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, SiO₂). Carbonate rocks are made of carbon and oxygen combined with a metallic element; calcium carbonate (CaCO₃) 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 (CuFeS₂), 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. 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 (CaCO₃), 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).

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<td>Diamond</td>
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**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
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 confounding 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.

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
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 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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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.
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, rifts, 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.
What are hydrothermal solutions?

Hot water enriched in salts such as sodium chloride (NaCl), potassium chloride (KCl), and calcium chloride (CaCl₂) 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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Regions 1–2

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.

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.

See Chapter 7: Energy to learn about fossil fuel resources in the Northwest Central.
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 (NaSO₄), 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.
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).
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.

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.

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.
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.

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.
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.
Mineral Resources

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.

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.
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).

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 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.
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$_2$S$_3$), 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).

**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.
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 (Al₂O₃). 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
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.
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.

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 uneconomic 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.
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.
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, Cu₂S) and (minor) chalcopyrite (copper-iron sulfide, CuFeS₂) 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

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).

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.

**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.

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

**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.
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 as small hollow spheres embedded within obsidian (Figure 5.22). Perlite is used in horticulture, water filters, lime, and cement.
Mineral Resources

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

Books and Articles


Websites

Handbook of Mineralogy, http://www.handbookofmineralogy.org. (Technical information on 420 minerals available as free individual pdfs.)

Mineral Data, Hudson Institute of Mineralogy, http://www.mindat.org. (Claims to be the world's largest public database of mineral information.)


Minerals of the Northwest Central


Mineral Resources


See also Resources in Chapter 2: Rocks.
The Teacher-Friendly Guide™

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