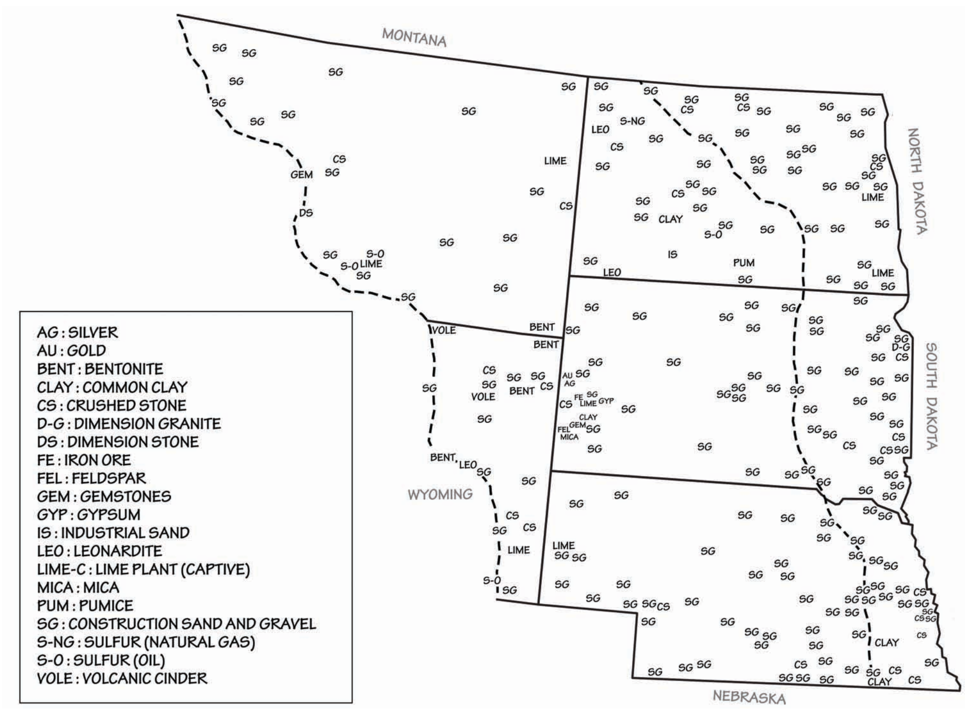


Figure 5.1: Principal mineral resources of the Great Plains and Central Lowland.

Large halite deposits that formed nearly 400 million years ago in the warm, evaporating seas of the **Devonian** are found deep beneath the Williston Basin of North Dakota and Montana. These salt beds represent a massive resource of **potash**, 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: for water softening, for snow melting, in a variety of industrial processes, as a medicine, and to produce potassium carbonate.

Several saline lakes (*Figure 5.2*) on the northern and northwestern plains of North Dakota are "mined" for salts such as sodium sulfate ($NaSO_4$), often in the form of **mirabilite** (also known as "Glauber salts" in its processed form) (*Figure 5.3*). This mineral is used in the manufacture of detergents, paper, and chemical processing, especially in the production of hydrochloric and sulfuric acids. The **playa lakes** that produce these salts were originally **potholes** created during the last glaciation of North Dakota.

See Chapter 6: Glaciers for more about the effect of glaciers on Great Plains topography.

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

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

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).*

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

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

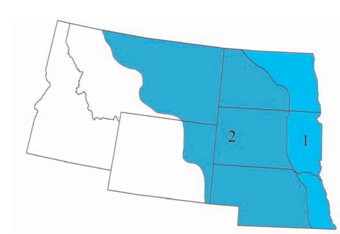


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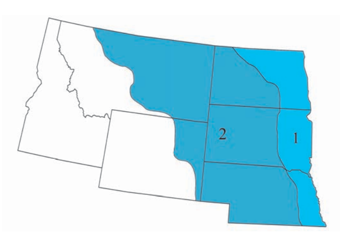
Figure 5.2: A white ring of salt can be seen around the outer rim of this evaporating playa lake in North Dakota. Typically, these shallow lakes fill up with about a foot of water during the spring and slowly dry throughout the summer, depositing layers of evaporite minerals such as halite as they diminish.

Figure 5.3: A crystal of mirabilite.



Halite is mined in two ways. When deposited in thick beds, this 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, where the water is 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*).

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

brine *• see hydrothermal solution; hot, salty water moving through rocks.*

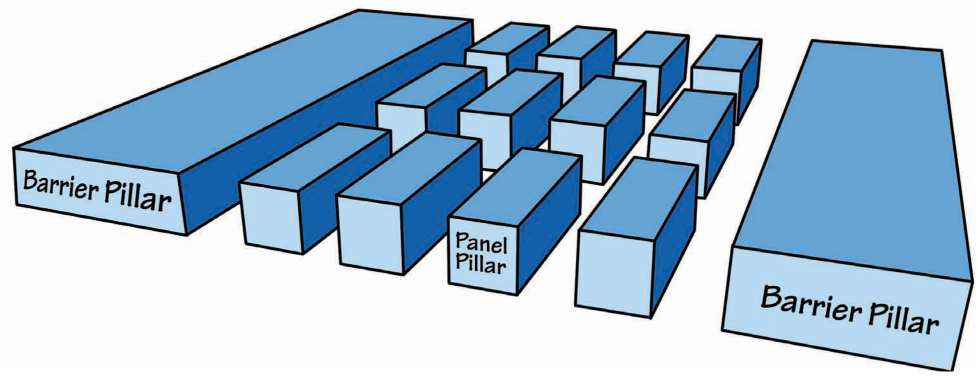


Figure 5.4: In pillar and room mining, the mine is divided up into smaller areas called "panels." Groups of panels are separated from one another by extra-large (barrier) pillars that are designed to prevent total mine collapse in the event of the failure of one or more regular-sized (panel) pillars.

