



Chapter 5: Mineral Resources of the Western US

What is a mineral?

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

Elements: The Building Blocks of Minerals

Elements are the building blocks of minerals. The mineral quartz, for example, is made of the elements silicon and oxygen, and, in turn, is also a major component of many rocks. Most minerals present in nature are not composed of a single element, though there are exceptions such as gold. Elements such as copper (Cu), lead (Pb), zinc (Zn), and even silver (Ag), gold (Au), and diamond (C) are not rare, but they are usually widely dispersed 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 (*Figure 5.1*). Since silicon (Si) and oxygen (O) are the most abundant elements in the crust by mass, it makes sense for silicates (e.g., feldspar, quartz, and garnet) to be some of the most common minerals in the Earth's crust and to also be found throughout the West.

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**. **Sandstone** may be made of **cemented** grains of feldspar, quartz, and mica. The minerals and the bonds between the crystals define a rock's color and resistance to **weathering**.

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

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

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

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

mica • a large group of sheetlike silicate minerals.

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

CHAPTER AUTHORS

David Gillam
Alexandra Moore
Gary Lewis

5



Mineral Resources

Review

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

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

iron • a metallic chemical element (Fe).

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

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

erosion • the transport of weathered materials.

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

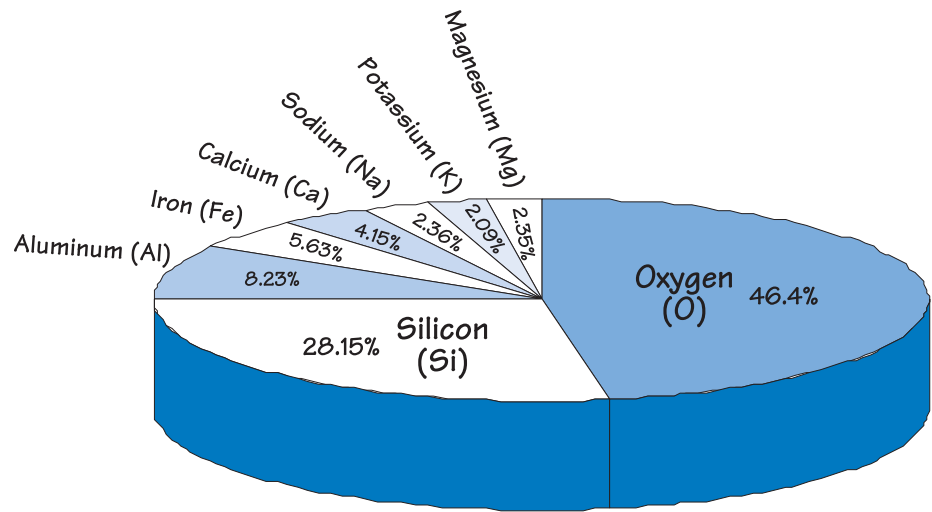


Figure 5.1: Mineral percentage by mass in the Earth's crust.

Metallic minerals are vital to the machinery and technology of modern civilization. However, many metallic minerals 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.

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** ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Generally much lighter in color than metallic minerals, 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 employed in identifying a mineral, each eliminating possible alternatives.

Hardness is a very useful property for identification, as a given mineral can only exhibit a narrow range of hardnesses, and it is easily testable, which quickly and simply minimizes the number of possibilities.

Hardness is important because it helps us understand why some rocks are more or less resistant to weathering and **erosion**. Quartz, with a rating of 7 on the **Mohs scale**, is a relatively hard mineral, but **calcite** (CaCO_3), rating 3 on the Mohs scale, is significantly softer. Therefore, it should be no surprise that



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. A fingernail has a hardness of around 2, a penny 3, window glass 5.5, and a knife blade 6.5.

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

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 is quite resistant due to its hardness and relative insolubility. Thus, quartz grains are the dominant mineral type in nearly all types of **sand**.

Color is helpful in identifying some minerals like sulfur, but it is uninformative or even misleading in others like garnet. **Luster** describes how light is reflected from a mineral's surface and can range from adamantine, seen in diamonds, to dull or earthy (effectively no luster), like **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-rhomboidal crystals. Relatedly, crystals may have planes of weakness that cause them to break in characteristic ways, called **cleavage**. Or they may not, and instead display **fracture** when broken. Mica and **graphite** have very strong cleavage, allowing them to easily be broken into thin sheets, while quartz and glass (the latter not being a mineral) have no cleavage, 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).

Review

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

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

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

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

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

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

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



Review

radioactive • when an unstable atom loses energy by emitting radiation.

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

effervesce • to foam or fizz while releasing gas.

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.

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 distinguishes a regular mineral from a gem?

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. Most gems, including tourmaline, topaz, and corundum, are durable because they are hard, making them scratch-resistant. On the Mohs scale of hardness, the majority of gemstones have values greater than 7. Isolated deposits of semi-precious gemstones can be found in most states.

Mineral Formation

Mineral deposits in the West range in age from over one billion years old to just a few thousands or tens of thousands of years, and their occurrence is related to different processes that operate in different geologic environments. Economically recoverable mineral deposits are formed by geologic processes that can selectively concentrate desirable elements in a relatively small area. These processes may be physical or chemical, and they fall into four categories:



Magmatic processes separate minor elements of **magma** from the major elements and concentrate them in a small volume of rock. This may involve the early crystallization of ore minerals from the magma while most other components remain molten, or late crystallization after most other components have crystallized. Magmatic processes responsible for the formation of mineral deposits in the West 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 sedimentary layers on the ocean floor or layers of sediment on lakebeds. Sedimentary mineral deposits form by direct precipitation from the water.

Weathering and erosion break down large volumes of rock by physical and chemical means and gather previously dispersed elements or minerals into highly concentrated deposits. **Residual weathering deposits** are mineral deposits formed through the concentration of a weathering-resistant mineral, while other minerals around it are eroded and dissolved. In contrast, mineral deposits formed by the concentration of minerals in moving waters are called **placer deposits**. In the Western US, placer deposits occur in rivers and streams that carry lighter sediment downstream but leave behind heavy minerals such as **gold**. Placer deposits can also occur on coastal beaches. The erosion of areas of small, low-grade gold veins and the subsequent concentration of the gold as stream sediment while the other minerals were carried downstream produced hundreds of placer deposits that were mined throughout the Western US during the 19th century. Mining of these deposits continues today.

Minerals in the West

The history of the Western States is driven in large part by the promise of mineral wealth. The rush for gold began in the 1840s, when much of the territory that would become California was ceded to the United States by Mexico. Gold discoveries in California resulted in Americans from the east and immigrants from around the world flocking to the area. The idea of acquiring wealth by finding gold became a backdrop for new communities and towns. As an area became either overcrowded or mined out, these gold seekers moved to new areas, eventually finding **silver** and gold in Nevada, and then gold and other

Review

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.

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.

hydrothermal solution • hot, salty water moving through rocks.



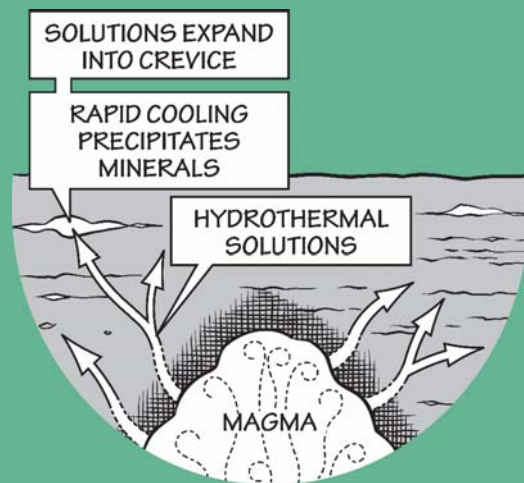
Review

passive margin • a tectonically quiet continental edge where crustal collision or rifting is not occurring.

volcanic island • one of a string of islands created when molten rock rises upward through oceanic crust.