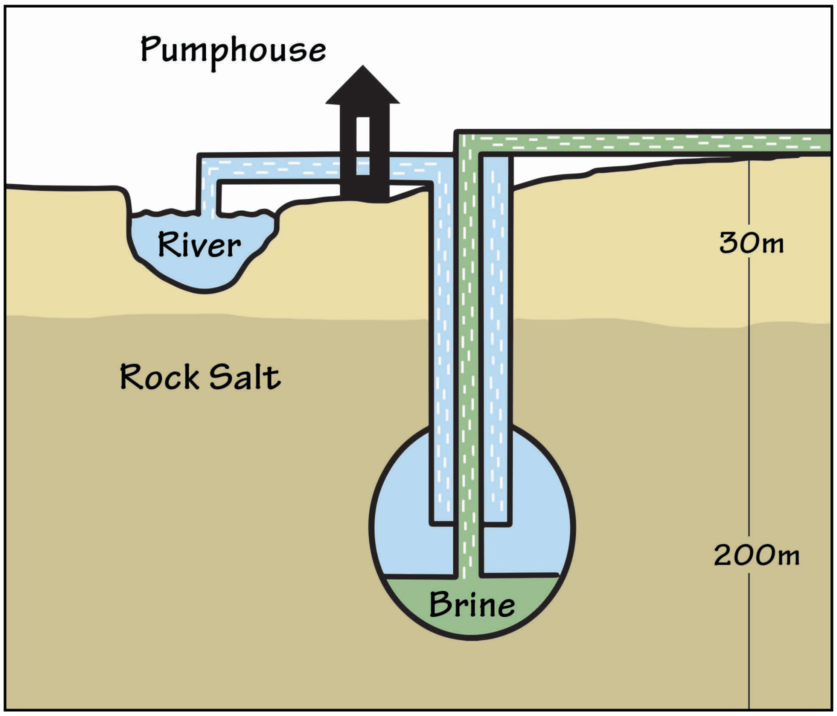
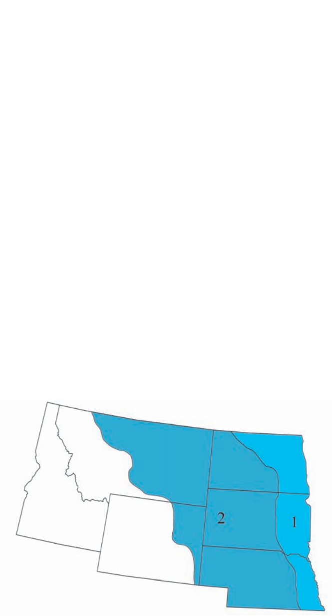


Figure 5.5: An example of solution mining that involves the pumping of fresh water through a borehole drilled into a subterranean salt deposit.



5 Mineral Resources

Regions 1–2

The Great Plains region also produces numerous industrial minerals. These include sand and **gravel**, cement and **lime**, dimension stone, and **leonardite**, a mineral found in association with **lignitic coals** and used as a source of humic acid for agriculture and remediation of polluted water sources. Gravel, sand, and other construction materials are mined extensively throughout the Dakotas and Nebraska.

The gravels of the Great Plains' streams and valleys, especially those of Montana, yield numerous gemstones. The origins of these stones, including one of Montana's state gemstones, the Montana **agate** (*Figure 5.6*), lie in older igneous material worn down by **Pleistocene glaciers** and then redeposited as glacial sediments.

Figure 5.6: The Montana agate or moss agate formed after silica-laden water infiltrated cavities in a volcanic ash bed laid down by an eruption of the Yellowstone hot spot.

In addition, catlinite, a metamorphosed mudstone that is usually reddish in color and also known as "pipestone" or "pipe clay," is found in the 1.7-billion-year-old Sioux Quartzite of southeastern South Dakota. This material has long been used by Native Americans and artists to make sacred pipes and sculptures.

See Chapter 2: Rocks to learn more about pipestone and the Sioux Quartzite.

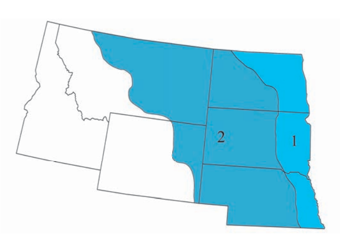
gravel *• unconsolidated, semi-rounded rock fragments larger than 2 millimeters (0.08 inches) and smaller than 75 millimeters (3 inches).*

lime *• an inorganic white or grayish-white compound made by roasting limestone (calcium carbonate, $CaCO_3$) until all the carbon dioxide (CO_2) is driven off.*

lignite *• a soft, brownish-black coal in which the alteration of plant matter has proceeded farther than in peat but not as far as in bituminous coal.*

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

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



Mineral Resources 5

Regions 1–2

Outcroppings of **Proterozoic** and **Archean** granites and metamorphic rocks in Wyoming's Hartville Uplift are similar in nature to those found in the adjacent Laramie Mountains of the Southern Rockies, and are located on the divide that marks the northern end of the Denver Basin. Ores of tin (such as the simple **oxide** cassiterite, SnO_2, *Figure 5.7*), iron (as hematite), copper, silver, uranium, and gold were emplaced here through hydrothermal processes during the late **Cretaceous** to **Paleogene** periods.

Figure 5.7: Bipyramidal crystals of cassiterite (SnO_2, tin oxide). Each crystal in the photo is approximately 30 millimeters (1.1 inches) across.

The Great Plains of Nebraska is home to the largest known deposit of the rare earth metal niobium, found near Elk Creek. Over 100 million tons of this **heat**-resistant element was emplaced here in a 545-million-year-old (late Precambrian) deposit of carbonatite (a type of a carbonate-rich igneous and volcanic rock), intruded into 1.8-billion-year-old metamorphic **gneisses**, **schists**, and granites. Niobium is often used in steel alloys, rocket engines, and the manufacture of superconducting materials, such as superconducting magnets for MRI scanners.

Economic deposits of uranium and **vanadium** are found in **Paleocene** and **Eocene** sediments of the southern Powder River Basin of Wyoming, and in the **Oligocene** rocks of northwest Nebraska at the Crow Butte mine. In 2013, extraction plants in Wyoming alone provided 81% of the nation's total uranium production. The lignitic coals of North Dakota also contain significant uranium content, and economic quantities of uranium have been produced from these coals. Uranium is primarily used for nuclear power, while vanadium's main use is in the production of specialty steel alloys.

See Chapter 7: Energy for more information on uranium and other energy resources found in the Northwest Central.

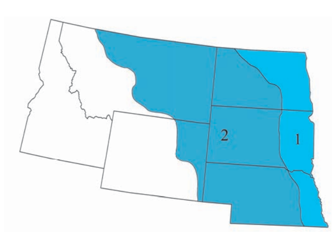
Pleistocene • *a subset of the Quaternary, lasting from 2.5 million to about 11,700 years ago.*

glacier • *a body of dense ice on land that does not melt away annually and has sufficient mass to move under its own weight.*

Proterozoic • *a geologic time interval that extends from 2.5 billion to 541 million years ago.*

Archean • *a geologic time period that extends from 4 billion to 2.5 billion years ago.*

oxidation • *a chemical reaction involving the loss of at least one electron when two substances interact.*



5 Mineral Resources

Regions 1–2

The Black Hills of South Dakota and Wyoming represent an anomaly with respect to Great Plains **physiography**: they share their geologic history with the ranges of the Rocky Mountain region farther west, and thus are often considered to be the easternmost outpost of the Rockies. The Black Hills are an eroded, dome-shaped **uplift** that formed during the Laramide Orogeny, near the end of the Cretaceous or early Paleogene. Standing roughly 900 meters (3000 feet) above the rest of the Great Plains, they contain an exposed core of Archean and Proterozoic metamorphic, granitic, and pegmatitic rocks. The Archean rocks are approximately 2.5 to 2.7 billion years old, while the Proterozoic granites are roughly 1.7 billion years old. A sequence of sedimentary rocks, covering more than 400 million years of Earth's history, is also exposed in these hills. Numerous mineral deposits occur in the Black Hills, the exploration and development of which led to the area's settlement. In 1874, General George Armstrong Custer's expedition discovered placer gold in Black Hills streams, just two years before the Battle of the Little Bighorn. Minerals containing gold, silver, **molybdenum**, tin, iron, copper, lead, uranium, vanadium, and rare earth elements are found in rocks ranging from Proterozoic through Quaternary in age.