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. These hot water brines can have varying origins. As magma cools, it releases its mineral-enriched, super-heated water into surrounding rock. Rainwater becomes a hydrothermal solution by picking up salt as it filters through rocks. 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. Rapid cooling of the hydrothermal solution over short distances allows concentrations of minerals to be deposited. Water moving quickly through fractures and openings in the rock, experiencing changes in pressure or composition, and being diluted with groundwater, can rapidly cool a hydrothermal solution.



minerals in Washington and Oregon. And finally, in the late 19th century, they headed to the Klondike and Alaska in search of new strikes. The minerals that early prospectors sought in rivers and streams are still being mined in many regions of the West.



Region 1

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.

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

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

Many Western mineral deposits are the products of several different concentration processes, sometimes operating tens or hundreds of millions of years apart. There are a variety of geologic environments in which these mineral-concentrating processes have operated over the past billion years to produce the abundance and diversity of mineral deposits found in the West today (Figure 5.2), including **passive continental margins** (Arctic Coast of Alaska), **volcanic island arcs** (Aleutian Islands), mountain-building events (Sierra Nevada, Cascades, Brooks Range), and basins formed by rifting events (Basin and Range of Nevada).

Mineral Resources of the Basin and Range Region 1

The Basin and Range region covers most of Nevada, some parts of eastern California, and a small part of southeastern Oregon. This province is defined by an alternating pattern of north-south trending **faults** and mountains with valleys in between. The Basin and Range, with its dry mountains and valleys, was initially seen as a barrier for those trying to reach the California gold fields. The little precipitation that does occur there quickly evaporates, flowing into short-lived lakes on the valley floors or sinking into the ground to become groundwater. These **climate** patterns have created abundant **evaporite** minerals such as salt; the geologic history of the region has also created the opportunity for large-scale mining of metallic minerals such as gold and silver, as well as of industrial materials, such as sand and gypsum (See Figure 5.2).

Metallic Minerals

The primary metallic minerals mined in the Great Basin (Figure 5.3) are gold and silver. In 1849, Mormon prospectors found placer gold in streams leading into the Carson River. However, these prospectors were on their way west to California, so it wasn't until 1859, with the discovery of silver in Nevada's Comstock Lode, that mining began in earnest. The mining boom brought prospectors who worked the mines, settlers who started farms and ranches to feed the miners, and shopkeepers who kept them

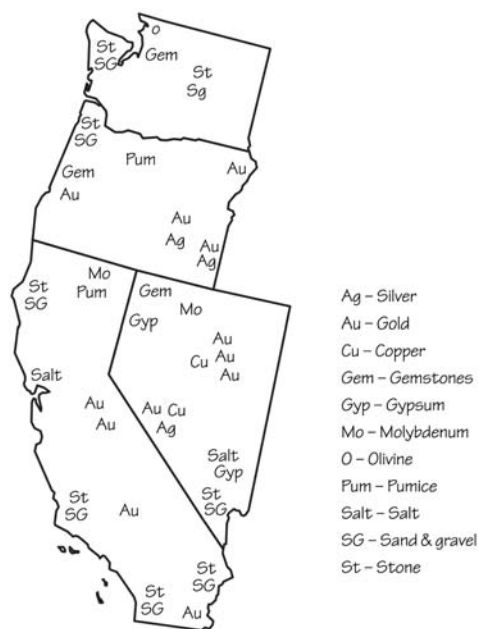


Figure 5.2: Mineral resources of Washington, Oregon, Nevada, and California.



5



Mineral Resources

Region 1

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

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

Eocene • a geologic time period extending from 56 to 33 million years ago.



Figure 5.3: Extent of the Great Basin.



supplied. Between 1860 and 1880, the Comstock District produced more than six million tons of ore.

Gold mining in the Great Basin produces 79% of the gold in the United States today. The Carlin Unconformity in Eureka and Elko Counties, Nevada, is one of the several sedimentary rock-hosted gold regions in the Great Basin. The Unconformity is associated with a period of collision between a **terrane** and the North American **plate** about 350 million years ago, generating higher crustal temperatures and pressures and producing numerous hot springs. The hot springs acted as hydrothermal solutions, precipitating gold from the bedrock. The belt of gold mineralization is found primarily in material from the late **Eocene** (~36–40 million years ago). Originally, placer deposits were found, but in 1960 mining began on a large scale in both open pit and underground mines (Figure 5.4). Slightly south of the Carlin Unconformity is the Battle Mountain-Eureka



Region 1

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

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



Figure 5.4: An aerial view of Round Mountain gold mine, an open pit mine in Nye County, Nevada. Round Mountain existed as an underground mine beginning in 1906, eventually being converted to an open pit sixty years later. The pit is about 2500 meters (9200 feet) wide and 1493 meters (4900 feet) deep.

Trend (here “trend” refers to an alignment of deposits), which has a similar geologic structure. Historically, mines in the area produced significant amounts of silver as well as gold.

Copper has been mined in several areas of the Great Basin. It is usually extracted in association with the other metals, like gold and silver. In White Pine County, Nevada, ore bodies produced by hydrothermal processes are being mined. The deposits are low-grade and include gold and silver as secondary products.

Low-grade gold deposits are more expensive to mine, as much more rock must be processed to extract a useful quantity of gold. Typically, precious metals are extracted from such deposits by using cyanide to leach them from crushed rock. This method is very slow, taking as long as two years to extract only 50% of the desired mineral.

Non-metallic Resources

In the northwest corner of the Basin and Range there are several mines that produce **opals**, which are used as **gemstones** (Figure 5.5). Opal is **silica**



5



Mineral Resources

Region 1

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

pyroclastic • rocks that form during explosive volcanic eruptions, and are composed from a variety of different volcanic ejecta.

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

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.

that lacks a crystalline structure, so it is not technically a mineral. These opal deposits formed over a period of 16 million years, in the silica-rich water of a wet, lush basin. The basin's forests were periodically buried under layers of **volcanic ash** and debris from **pyroclastic** flows. Over time, hot groundwater picked up silica-rich deposits that slowly replaced the carbon molecules in the buried **trees**. When the area was **uplifted** during the formation of the Basin and Range, erosion exposed the opal deposits.

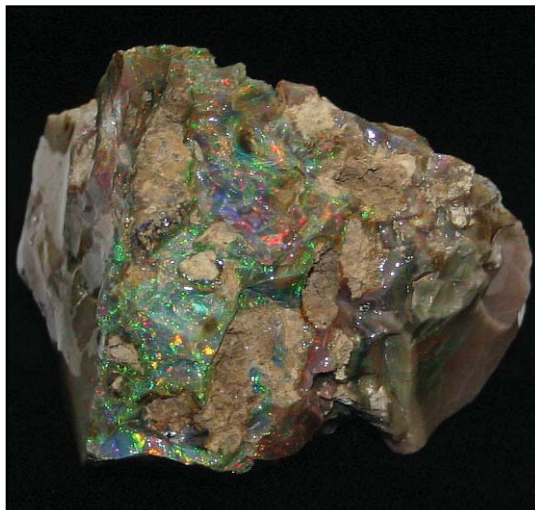


Figure 5.5: This rough opal was quarried in the Virgin Valley opal fields, located in Humboldt County, Nevada. The Smithsonian Institution's largest polished (160 carats) and unpolished (2585 carats) black opals both came from this area. (See TFG website for full-color version.)



In many places, salt deposits have formed where land-locked lakes evaporated. Because these **playas** capture all the salt and saline compounds that are washed out of the surrounding mountains, the deposits have become quite thick (and commercially viable). They are currently mined in southern Nevada and the southeast part of California. Gypsum also forms as an evaporite, and is found in similar settings.

Mineral Resources of the Columbia Plateau Region 2

The Columbia Plateau covers a vast area of eastern Washington, northern Oregon, and southwestern Idaho. This region is the result of one of the world's largest accumulations of **lava**, with over 500,000 square km (193,000 square miles) covered by flood **basalts**. The majority of these flows occurred from 17 to 14 million years ago. Mineral resources within the Columbia Plateau are often hidden under these prodigious flows, so they tend to be found within river canyons or in **accreted terranes** that rise above the flood basalt. These terranes were brought to North America on the Pacific plate, when the coast was near the border of Idaho and eastern Washington and Oregon. As the Pacific plate **subducted** underneath the North American plate, the terranes were welded onto the growing plate. Some elevated portions of these terranes were not covered by the lava flows, allowing them to be accessed for their mineral resources (See *Figure 5.2*).

Metallic Resources

In the Columbia Plateau, gold is the most common metallic resource. In the Blue Mountains of Oregon, which are part of an exposed terrane surrounded by the basaltic flow, placer and **lode** gold was mined near John Day and Baker City. In the southwest corner of the region, intense volcanic and hot spring activity led to the hydrothermal formation of fine-grained gold deposits in Oregon's Owyhee Uplands.

See Chapter 4: Topography to learn more about how flood basalts affected the landscape of the Columbia Plateau.

Non-metallic Resources

The primary mineral resources found in the Columbia Plateau are glacial deposits of sand, **gravel**, and stone. These are used as building materials, and are also shipped outside the region for use elsewhere. Due to the large quantity of glacial deposits in the region, commercial-size quarries can be found in just about every county in Washington and Oregon that lies within the Columbia Plateau.

Regions 1–2

playa lake • ephemeral or dry lakebed that occasionally contains only a thin layer of quickly evaporating water.

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

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

subduction • the process by which one plate moves under another, sinking into the mantle.

lode • an ore deposit that fills a fissure or crack in a rock formation.





Regions 3–4

lead • a metallic chemical element (Pb).

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



Mineral Resources of the Northern Rocky Mountains Region 3

In the far northeast corner of Washington State is a small arm of the Rocky Mountain system. The Rocky Mountains formed about 70 million years ago when an oceanic plate began subducting under the North American plate. The angle of subduction was significantly shallower than usual, causing the Rockies to form much farther inland.

Metallic Resources

Metallic resources are limited in this region. In Ferry County, Washington, mining operations began in the Kettle River-Buckhorn Mountain area. The mine is an underground facility designed to maintain as small a footprint as possible in order to minimize environmental impact. In the year 2013, the mine had a gold equivalent production (wherein silver production is converted to a gold equivalent) of 42 million grams (150,000 ounces).

The other metallic mining operation lies in Pend Oreille County, Washington. This mine accesses a **lead-zinc** ore body that is located in a narrow belt of sedimentary, volcanic, and metamorphic rocks.

Non-metallic Resources

Non-metallic resources in this region include sand, gravel, and stone. These materials are used as building materials for roads and other infrastructure in the region and are also shipped outside the region. Commercial-size quarries are found in the area.

Mineral Resources of the Sierra-Cascade Mountains Region 4

The Cascade-Sierra Mountains form a nearly uninterrupted barrier along the western edge of the United States. Interestingly, these two ranges have very little in common. The Sierra Nevada are composed of granitic intrusions (**plutons**) that once formed the molten core of an arc-shaped chain of volcanoes during the **Mesozoic**. Erosion wore away the volcanoes, leaving the granite exposed (*Figure 5.6*). Then, less than five million years ago, these granitic blocks began to rise along their eastern edge, tilting to the west in the process. The modern Sierra, as a result, have a gently sloping west side and

See Chapter 1: Geologic History for more detail on mountain-building in the Mesozoic.



a very steep east side. The Sierra are all that remains of an ancient volcanic arc, but the Cascades form an active volcanic arc that stretches from British Columbia to northern California. Thirteen major volcanic centers are strung along this arc. Between these large volcanoes lie thousands of short-lived volcanoes. In the North Cascades, the geologic picture is more complicated, as modern volcanoes are superimposed on a series of accreted terranes.

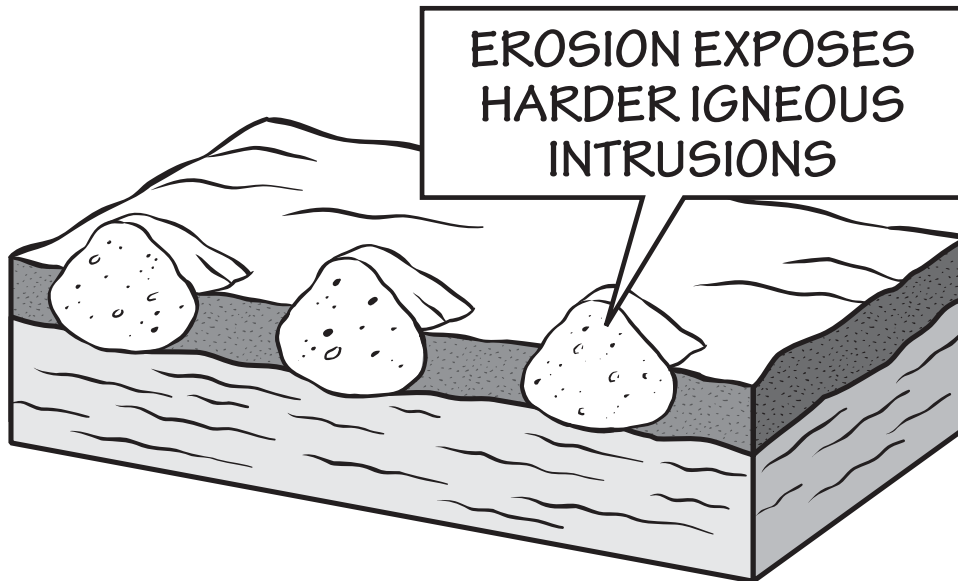


Figure 5.6: Igneous intrusions (plutons) are exposed after millions of years of erosion.

Region 4

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

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

Metallic Resources

Gold formation in the Sierra Nevada occurred within saturated sediments. Hydrothermal fluids were heated at depth, causing them to rise through the overlying rock. The fluids cooled as they rose to the surface, concentrating metals like gold. This gold, in the foothills of the western Sierra Nevada, was the source of the California Gold Rush of 1848–1849. The initial find at a mill on Sutter's Creek led to thousands of prospectors arriving from around the world in hopes of striking it rich. Eventually, the gold that was relatively easy to find was depleted, and miners either moved on to other gold fields or began looking for less convenient gold sources.

Gold is still mined in the Sierra Nevada today, but on a much smaller scale. In California's Amador, El Dorado, Placer, and Nevada counties, there are several small operations that employ 20 or fewer employees. In addition, there are several designer mines that make jewelry out of gold-intruded quartz (Figure 5.7). The quartz is cut and polished so the gold veining shows.