Much of the gold produced in the Black Hills came from the Homestake Mine in Lead (pronounced "leed"), South Dakota, where it is found in late Cretaceous to **Cenozoic** veins that were intruded into early Proterozoic rocks during the Laramide Orogeny. Homestake was originally an underground mine that reached a depth of over 2400 meters (8000 feet), and it was once ranked as the deepest mine in the Western Hemisphere. Considered a "world-class" gold deposit, the mine was discovered in 1876 and sold in 1877 for the 2014 equivalent of $1.5 million dollars. It was later developed as an open pit operation (*Figure 5.8*). Before its eventual closure in 2002, the Homestake Mine produced over 1.1 billion grams (40 million ounces) of gold—worth over $50 billion in today's gold prices! Outside of the Homestake area, a number of Paleocene and Eocene-aged igneous intrusions occur in the northern Black Hills. These also carry gold, sometimes in commercial quantities.

On the northwestern edge of the Black Hills, deposits of **thorium**, a radioactive rare earth element, have been found in the Bear Lodge Mountains near the town of Sundance, Wyoming. These Eocene-aged deposits are intruded into **Paleozoic** and **Mesozoic** sedimentary rocks. Thorium is considered to be a "critical" rare earth element, meaning one in limited supply. It has potential applications in next-generation nuclear reactors that could be safer and more environmentally friendly than current uranium reactors.

The Black Hills are also well known for deposits of beryllium, lithium, tin, tungsten, and potassium-bearing minerals. These minerals are found in early Proterozoic pegmatites, some of which contain giant crystals of **spodumene** (lithium aluminum inosilicate, *Figure 5.9*). Lithium is important to the manufacture of modern batteries, especially those used in computers, cell phones, and electric and hybrid vehicles.

physiography • *a subfield of geography that studies the Earth's physical processes and patterns.*

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

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

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

thorium • *a radioactive rare earth element.*

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

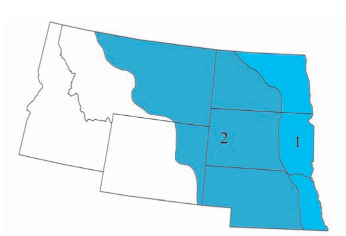


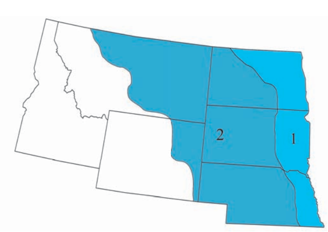
Figure 5.8: Gold veins are visible in the Homestake Mine open pit, Lead, South Dakota.

Figure 5.9: Giant spodumene crystals in the pit wall of Etta Mine, Keystone, South Dakota, in 1916. Note miner (right) for scale.

Regions 1–2

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

spodumene • *a translucent pyroxene mineral (lithium aluminum inosilicate) occurring in prismatic crystals, and a primary source of lithium.*



5 Mineral Resources

Region 3

Mineral Resources of the Rocky Mountains

Region 3

The Rocky Mountain region is somewhat discontinuous, containing a scattered collection of mountain ranges and rocks of varying geologic origins and ages. The region's mineral resources are found within its four physiographic subregions: the Northern, Middle, and Southern Rockies, as well as the Wyoming Basin (*Figure 5.10*).

See Chapter 4: Topography for more information about the physiographic subregions of the Rocky Mountains.

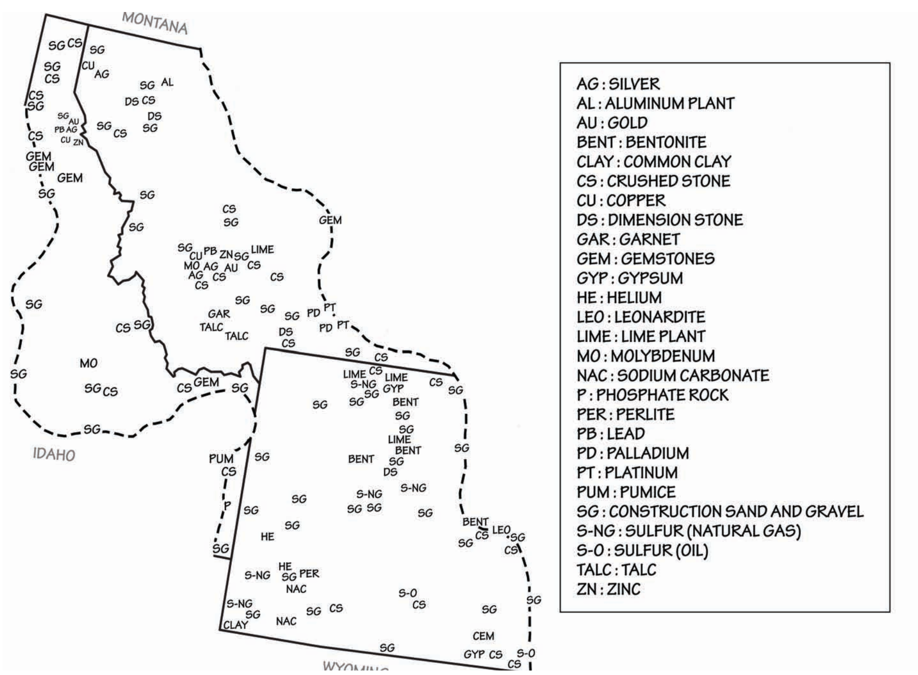
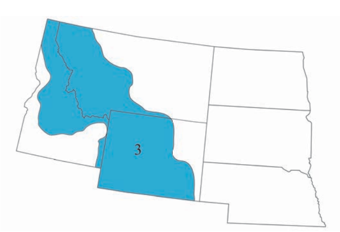


Figure 5.10: Principal mineral resources of the Rocky Mountains region.