In the southern Cascades, in and around Jackson County, Oregon, a number of small gold mines were developed after the 1850s. Many of these were placer



5



Mineral Resources

Region 4

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

cinder • a type of pyroclastic particle in the form of gas-rich lava droplets that cool as they fall.

porosity • openings in a body of rock such as pores, joints, channels, and other cavities, in which gases or liquids may be trapped or migrate through.

aggregate • crushed stone or naturally occurring un lithified sand and gravel.



Figure 5.7: A sample from a quartz-gold vein mined near the Harvard Open Pit Mine in the Sierra Nevada foothills, California. (See TFG website for full-color version.)

claims that brought in dredges to move and process larger amounts of material from the riverbeds. Most of these claims were abandoned by the 1920s. Today, small placer claims are still worked along the rivers and streams that flow from the Cascades to the Pacific Ocean.

In the northern Cascades, silver, copper, and gold mining was a prominent industry in the late 19th and early 20th centuries. One of the largest copper mines in the country, the Howe Sound Holden Mine in Holden, Washington, produced \$66 million worth of ore before it was shut down in the 1950s as mineral prices dropped. Today, the US Forest Service and Rio Tinto mining group are engaged in a multi-million-dollar project to remediate environmental problems at the Holden Mine area, including the disposal of old mining waste and dismantling the old buildings (Figure 5.8).

Other metals, including silver and zinc, have been found throughout the Sierra Nevada and Cascade Range, but not in quantities that currently make them commercially viable.

Non-metallic Resources

In the Sierra Nevada and Cascade Range, gravel, stone, and sand are quarried for use in building roads, houses, and other infrastructure. In addition, **pumice** and volcanic **cinders** are quarried in the volcanic southern Cascade Range. These deposits are notable for having a lower density and higher **porosity** than most other rocks (Figure 5.9); this makes them commercially valuable for use as a lightweight yet strong construction material. Pumice can also be used as lightweight **aggregate**, insulators, absorbents, and abrasives. Pumice and cinders are quarried in Deschutes County, Oregon, near the town of Bend. Further south in Klamath County, Oregon, pumice is also quarried commercially.



Region 4



Figure 5.8: The skeleton of an old mill building at the Holden Mine site.

Near the Canadian border in the northern Cascades, the Twin Sisters **dunite** contains one of only two **olivine** mines in the United States. Dunite is olivine-rich **ultramafic mantle** rock, and is rarely found at the surface. Olivine has a high **heat** tolerance, making it ideal for use in foundries when casting objects and when lining kilns, furnaces, incinerators, and reactors. It is also a good material for sandblasting and for other abrasive uses. In Whatcom County, olivine is

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

ultramafic rocks • igneous rocks with very low silica content ($< 45\%$), which are composed of usually greater than 90% mafic minerals.

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

heat • the transfer of energy from one body to another as a result of a difference in temperature or a change in phase.



5



Mineral Resources

Regions 4–5



Figure 5.9: A close-up of a pumice stone, revealing its highly porous and vesicular texture. These gas bubbles make the rock so lightweight that it is able to float. Field of view is 2.7 centimeters (1 inch) across.

mined mostly for abrasive purposes, although a small amount of foundry-grade material is also produced.

Mineral Resources of the Pacific Border Region 5

The Pacific Border is defined by a series of mountain ranges that run along the coast. These mountains include (from north to south) the Olympic Mountains, the Oregon Coast Range, the Klamath Mountains, the California Coast Range, the Transverse Range, and the Peninsular Range. Much of the area formed due to Pacific plate subduction, as sea bottom sediments, basaltic upper crust, and ultramafic lower crust were scraped onto the overriding North American plate and subsequently metamorphosed, uplifted, and finally eroded.

Metallic Resources

Placer gold deposits were mined along the coast of Oregon and California. In southern Oregon, gold was originally found near the mouth of the Rogue River, and these beach deposits were extensively mined starting in the 1850s. There are still a few gold mining operations upriver on the Rogue, and gold can still be panned on the beach (Figure 5.10).





Region 5

Devonian • a geologic time period spanning from 419 to 359 million years ago.

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

slate • a fine-grained, foliated metamorphic rock derived from a shale composed of volcanic ash or clay.



Figure 5.10: Gold panning near Jamestown, California.

In the Klamath Mountains of southern Oregon and northern California, sedimentary deposits from the **Devonian** and **Carboniferous** periods form tightly folded **slates**. These slates are riddled with highly siliceous intrusions that contain copper and zinc. These minerals were mined extensively from the 1890s to about 1920.

Non-metallic Resources

As cities like Los Angeles and San Francisco began to grow along California's coast, there was a demand for cheap building materials for roads, buildings, and other infrastructure. As a result, the quarrying of materials, including sand, gravel, and stone, became an important industry, and these materials are produced throughout this region. Large stones are used as breakwaters and jetties to protect coastal infrastructure from battering waves. Interestingly, the famous sandy beaches of Southern California no longer receive sand from the inland mountains. The growth of Los Angeles has interrupted the rivers that used to transport eroded sediments from the mountains to the beaches. As a result, rock is quarried from the mountains, mechanically pulverized into sand-sized grains, and then trucked to the beach.

Salt is produced in the San Francisco Bay—ponds are filled with saltwater from the bay, which is then allowed to evaporate (Figure 5.11). It takes over four years for this process to turn saltwater into harvestable salt. The salt was originally used for paper pulp production, livestock, and food preservation,



5



Mineral Resources

Regions 5–6

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



Figure 5.11: Salt evaporation ponds on the western shore of San Francisco Bay. Different microorganisms thrive in varying levels of salinity, causing the ponds to change in color. Low-salinity ponds are inhabited by blue-green algae, while saltier waters support orange brine shrimp and red bacteria. (See TFG website for full-color version.)

but today it is sold as table salt. Bittern, a byproduct of the salt purification, consisting of magnesium chlorides, sulfates, and other chemical compounds, is sold as dust control for construction sites and vineyards.

Further north, **agate** can be found along many beaches in Washington and Oregon. This semi-precious gemstone is collected and used for jewelry and other decorative purposes.

Mineral Resources of Alaska Region 6

Alaska encompasses a large landmass that contains a wide variety of mineral resources. However, difficulties associated with a lack of transportation and challenging environmental conditions (extreme cold, snow, and darkness) have limited the amount of mining that can occur there. Despite these obstacles, mineral resources continue to play an important role in the state's development (Figure 5.12).

Alaska can be divided into separate areas, classified mainly by their differing modes of formation (Figure 5.13). Northern Alaska formed as the Yukon-Tanana terrane collided with the North American plate about 200 million years ago. This movement uplifted sections of the Arctic Sea floor, forming the Brooks Range



Mineral Resources



5

Region 6

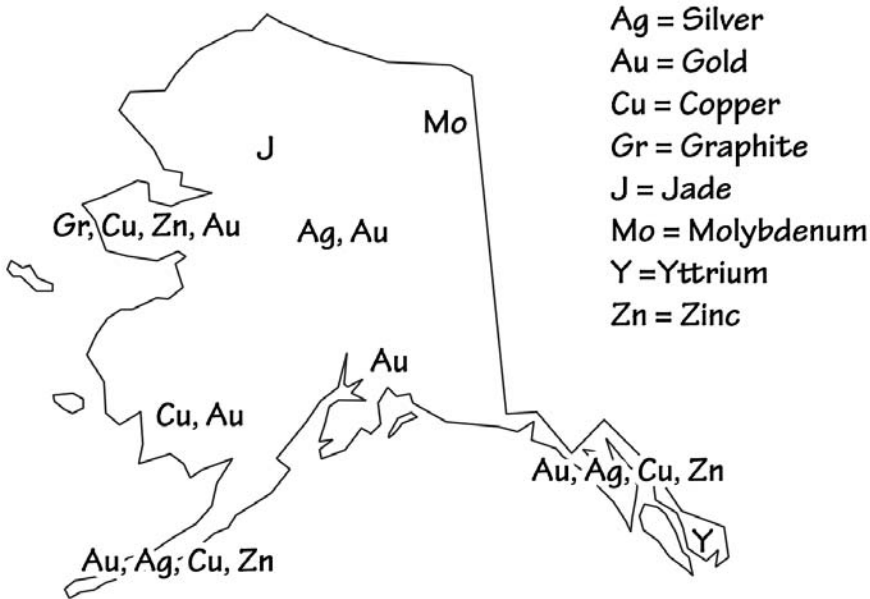


Figure 5.12: Mineral resources of Alaska.