The Northern Rocky Mountains

The Northern Rockies subregion is located primarily in western Montana and eastern Idaho, and includes the massive Idaho Batholith, the Boulder Batholith, the Stillwater Igneous Complex at Nye, Montana, and the famous Coeur d'Alene mining district in the metamorphosed Precambrian

See Chapter 2: Rocks to learn more about Belt Series rocks from the Belt and Snowy Pass supergroups.



sediments of northernmost Idaho. Many of the area's mineral resources are concentrated within its **batholiths**, igneous complexes, and Precambrian sedimentary "Belt Series" rocks.

The Boulder Batholith, a **pluton** emplaced during the early Laramide Orogeny at Butte, Montana, has been called "the richest hill on Earth," and it was a major producer of copper from about 1880 until 2004. The mines at Butte produced over 9.5 billion kilograms (21 billion pounds) of copper along with considerable quantities of **zinc**, lead, **manganese**, silver, gold, and molybdenum. The Berkeley Pit, one of Butte's major open pit mines, produced about 450,000 kilograms (one billion pounds) of copper, silver, and gold during its operation from 1955 to 1982 (*Figure 5.11*). Today, the pit is classified as a Superfund site due to the infiltration of groundwater that has become highly acidic and laden with heavy metals and dangerous chemicals leached from the surrounding rock.

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.

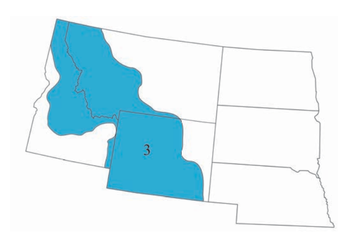
Figure 5.11: The Berkeley Pit and associated tailings pond. This open pit copper mine reaches a depth of about 540 meters (1780 feet), and is filled to a depth of about 270 meters (900 feet) with metal-laden acidic water. The mine is 1.6 kilometers (1 mile) long and 0.8 kilometers (0.5 miles) wide.

batholith *• a large exposed structure of intrusive igneous rock that solidified at depth, and covers an area of over 100 square kilometers (40 square miles).*

pluton *• a large body of intrusive igneous rock that formed under the Earth's surface through the slow crystallization of magma.*

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

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



5

Mineral Resources

Region 3

chromium • *a lustrous, hard, steel-gray metallic element (Cr), resistant to tarnish and corrosion.*

fuel • *a material substance that possesses internal energy that can be transferred to the surroundings for specific uses.*

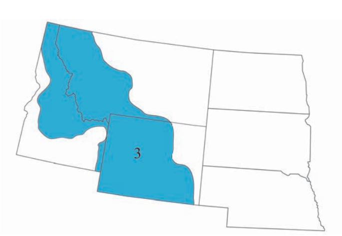
nickel • *a ductile, silvery-white metallic element (Ni) generally found in combination with iron.*

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 undertaken 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.

The Stillwater Complex in the Beartooth Mountains northeast of Yellowstone is a 2.7-billion-year-old layered mafic intrusion, an inverted umbrella-shaped intrusive body that contains distinct layers. It is a major producer of **chromium** and the rare precious metals palladium, platinum, and other associated metal ores. Platinum group metals are used in many industrial applications, including the manufacture of catalytic converters for vehicles, data storage devices, anti-cancer drugs, fiber optic cables, gasoline additives, and **fuel** cells. Quantities of gold, silver, copper, and **nickel** are also recovered from this complex.



The Idaho Batholith, which was emplaced in multiple phases during the **Sevier Orogeny**, has three major lobes: the Atlanta lobe (100 to 75 million years ago), the Kiniksu Lobe (94 million years ago), and the Bitterroot Lobe (85 to 65 million years ago). Several million ounces of gold and silver, along with quantities of lead, zinc, and **antimony** in the form of the mineral stibnite (antimony sulfide, Sb_2S_3), have been mined from this batholith.

The Coeur d'Alene (Silver Valley) mining district of Idaho occurs within 1.4-billion-year-old metamorphosed sediments. These rocks are interpreted by some as having been deposited in a failed **rift basin** in the continental crust, probably similar to, but less developed than, the East African rift zone. Gold was discovered on the Coeur d'Alene River in 1874, which led to a short-lived gold rush. In 1884, the first major discovery of lead-zinc-silver ores was made, and within a year several major mines were in operation. The district has produced over 51 billion grams (1.8 billion ounces) of silver, 2.7 million metric tons (3 million tons) of zinc, and 7.3 metric tons (8 million tons) of lead from 90 mines, some of which reach a depth of roughly 2400 meters (8000 feet). Two or three of these mines still produce today. The area is also famous for its many large specimens of pyromorphite, a crystalline lead **phosphate** mineral (*Figure 5.12*)

See Chapter 1: Geologic History for more about rifting and failed rifts.

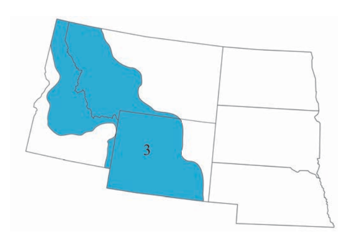
Figure 5.12: Pyromorphite from the Bunker Hill Mine, Coeur d'Alene mining district, Idaho. This mineral is found in association with lead-rich ores.

Sevier Orogeny *• a mountain-building event resulting from subduction along the western edge of North America, occurring mainly during the Cretaceous.*

antimony *• a lustrous gray metallic element (Sb), mainly found in nature as the sulfide mineral stibnite (Sb_2S_3).*

rift basin *• a topographic depression caused by subsidence within a rift.*

phosphate *• an inorganic salt of phosphoric acid, and a nutrient vital to biological life.*



5 Mineral Resources

Region 3

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.*

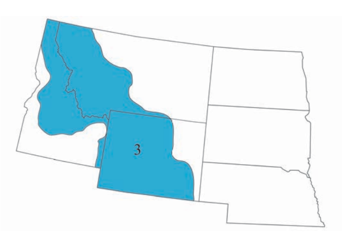
Miocene • *a geological time unit extending from 23 to 5 million years ago.*

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

corundum • *an aluminum oxide mineral (Al_2O_3) that is, after diamond, the hardest known natural substance.*

dike • *a sheet of intrusive igneous or sedimentary rock that fills a crack in a pre-existing rock body.*

opal • *a silicate gemstone lacking a rigid crystalline structure.*



Mining Districts

Mines in the American West are grouped into "mining districts," defined by their mineral resources as well as by natural boundaries such as rivers. Districts were originally defined informally by miners, but in the late 19th century the US federal government developed regulations for staking claims, property ownership, and mining itself. Some districts have been defined by political boundaries.