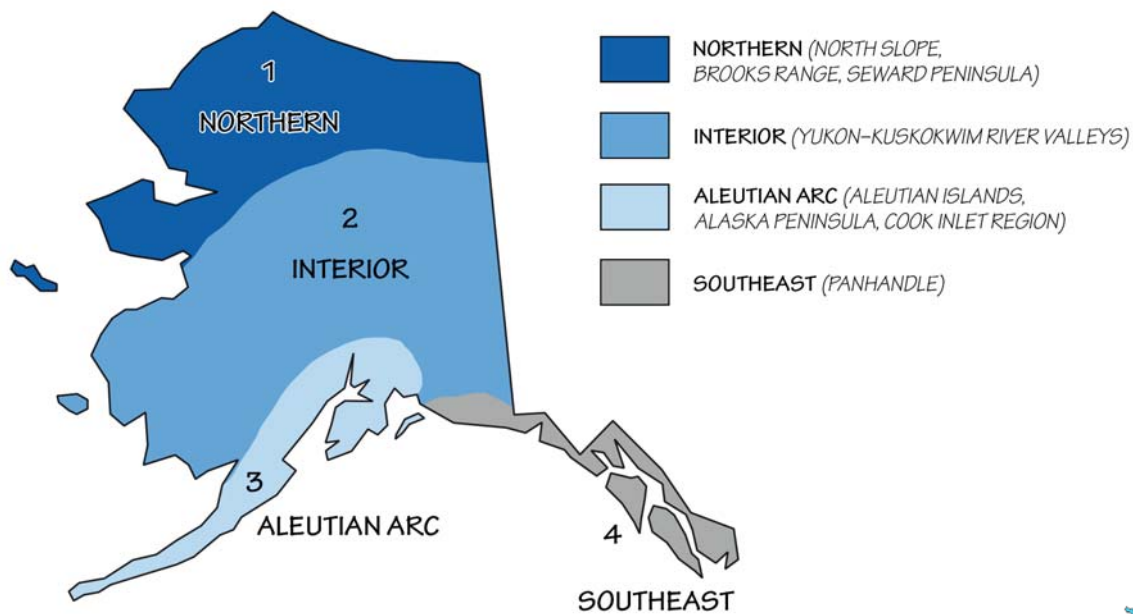


Figure 5.13: Common subdivisions of Alaska



5



Mineral Resources

Region 6

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

ice age • a period of global cooling of the Earth's surface and atmosphere, resulting in the presence or expansion of ice sheets and glaciers.

compression • flattening or squeezing as a result of forces acting on an object from all or most directions.

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

isostasy • an equilibrium between the weight of the crust and the buoyancy of the mantle.



and White Mountains, and leaving behind the Arctic Plain (North Slope) between the Brooks Range and the Arctic Ocean. Major **oil** and gas development has taken place on the Arctic Plain. Mineral deposits, including zinc, silver, gold, graphite, and jade, are found in and around the Brooks Range and the White Mountains.

See Chapter 7: Energy for more about Alaska's oil and gas resources.

Alaska's Interior lies between the Brooks Range to the north and the Aleutian Arc (and associated Alaska Range) to the south. It consists of sediment-covered crustal material from the Yukon-Tanana terrane. Two major river systems run through the Interior, along with a number of smaller rivers and tributaries, contributing to erosion and depositing sediments throughout. Placer gold mining brought prospectors to the area in the late 19th century, and mining remains an important industry there today.

The Aleutian Island Arc lies along the southern edge of the North American plate in Alaska. This area is an active subduction zone, where the Pacific plate subducts beneath the North American plate. As the subducting plate descends and begins to melt, water is released from the oceanic crust; this leads to melting of the overlying mantle and the generation of volcanism. The result is an arc of volcanic islands that stretches 2500 kilometers (1550 miles) from the Alaskan mainland through the Aleutians to Russia's Kamchatka Peninsula. The arc is relatively young and continues to change as a result of regional volcanism. Some small-scale mineral development has occurred, and exploration of the area's resources is ongoing.

Southeast Alaska is one of the state's most geologically complex areas. It consists of a narrow archipelago of about 1100 islands and a thin strip of the Pacific Coast Range mountains, about 965 kilometers (650 miles) long with an average width of 193 kilometers (120 miles). Much of the land is mountainous, rising directly from sea level to great heights, and subsequently carved by recent glaciations. Since the last **ice age**, the removal of vast quantities of glacial ice from the landscape has allowed the land to rebound, elastically springing back to its former height (before it was **compressed** by the **glaciers**). This process, known as **isostasy** or isostatic rebound (*Figure 5.14*), has elevated the ocean shelf as much as several hundred meters (yards) above sea level. Physical structures in the area are generally oriented from the northwest to the southeast. The islands have long axes in these directions, forming strips of land that are roughly parallel to each other. Rocks in Southeast Alaska can be subdivided into 10 groups: five **terranes** that have distinct geologic records and five rock groupings that are depositional, intrusive, or of unknown connection to the terranes. Most of the area is accessible only by plane or ship, making mineral development difficult. There are exceptions, however, such as large gold mining operations in the Juneau area and historical garnet mining near Wrangell.

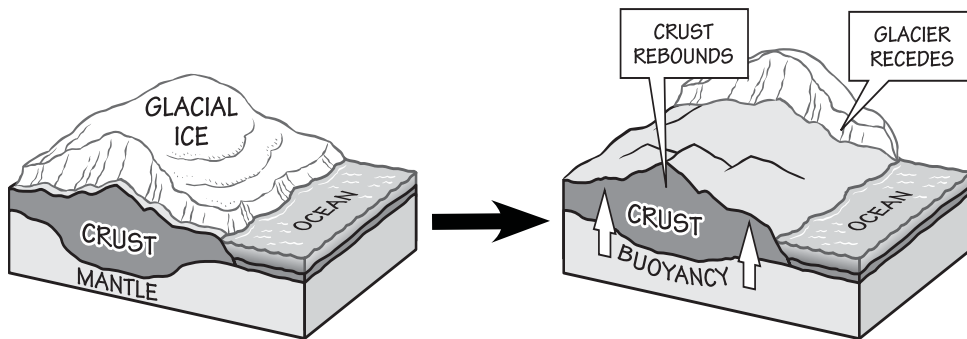


Figure 5.14: Isostatic rebound resulting from glacial retreat.