In Lemhi County, Idaho, the most important mineral districts produce or have produced gold, silver, lead, copper, cobalt, nickel, tungsten, and molybdenum (*Figure 5.13*). The Lemhi Pass area of Idaho and Montana is also one of the principal US sources of rare earth elements, including thorium. The area's complex geology contains elements of crustal extension as well as thrust **faulting** associated with mountain building. The eastern portion of this area is dominated by "thin-skinned" thrusts (low-angle faults through surface sedimentary layers) that appear to contain controlled ore emplacement that occurred in two different phases. The first phase corresponds with the Sevier Orogeny (about 140 to 50 million years ago) and overlaps the Laramide Orogeny (about 70 to 40 million years ago). The second phase of emplacement began in the **Miocene** and **Pliocene**, corresponding to later phases of the formation of the Basin and Range (about 35 to 12 million years ago or later).

The Northern Rockies also produce high-quality gemstones. One of the area's more famous gemstone localities is the Yogo Sapphire deposit in the Little Belt Mountains of Montana. Sapphire is otherwise known as the mineral **corundum** (Al_2O_3). Discovered in 1876, the Yogo mine was not recognized as a sapphire deposit until 1895, when Tiffany's of New York pronounced Yogo sapphires to be "the finest precious gemstones" in the United States. Yogo sapphires, produced from greenish colored, igneous **dikes** called lamprophyres, range in color from cornflower blue to purple. Their coloring is due to traces of iron and titanium in the corundum's crystal lattice. Montana also produces sapphires from three other major areas: the Missouri River area, which has yielded large blue-green sapphires of up to twenty carats in size, and the Rock Creek and Dry Cottonwood areas, which yield smaller, rounded gems that come in a variety of intense colors, from green and blue to pink and yellow (*Figure 5.14*). The abundance of sapphires and other gem and mineral resources found in Montana has led to it being nicknamed the "Treasure State."

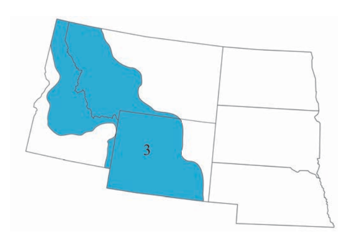
The Rocky Mountains of Idaho are also renowned for their production of gemstones, including garnets, **opal**, topaz, jade, zircon, agate, and tourmaline. Idaho, as the "Gem State," is especially famous for its gem-quality star garnets (*Figure 5.15*), an extremely rare form of garnet that is found in commercial

Figure 5.13: The Thompson Creek Molybdenum Pit Mine in Custer, Idaho. The mill here processes about 27,200 metric tons (30,000 tons) of ore per day, producing molybdenum sulfide concentrate that is later converted to specialty materials.

Figure 5.14: A variety of cut sapphires from Montana.

soil • *the collection of natural materials that collect on Earth's surface, above the bedrock.*

quantity in only two places in the world, Idaho and India. Idaho's garnets are found in pegmatites, schist, and other metamorphic rocks; although they can be removed from these rocks or the surrounding **soil**, they are most often collected from placer deposits in streams. Additionally, opals are produced in commercial quantities from mines near Spencer, Idaho.



5 Mineral Resources

Region 3

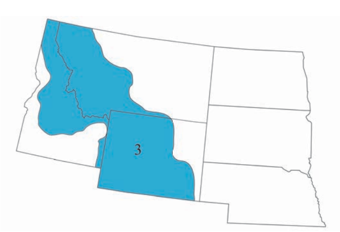
Figure 5.15: The star garnet, Idaho's state gem, is a rare garnet that refracts light in the shape of a 4- or 6-pointed star when polished.

The Middle Rocky Mountains

Geologically, the Middle Rockies subregion represents a somewhat scattered and discontinuous collection of mountain ranges that vary in geologic origin and age. Many of these ranges formed during various intervals from the Cretaceous to the Miocene, and have Archean rocks at their core. They contain faults ranging from low-angle thrust faults to Basin and Range-type block faulting. At least one range owes its origin to volcanic and igneous activity rather than uplift.

See Chapter 4: Topography to learn about the formation of the various mountain ranges and geologic features in the Middle Rocky Mountains.

The Teton Range near Jackson Hole, Wyoming is composed largely of Archean gneisses and has not yielded significant mineral deposits. The area, protected as part of Grand Teton National Park, formed around nine to six million years ago through Basin and Range-type extension. Southeast of Jackson Hole lie the Gros Ventre Range, the Wind River Range, and the Granite Mountains. These mountains contain some of the oldest known rocks exposed on the North



American continent. Archean granitic gneisses in these ranges have been dated at up to approximately 3.8 to 3.65 billion years old, along with metamorphosed sediments and volcanics (**greenstone belts**) at roughly 3.3 to 2.6 billion years old. Mining districts developed on these **terranes** yield gold, copper, and minor silver. To the north of the Wind River Range and east of Yellowstone National Park and the Tetons is the Absaroka Volcanic Plateau, which formed some 50 to 34 million years ago during the Eocene. The volcanics of this range are unrelated to those of the nearby and much younger Yellowstone Plateau (about 2 to 0.6 million years old) and are home to several mining districts that have yielded copper, molybdenum, lead, zinc, gold, and silver from what are known as copper-gold **porphyry** complexes. The Sunlight, New World, Kirwin, and Stinking Water districts in the Absaroka Mountains all contain placer gold deposits that can be recovered by panning, sluicing, and dredging (*Figures 5.16, 5.17*). Although limited commercial efforts have been put into this area, gold prospecting is a popular recreational activity here.

The Bighorn Mountains, which lie east of the Absarokas and the Bighorn Basin, were uplifted during the Laramide Orogeny and contain Archean rocks at their core. The area has thus far proven somewhat uneconomically viable, although gold is known here, and placer deposits were likely mined by the Spanish in the 1700s and by Native Americans prior to the arrival of the Spaniards. The

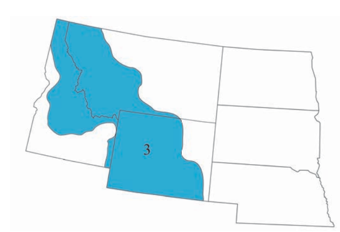
How is gold mined?