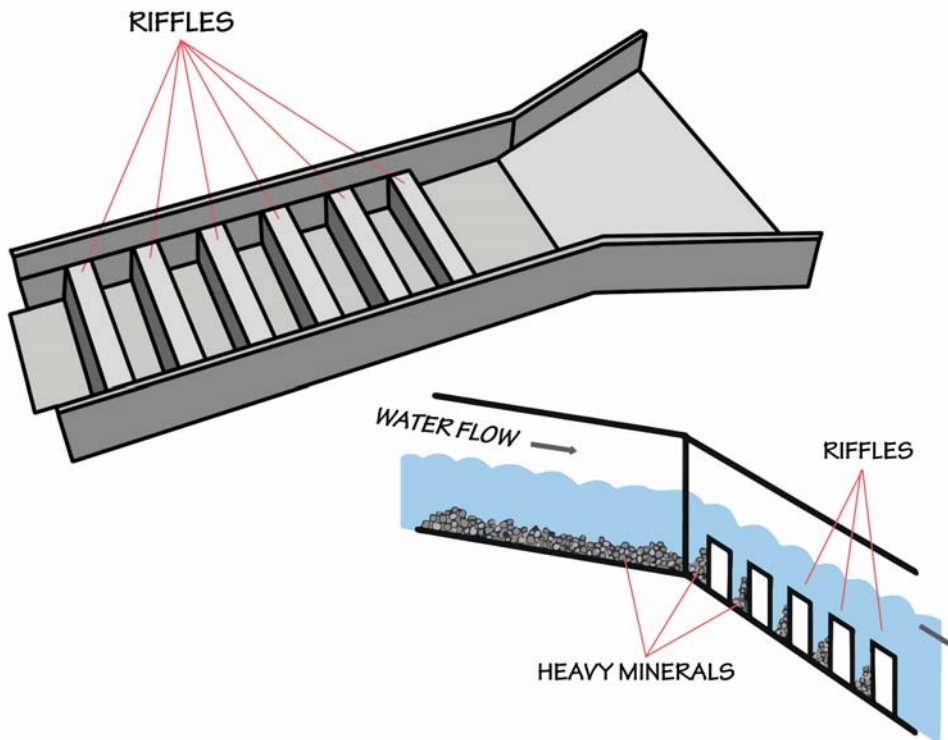


Figure 5.15: A sluice is a long tray through which water containing gold is directed. The sluice box contains riffles, or raised segments, which create eddies in the water flow. Larger and heavier particles, such as gold, are trapped by the eddies and sink behind the riffles where they can later be collected.

Region 6

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

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

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

Mineral Resources of Northern Alaska

Metallic Minerals

In the southern part of the Brooks Range, mineral deposits are found in **Paleozoic**-age metamorphosed sedimentary rocks that contain similarly aged basalt **dikes**. In several areas close to the Dalton Highway, small mining



5



Mineral Resources

Region 6

shale • a dark, fine-grained, laminated sedimentary rock formed by the compression of successive layers of silt- and clay-rich sediment.

Jurassic • the geologic time period lasting from 201 to 145 million years ago.

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

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

active plate boundary • the boundary between two plates of the Earth's crust that are colliding, pulling apart, or moving past each other.



operations extract small quantities of placer gold. Near Coldfoot, larger-scale operations use hydraulic pumps to blast frozen gravel from hillsides that is then washed in large sluice operations (Figure 5.15).

On the western end of the Brooks Range, mineral deposits are found in Paleozoic black **shales**, creating a sulfide ore zone from which zinc and lead are mined. Because this area is north of the Arctic Circle, extreme winter conditions (with temperatures as low as -51°C [-59°F]) make mining in this area difficult.

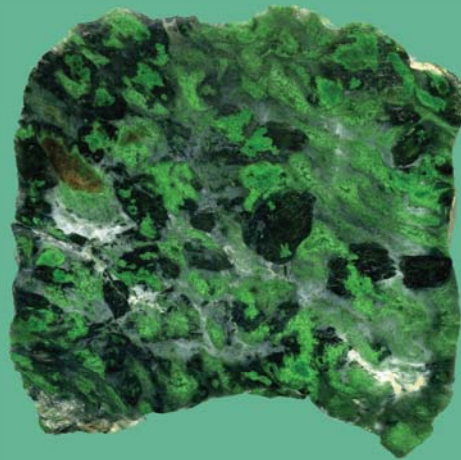
The placer gold found on the beaches of Seward Peninsula became the center of a gold rush in the late 19th century. The beaches around what eventually became the community of Nome were staked out and mined. Later, dredges were built on the rivers around Nome. Today, the beaches and ocean shelf around Nome are still home to a number of placer mining operations.

Non-metallic Minerals

Northeast of Nome on the Seward Peninsula, a graphite mine—the Graphite Creek Deposit—is under development. The graphite here formed through

Jade

The word “jade” is applied to two minerals that look similar and have similar properties: jadeite (a kind of *pyroxene*) and nephrite (a kind of *amphibole*). The two minerals are so similar that they weren’t distinguished from one another until 1863. Both minerals are formed during metamorphism and are found primarily near subduction zones, which explains why jade is abundant in a variety of locations along the *active plate boundaries* of both Alaska and the western continental U.S.



Late Triassic chromian jade, which contains both pyroxene and amphibole.



metamorphism in the late **Jurassic** to early **Cretaceous**. It is generally found as flakes dispersed throughout the host rock, but can also be found in highly concentrated pockets.

Jade found in the Kobuk area has been mined in small amounts since the 1940s, and is used for jewelry and small, carved objects. The jade is found in ultramafic and mafic rocks formed in the middle to early Jurassic periods.

Mineral Resources of Interior Alaska

Metallic Minerals

Prospectors first came to Alaska's interior following the Klondike gold rush in the late 19th century. Miners who arrived to the Klondike too late to stake claims, or simply chose to move on, would travel down the Yukon River. Eventually, near Fairbanks, placer gold was found in the creeks and streams that feed into the Yukon and Tanana Rivers. These early claims led to massive dredging operations in the early 20th century (*Figure 5.16*). Today, two large gold mines



Figure 5.16: An abandoned gold dredge in Chatanika, Alaska, northeast of Fairbanks.

are found in this area. The Pogo Mine near Delta Junction is in high-grade **gneiss** intruded by Cretaceous granitic bodies. Closer to Fairbanks, the Fort Knox Mine is found in a granite body known as the Fort Knox pluton. The gold is found in quartz veins, which are the precipitated remains of hydrothermal fluids that once circulated through the pluton. Although the gold has been concentrated in the quartz veins, the ore must be further processed in order to separate the gold from the quartz.

More recently, at the Pebble Deposit in the Kuskokwim River drainage, copper, **molybdenum**, and gold have been found in veins and within granitic rocks. In part of the deposit, these minerals are partially exposed at the surface, while other portions are concealed beneath younger volcanic and sedimentary rock.

Region 6

gneiss • a metamorphic rock that may form from granite or layered sedimentary rock such as sandstone or siltstone.

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



5



Mineral Resources

Region 6

climate change • See global warming: the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.

permafrost • a layer of soil below the surface that remains frozen all year round. Its thickness can range from tens of centimeters to a few meters.

Non-metallic Minerals

Large amounts of sand and gravel (aggregate) are extracted throughout the area for use in road building and construction. Besides building new roads, aggregate is used to cope with the effects of **climate change**: as **permafrost** melts, **soil** compacts and overlying roads and infrastructure become unstable, requiring solid material to fill in the gaps. Large stone is also quarried for use as **rip-rap** along riverbanks in populated areas.

See Chapter 9: Climate to learn more about the effects of melting permafrost.

Mineral Resources of the Aleutian Arc

Metallic Minerals

Little is known about metallic deposits on the Aleutian Islands, and mining has occurred only in small pockets. On Unga Island, close to the Alaska Peninsula, gold and silver have been found in quartz deposits. Further out in the Aleutians, on Salt Island, the indigenous peoples collected native copper from the basaltic rocks for use as tools (such as awls, needles, and knives) and decoration.