Gold can be extracted using a wide variety of methods. *Placer mining* searches stream bed deposits for minerals moved from their original source by water. Placer deposits can be mined in several different ways: *panning*, which uses a small, hand-held pan to manually sort the gold from sand and rock fragments; *sluicing*, in which water is sent through a man-made stepped channel that traps particles of gold; or *dredging*, where a large machine uses mechanical conveyors or suction to pull loads of material from the river bottom and then dump smaller fragments into a sluice box. Gold that is trapped in layers of rock may be excavated through *underground mining*, where tunnels or shafts are used to locate the ore, or by *open pit mining*, which is used when deposits are relatively close to the surface.

greenstone belt • *a series of interlayered volcanic and sedimentary rocks that have been metamorphosed into meta-sedimentary rocks and amphibolite.*

terrane • *a piece of crustal material that has broken off from its parent continent and become attached to another plate.*

porphyry • *an igneous rock consisting of large grained crystals, or phenocrysts, cemented in a fine-grained matrix.*



Region 3

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

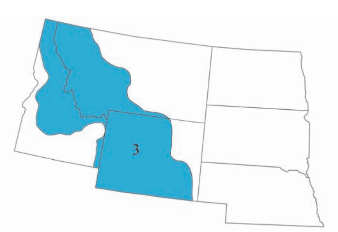
pyroxene • *dark-colored rock-forming silicate minerals containing iron and magnesium.*

inclusion • *a fragment of older rock located within a body of igneous rock.*

Figure 5.16: Gold dust (placer gold) found near Cody, Wyoming.

area also contains a relatively large deposit of rare earth elements—including dysprosium, used in high-performance magnets and compact fluorescent bulbs—and minor amounts of uranium have also been produced in the Bighorns.

The Middle Rockies of Wyoming, especially the Granite and Seminole Mountains, are famous for "Wyoming Jade," otherwise known as nephrite jade (the mineral nephrite, an **amphibole** group mineral), which is highly prized for its deep apple-green color and transparency and is considered to be some of the finest nephrite in the world (*Figure 5.18*). It ranges in color from deep green to a light yellowish variety known as "mutton fat." Nephrite jade should not be confused with the pale green "true" jade (the mineral jadeite of the **pyroxene** mineral group). These two minerals are so similar that they were not distinguished from one another until 1863. Both minerals are formed during metamorphism, and Wyoming Jade is found within granites and gneisses where amphibole **inclusions** were altered by hydrothermal fluids.



The Wyoming Basin

The Wyoming Basin subregion covers most of southwestern Wyoming, and it effectively separates the Southern Rockies from the Middle Rockies. The

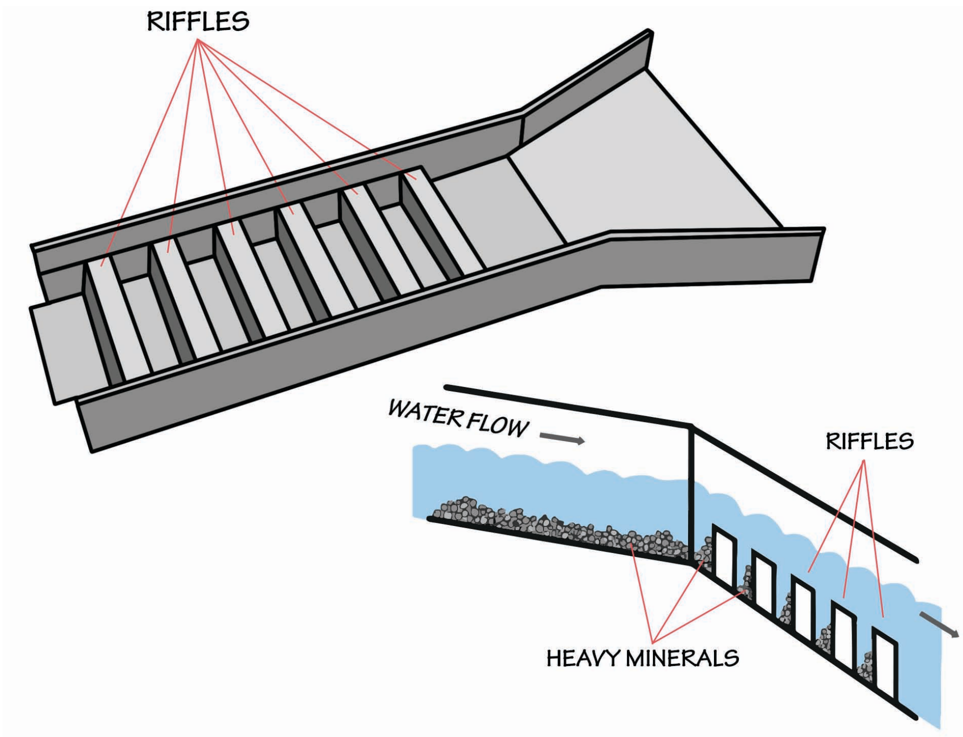
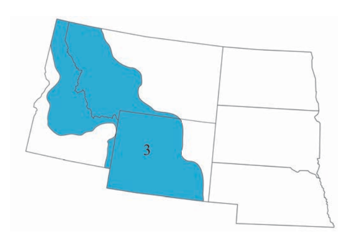


Figure 5.17: A sluice is a long tray through which water that contains gold is directed. The sluice box contains riffles, or raised segments, which create eddies in the water flow. Larger and heavier particles, such as gold, are trapped by the eddies and sink behind the riffles where they can later be collected.

Figure 5.18: Nephrite jade from Crooks Mountain, central Wyoming.



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

accretion • *the process by which a body of rock increases in size due to the addition of further sedimentary particles or of large chunks of land.*

craton • *the old, underlying portion of a continent that is geologically stable relative to surrounding areas.*

quartzite • *a hard metamorphic rock that was originally sandstone.*

breccia • *a pyroclastic rock composed of volcanic fragments from an explosive eruption.*

Leucite Hills, at the northeast end of the Rock Springs Uplift, have yielded potassium- and magnesium-rich minerals as well as rare earth elements from young (about 1-million-year-old) **lamproites**. These rocks are rare and sometimes include diamond-bearing igneous rocks chemically similar to kimberlites; only 25 such occurrences are known worldwide. In the southwest part of the Wyoming Basin, indicator minerals associated with diamond-bearing kimberlites have been found in surface sediments. The presence of indicator minerals suggests the presence of diamond pipes beneath the sedimentary cover in this area. A number of uranium deposits are found in the northeastern part (Great Divide Basin) of the Wyoming Basin, where several new mines are in the process of receiving permits.

The Green River Basin in Wyoming is home to the world's largest deposit of trona, a non-marine evaporite mineral that is mined as a primary source of sodium carbonate. The layered deposits in Wyoming, which lie 240 to 490 meters (800 to 1600 feet) below ground, were deposited in a lake during the Paleogene. Trona is a common food additive and water softener, and it also has applications in the manufacturing of paper, textiles, glass, and detergents.