Figure 5.17: An old mining cabin in Hatcher Pass, Alaska, the home of Independence Mine. The first mining claims in this area were staked in 1906.



Metallic mineral deposits are more common on the Alaska Peninsula itself, and also in the Cook Inlet. Placer gold deposits have been found on the beaches of the Alaska Peninsula and Kodiak Island, as well as in small creeks throughout the area. Deposits of copper and molybdenum have been found in the Pyramid Mountain area and are being explored for possible development.

In Cook Inlet, small placer deposits led to gold rushes during the early 20th century, and major mining operations started targeting underground deposits.



Along Turnagain Arm, near Anchorage, gold was found in Crow, Hope, and Six-Mile creeks. Placer mines were developed, and some individuals still mine these small claims (*Figure 5.17*). North of Anchorage, in the Talkeetna Mountains, placer gold was found in creeks. As prospectors moved to the headwaters of these creeks they found surface veins of gold, which led to underground mining at Independence Mine. The mine reached peak production in 1941 with a workforce of over 200 men blasting nearly 20 kilometers (12 miles) of tunnels and producing 975,677 grams (34,441 ounces) of gold. In 1942, shortly after the United States entered World War II, the War Production Board decided that gold was non-essential to the war effort. Gold mining throughout the United States was halted as a result—Independence Mine continued to operate, however, because of the presence of **scheelite**. Scheelite is a source of tungsten, a strategic metal for the war effort, and it was found in the same gold-bearing quartz veins being excavated by the mine. Since the production of scheelite was low, the mine closed in 1943. After the war, the price of gold dropped—mining at Independence was no longer profitable, and the mine closed for good in 1951.

Non-metallic Minerals

Non-metallic minerals found in this area are used in the road and building industries. Large amounts of sand and gravel are extracted for use in road building and construction. In the Matanuska Valley and the Anchorage area, rivers and glaciers left large sedimentary deposits that provide an inexpensive source of sand and gravel.

After World War II, the city of Anchorage grew quickly, and it therefore needed building materials. A pumice mine was developed nearby, on volcanic Augustine Island. From 1946 to 1949, pumice was mined and transported by barge to Anchorage to be used as an additive in cement and concrete. The mining ended when Mt. Augustine erupted, destroying the roads and several structures on the island.

Mineral Resources of Southeast Alaska

Metallic Minerals

Alaskan gold was first discovered in the southeastern part of the state, as prospectors had been following the gold fields north from California in the 30 years since the finds at Sutter's Mill in 1848–1849. By the 1870s, gold had been found in small amounts near Wrangell and Sitka. In 1880, a major strike took place in what would become Juneau, the state capital. At the far north of Southeast Alaska, the Kennecott Copper Mine was developed starting in 1900, and produced millions of tons of ore over 27 years of operation (*Figure 5.18*). In addition to copper, the mines also produced a significant amount of silver.

Today, gold is the primary metal mined in Southeast Alaska, although recent discoveries of silver, zinc, and lead in commercial quantities have led to new mines. Southwest of Juneau, on Admiralty Island, a large mine at Green Creek has been developed in **schists** metamorphosed from volcanic and sedimentary rocks—this mine produces gold, silver, copper, lead, and zinc produced by magmatic and hydrothermal processes.

Region 6

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

rip-rap • rock and rubble used to fortify shorelines, streambeds, pilings, and other structures against erosion.

scheelite • a yellow-brown mineral that is often found in association with quartz.

schist • a medium grade metamorphic rock with sheet-like crystals flattened in one plane.



5



Mineral Resources

Region 6

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

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



Figure 5.18: The 14-story concentration mill at the Kennicott Copper Mine, built in 1906. Today, the mill and mines are located in Wrangell-St. Elias National Park & Preserve.

Non-metallic Minerals

A number of non-metallic minerals are currently mined in Alaska's southeast. Near Wrangell, a garnet-bearing schist wall has been mined for specimen-grade garnets since the early 1900s (Figure 5.19). The mine is currently owned



Figure 5.19: A 2.5 centimeter (1 inch) wide garnet from Wrangell, Alaska.





by the local Boy Scout Troop, which collects and sells the garnets to tourists. Further north at Gypsum Creek, a mine produces gypsum from the Paleozoic Iyoukeen Formation. At the southernmost end of the Panhandle, on Prince of Wales Island, Bokan Mountain is being explored for heavy **rare earth elements**. Surveys have shown that about 40% of the area (by weight) is composed of these rare elements, including dysprosium (used in **nuclear** reactors and data storage), terbium (used in solid-state devices and **fuel** cells), and yttrium (used in the production of lasers, electrodes, and superconductors).

Region 7

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

Mineral Resources of Hawai‘i Region 7

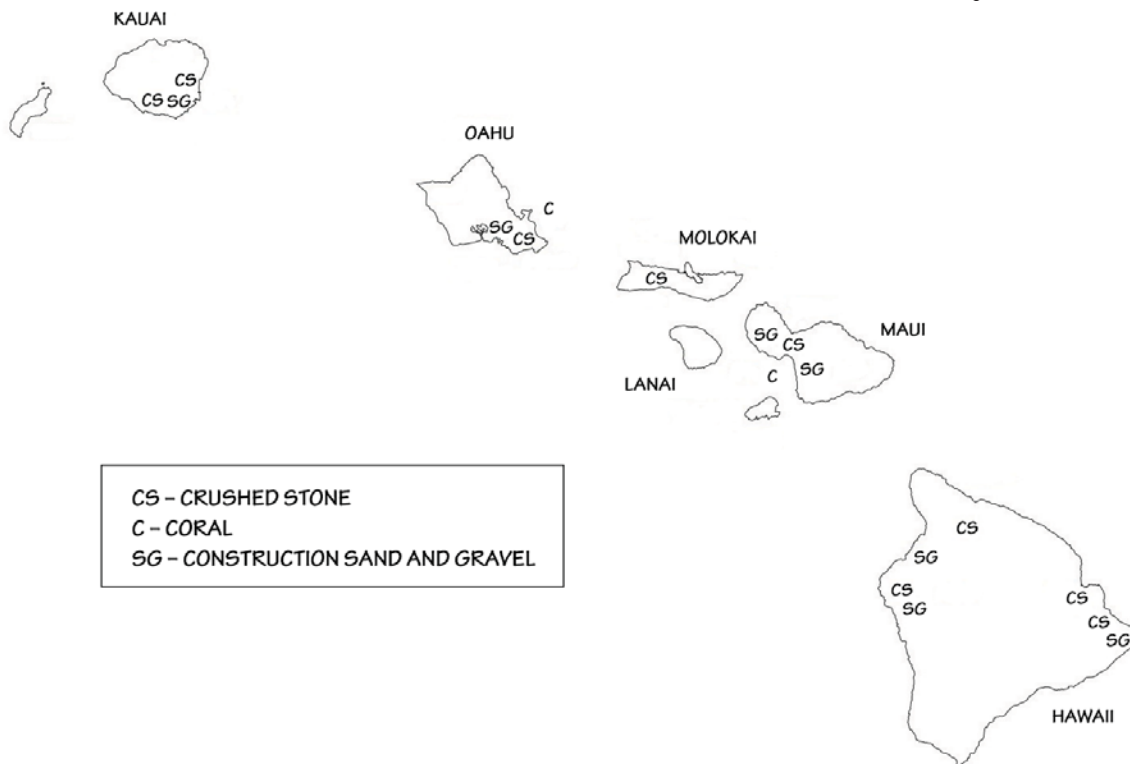


Figure 5.20: Mineral resources of Hawai‘i.