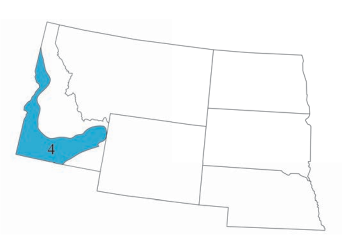
The Southern Rocky Mountains

In Wyoming, this subregion is defined by the Laramie and Medicine Bow mountains, and the Sierra Madre. Within this area lies the geologic boundary between early **accreted** terranes of the Proterozoic, at 1.9 to 1.8 billion years old, and very old (2.4- to 2.2-billion-year-old) early Proterozoic metamorphic rocks originally deposited as **cratonic** sediments. The Southern Rockies of Wyoming have produced gemstones as well as precious and base metals. Iron and diamond-bearing kimberlites are found in the Laramie Range and the State Line District, spanning the Wyoming-Colorado border. More than 130,000 diamonds have been recovered since they were first discovered here in 1975.

Gold and silver have been mined in the Gold Hill District and other parts of the Medicine Bow Mountains, and also in the Purgatory Gulch area of the Sierra Madre west of the Medicine Bows (*Figure 5.19*). These mountains were prospected extensively from the 1800s up through the Great Depression, when metal prices dropped to the point at which mining was no longer profitable. Rich copper deposits are found in the Ferris-Haggerty District of the Sierra Madre where massive chalcocite (copper sulfide, Cu_2S) and (minor) chalcopyrite (copper-iron sulfide, $CuFeS_2$) ores are found in **quartzite breccia**. Uranium is produced from the Shirley Basin immediately west of the Laramie Range.

Mineral Resources of the Columbia Plateau

Region 4



The Columbia Plateau, dominated by the Miocene-aged Columbia Flood Basalts, is present in only a small area of the Northwest Central US, in far west-central Idaho. This area does not contain any mineral occurrences of note. The

Mineral Resources

5

Regions 3–4

Figure 5.19: The Carissa Gold Mine, which operated from 1867 to 1954. In 2003, the state of Wyoming restored the mine and mill as a historic attraction.

hot spot • *a volcanic region thought to be fed by underlying mantle that is anomalously hot compared with the mantle elsewhere.*

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

rhyolite • *a felsic volcanic rock high in abundance of quartz and feldspar.*

Snake River Plain of southern and central Idaho, which marks the movement of the North American plate over the Yellowstone **hot spot**, has only a few small associated gold placers. However, the volcanic and igneous activity associated with the formation of this feature may have contributed to the formation of hydrothermal gold deposits in nearby mining districts. Gold and other precious metals, as hydrothermal deposits, are also found in the hot springs of the Yellowstone Plateau, which is the terminus of the Snake River Plain (*Figure 5.20*).

See Chapter 2: Rocks to find out how the Columbia Flood Basalts were formed.

The most notable mineral deposit near the Snake River Plain is the Silver City-De Lamar District, a remote area in southwestern Idaho. This district has produced over 28 million grams (1 million ounces) of gold and more than 910 million grams (32 million ounces) of silver from selenium-rich ores emplaced about 16 million years ago in the middle Miocene. Common minerals and metals found here include gold, silver, naumannite, aguilarite, and argentite, and the ruby silver minerals cerargyrite and acanthite. Today, De Lamar and Silver City are both ghost towns, largely abandoned after their nearby mines were depleted.

Bruneau Canyon, in Owyhee County, southwestern Idaho, produces large quantities of **jasper**. This silicate mineral precipitated within the cavities and fractures of **rhyolite** flows, and it ranges in color from brown to reddish cream.

5 Mineral Resources

Regions 4–5

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.*

pumice *• a pyroclastic rock that forms as frothing and sputtering magmatic foam cools and solidifies.*

obsidian *• a glassy volcanic rock, formed when felsic lava cools rapidly.*

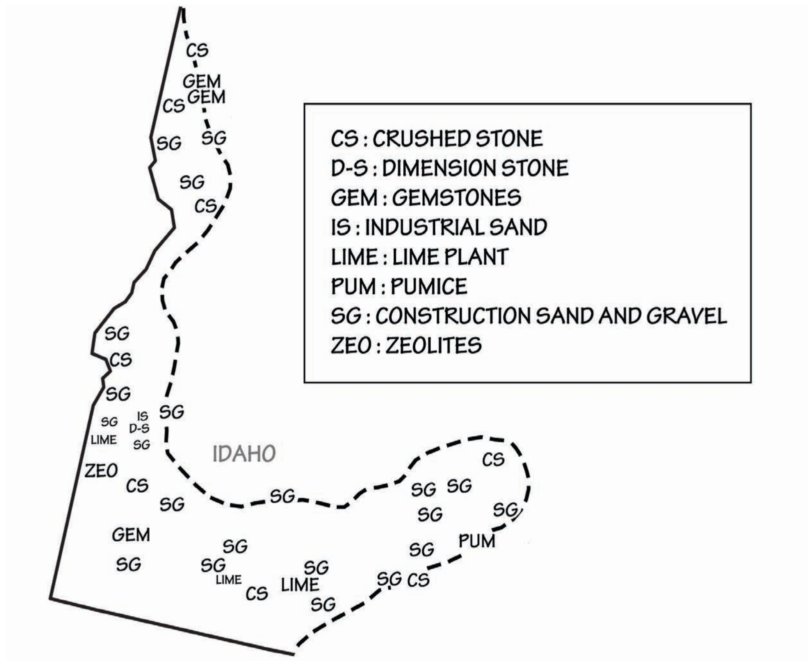


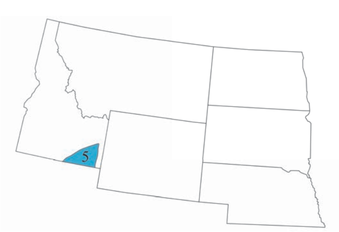
Figure 5.20: Principal mineral resources of the Columbia Plateau.

Zeolites—porous alumino-silicate minerals with cation-exchange properties that can transform hard water into soft water—are mined along the Idaho-Oregon border. These deposits were created from alkaline volcanic ejecta that was deposited into a fresh or salt water source.

Mineral Resources of the Basin and Range

Region 5

The Basin and Range region, with its distinctive horst and graben features formed by extensional tectonics, is present only in southeastern and east-central Idaho. Aside from a few gold placer deposits associated with the southern margin of the Snake River Plain, the Basin and Range region in Idaho contains only one metallic ore deposit of even marginal significance: the Mount Pigsah District in the Caribou Mountains, which produced some 454,000 grams (16,000 ounces) of gold from ore bodies intruded into Mesozoic sediments. In addition, this area produces industrial minerals such as **pumice** and phosphate for use in fertilizer and the making of phosphoric acid and dimension stone (*Figure 5.21*). It also produces perlite, an amorphous hydrated volcanic glass often found ias small hollow spheres embedded within **obsidian** (*Figure 5.22*). Perlite is used in horticulture, water filters, lime, and cement.