The uniform geology of the Hawaiian Islands does not produce the variety of mineral resources seen in many other parts of the world (Figure 5.20). However, human development has spurred demand for building materials, which, in turn, has driven the development of basalt and limestone resources. In ancient times, Hawaiians used dense basalt for tools and implements. Evidence of



5



Mineral Resources

Region 7

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

reef • a feature lying beneath the surface of the water, which is a buildup of sediment or other material built by organisms, and which has positive relief from the sea floor.

quarry sites once used for these purposes can be found throughout the islands. The Hawaiians also used basalt rocks for building hut bases and ceremonial walls (*Figure 5.21*).



Figure 5.21: Impressive ancient dry stone construction at Pu'uhonua O Hōnaunau National Historical Park, Hawai'i Island.

The arrival of Europeans and the subsequent development of the Hawaiian Islands led to an expansion of the construction industry, ultimately requiring more materials. More recently, some companies have been working to develop deposits of extremely weathered soils for their aluminum potential.

The US Geological Survey divides the current utilized mineral resources of Hawai'i into three categories: crushed stone, construction sand/gravel, and gems.

Crushed stone is Hawai'i's largest mineral resource, making up over 85% of the state's mineral production resources (*Figure 5.22*). Crushed basalt is used for a variety of purposes in the construction industry, such as in road bases and as an aggregate in concrete, drainage, and stone retaining walls. Sand made of cinder from cinder cones is also sought after as a landscaping material. Limestone from emerged **Pleistocene-age reefs**, and the coastal carbonate sand dunes that fringe O'ahu and older Hawaiian islands, has been used to make cement products.

The "gems" mined in Hawai'i are limited to black and precious corals. Approximately \$150,000 a year of this material is taken from the waters off the





Figure 5.22: Crushed stone quarry nestled in the hills of O'ahu.



Figure 5.23: Coral bracelet.



5



Mineral Resources

Region 7

coasts of O'ahu and Maui to be used for jewelry production (*Figure 5.23*). It is often thought that the olivine (peridot) sold in stores around the islands is sourced from the local rocks, but collecting and selling olivine is considered disrespectful in traditional Hawaiian custom. It is therefore illegal to extract it from most sites, and the olivine sold in Hawai'i is actually sourced from locations outside the islands.





Resources

Resources

Books

Skinner, B. J., 1989, *Mineral Resources of North America*, pp. 575–584, in: A. W. Bally, & A. R. Palmer (eds.), *The Geology of North America—An Overview*, The Geology of North America, vol. A, Geological Society of America, Boulder, CO.

State-based Resources

Frank, D. G., A. R. Wallace, & J. L. Schneider, 2010, Western Mineral and Environmental Resources Science Center—providing comprehensive earth science for complex societal issues, *US Geological Survey Circular* 1363, 32 pp.

Mineral Resources [of California], California Geological Survey, Department of Conservation, http://www.consrv.ca.gov/cgs/geologic_resources/mineral_resource_mapping/Pages/Index.aspx.

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.)

Gold

Hill, M., 1999, *Gold: the California Story*, University of California Press, Berkeley, 306 pp.

Gold Geology and Prospecting, Alaska, Gold in Alaska (Blogspot), 10 February 2010, <http://goldalaska.blogspot.com/2010/02/gold-geology-and-prospecting-alaska.html>.

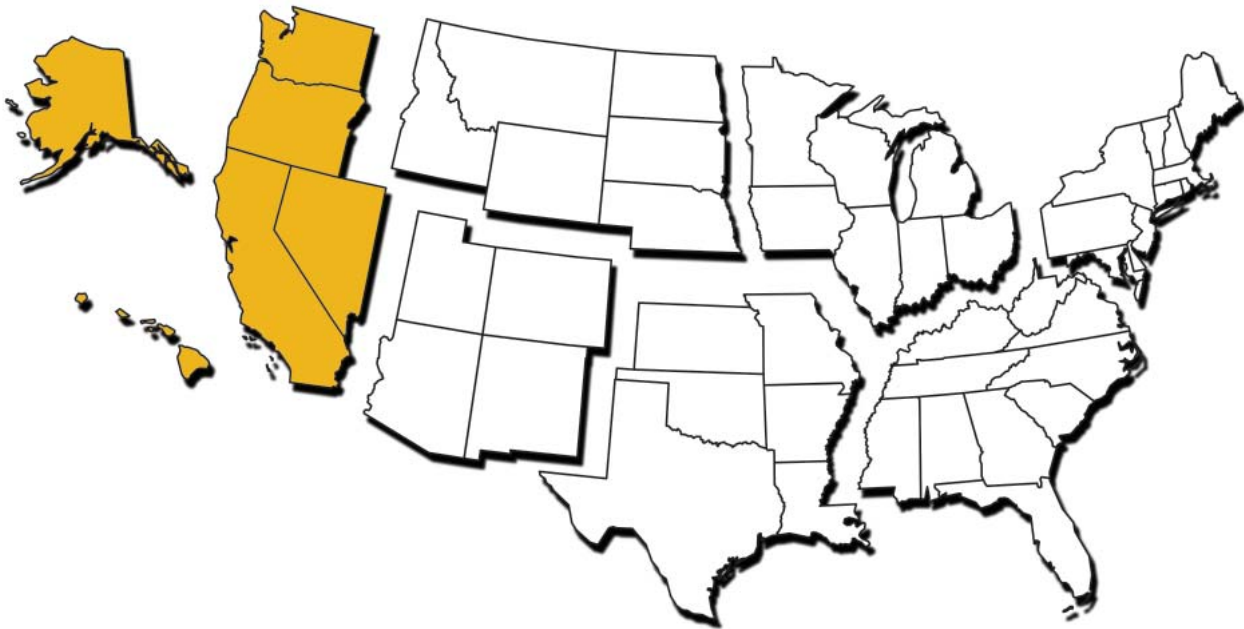
Gold Prospecting in the United States, Geology.com, <http://geology.com/usgs/gold-prospecting/>.

Kirkemo, H., 1991, *Prospecting for Gold in the United States*, *US Geological Survey Unnumbered Series General Interest Publication*, 19 pp., <http://pubs.usgs.gov/gip/prospect2/prospectgip.html>.

Mendahl, K. H., 2008, *Hard Road West: History and Geology along the Gold Rush Trail*, University of Chicago Press, Chicago, 329 pp.

The
Teacher-Friendly
Guide™

to the Earth Science of the
Western US



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

Paleontological Research Institution
2014

ISBN 978-0-87710-509-1
Library of Congress no. 2014959038
PRI Special Publication no. 47

© 2014 Paleontological Research Institution
1259 Trumansburg Road
Ithaca, New York 14850 USA
priweb.org

First printing December 2014

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.

Any part of this work may be copied for personal or classroom use (not for resale). Content of this *Teacher-Friendly Guide*™ and its interactive online version are available for classroom use without prior permission.

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.

The Teacher-Friendly Guide™ is a trademark of the Paleontological Research Institution.

Cite this book as:

Lucas, M. D., R. M. Ross, & A. N. Swaby (eds.), 2014, *The Teacher-Friendly Guide to the Earth Science of the Western US*, Paleontological Research Institution, Ithaca, New York, xii + 424 pp.

Cite one chapter as (example):

Anderson, B., A. Moore, G. Lewis, and W. D. Allmon, 2014, Fossils of the Western US. Pages 81–123, in: M. D. Lucas, R. M. Ross, & A. N. Swaby (eds.), *The Teacher-Friendly Guide to the Earth Science of the Western US*. Paleontological Research Institution, Ithaca, New York.

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