See Chapter 4: Topography for more about horst and graben landscapes.

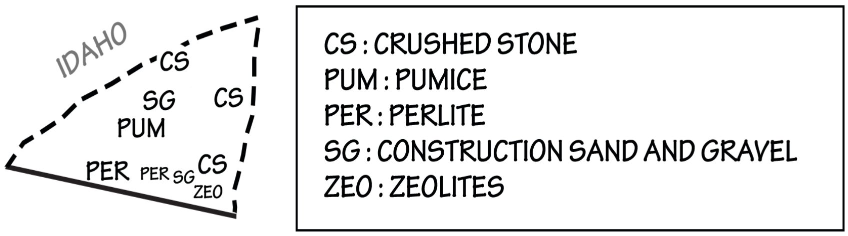


Figure 5.21: Principal mineral resources of the Basin and Range.

Figure 5.22: An outcrop of flow-banded perlite (amorphous hydrated volcanic glass) in obsidian. Perlite occurs as small hollow spheres called “spheruloids.”

Resources

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Mineral Resources

5

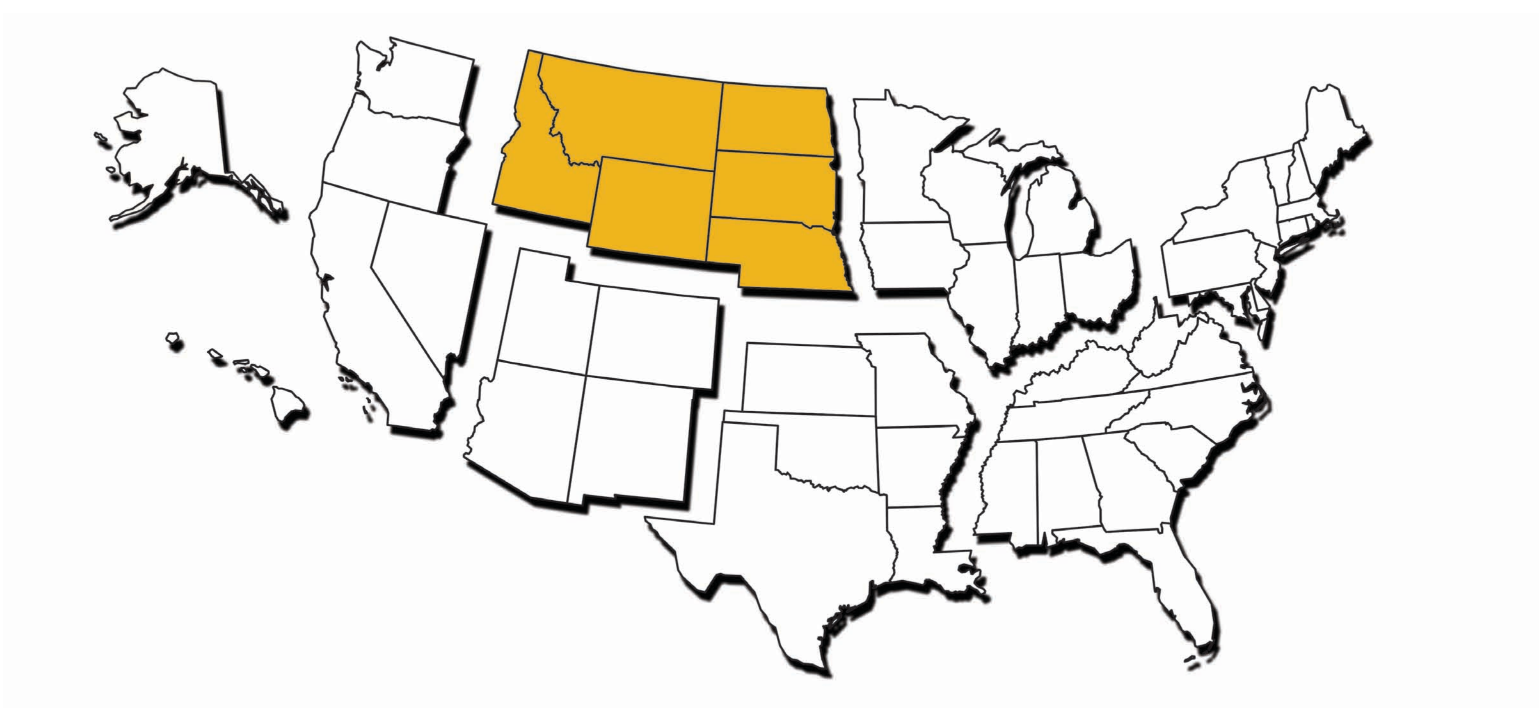
Resources

USGS Minerals Yearbook, Volume II—Area Reports: Domestic, State and Territory Chapters, http://minerals.usgs.gov/minerals/pubs/state/index.html#pubs. (State-by-state information about mineral mining and production.)

See also Resources in Chapter 2: Rocks.

The *Teacher-Friendly* Guide™

to the Earth Science of the Northwest Central US



Edited by Mark D. Lucas, Robert M. Ross, & Andrielle N. Swaby

Paleontological Research Institution
2015

ISBN 978-0-87710-511-4
Library of Congress no. 2015951888
PRI Special Publication no. 49

1259 Trumansburg Road
Ithaca, New York 14850 USA
http://priweb.org

First printing September 2015

This material is based upon work supported by the National Science Foundation under grant DRL-0733303. Any opinions, findings, and conclusions or recommendations are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. The publication also draws from work funded by the Arthur Vining Davis Foundations and The Atlantic Philanthropies.

The interactive online version of this *Teacher-Friendly Guide*™ (including downloadable pdfs) can be found at http://teacherfriendlyguide.org. Web version by Brian Gollands.

The Teacher-Friendly Guide™ series was originally conceived by Robert M. Ross and Warren D. Allmon. Original illustrations in this volume are mostly by Jim Houghton (The Graphic Touch, Ithaca), Wade Greenberg-Brand, and Christi A. Sobel.

Layout and design by Paula M. Mikkelsen, Elizabeth Stricker, Wade Greenberg-Brand, and Katherine Peck.

Cite this book as:
Lucas, M. D., R. M. Ross, & A. N. Swaby (eds.), 2015, *The Teacher-Friendly Guide to the Earth Science of the Northwest Central US.* Paleontological Research Institution, Ithaca, New York, x + 450 pp.

Cite one chapter as (example):
Allmon, W. D., and D. S. Friend, 2015, Fossils of the Northwest Central US. Pages 81–141, in: M. D. Lucas, R. M. Ross, & A. N. Swaby (eds.). *The Teacher-Friendly Guide to the Earth Science of the Northwest Central US.* Paleontological Research Institution, Ithaca, New York.

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