Chapter 2: Rocks of the Northwest Central US

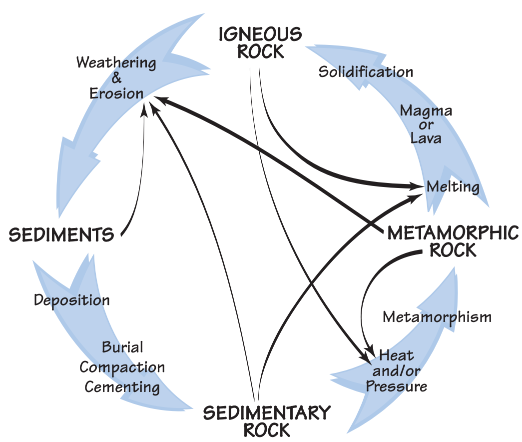
The amazing diversity of rocks in the Northwest Central records several billion years of history—from 3.8-billion-year-old **Precambrian** granites to sedimentary deposits from the most recent **ice age**. Colliding **plates**, **rifting**, **inland seas**, deposition, **erosion**, igneous and metamorphic activity, and recent **glacial** processes are all part of this story. The Northwest Central's different rock types influence its **topography** and tell us where to look for certain **fossils** or natural resources. Each type of rock forms in a particular environment under particular conditions (*Figure 2.1*).

Igneous Rocks of the Northwest Central

andesite	granite	obsidian	rhyolite
basalt	komatiite	phonolite	syenite
dacite	lamproite	pyroclastic rocks	tuff

Unconsolidated Sediments of the Northwest Central

clay
gravel
loess
sand
silt



Metamorphic Rocks of the Northwest Central

gneiss
greenstone
marble
novaculite
quartzite
schist

Sedimentary Rocks of the Northwest Central

chalcedony	mudstone
chert	shale
conglomerate	siltstone
halite (rock salt)	sandstone
gypsum	tillite
limestone	travertine

Figure 2.1: The rock cycle shows the relationships among the three basic types of rock.

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

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.*

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

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

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

CHAPTER AUTHORS

Lisa R. Fisher
Bryan Isaacs

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Rocks

Review

mineral • *a naturally occurring solid with a specific chemical composition and crystalline structure.*

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

plate tectonics • *the process by which the plates of the Earth's crust move and interact with one another at their boundaries.*

lithification • *the process of creating sedimentary rock through the compaction or sementation of soft sediment.*

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

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

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

A rock is a naturally occurring solid substance composed of one or more **minerals**. Broadly speaking, there are three types of rock: sedimentary, igneous, and metamorphic. The rock cycle describes the many processes that produce rocks, while also illustrating differences between the rock types. One type of rock may be transformed into either of the other types, often with the help of other parts of the Earth **system**, such as **plate tectonics**, the water cycle, and biological processes, to name a few.

Sedimentary rock is formed by the **lithification** of sediments (e.g., unconsolidated mineral and organic particles created through the **weathering** of other materials, such as rock and organic matter). Typically, sediments are created in an environment where erosion is a dominant force, and they are transported by **wind**, water, or ice to a depositional environment. For example, a rushing river can wear away the rock it is flowing over, and it also has enough energy to transport the resulting sediment to a lake. The water slows down, losing energy, and deposits the sediment on the bottom of the lake.

Sedimentary Rock Classification

Sedimentary rocks are classified by their sediment size or their mineral content, and each one reveals the story of the depositional environment where its sediments accumulated and were eventually lithified.

Sediment size (decreasing size)	Sedimentary rock	Environment of deposition
gravel	conglomerate	river beds, mountains
sand	sandstone	beaches, river sand bars, sand dunes
sand, silt, clay	graywacke	continental shelf
silt	siltstone	quiet water
clay	shale	very quiet water, lakes, swamps, shallow oceans

Mineral Content	Sedimentary Rock	Environment of Deposition
calcium carbonate skeletons of marine organisms	limestone	tropical reefs, beaches, warm shallow seas
precipitated calcium carbonate	travertine, tufa	hot spings, playas (dry lake beds), drying seas
gypsum	rock gypsum	playas, dryng seas
halite	rock salt	playas, drying seas

Lithification of sediments occurs in several ways. As sediments build up and lower layers are buried more deeply, they may become permeated by water. Minerals dissolved in the water are precipitated, filling the spaces between particles and **cementing** them together. This cementation helps to form many common sedimentary rocks, such as **shale**, **sandstone**, and most **conglomerates**. The evaporation of water may also form sedimentary rocks by leaving behind evaporites (previously dissolved minerals) such as **salt**. Deposits of **calcium carbonate**, usually created through the accumulation of calcium carbonate skeletal material (such as clams and corals), form the sedimentary rocks **limestone** and **dolostone**.

Igneous rocks form from the cooling of **magma** (molten rock underground) or **lava** (molten rock at the Earth's surface). When magma cools slowly underground, it has time to produce large crystals that are visible to the naked eye. Rocks that form in this manner, such as **granite**, are called **plutonic**. When magma comes to the surface (as lava), it cools quickly so that individual crystals are not visible, resulting in a **volcanic** rock such as **basalt**. In some circumstances, lava may cool so quickly that crystals do not form at all, creating a **glassy rock** such as **obsidian**. Smaller fragmental rocks that cool quickly at the surface form during explosive eruptions; these are called pyroclastic rocks, and they are composed of a variety of different volcanic ejecta.

Igneous Rock Classification

Igneous rocks differ not only in their cooling rates and subsequent crystal sizes, but also in their chemical compositions. Rocks found in continental crust, such as granite, have high silica content and low iron and magnesium content. They are light in color and are called *felsic*. Rocks found in oceanic crust, like basalt, are low in silica and high in iron and magnesium. They are dark in color and are called *mafic*.

Crystal size	Felsic	Intermediate	Mafic	Ultramafic
large (plutonic)	granite	diorite	gabbro	peridotite
small (volcanic)	rhyolite	andesite	basalt	--
none (glassy)	obsidian, tuff, pumice	obsidian	obsidian	--

Review

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

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

conglomerate • *a sedimentary rock composed of multiple large and rounded fragments that have been cemented together in a fine-grained matrix.*

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

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

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

dolostone • *a rock primarily composed of dolomite, a carbonate mineral.*

2 Rocks

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heat • *a form of energy transferred from one body to another as a result of a difference in temperature or a change in phase.*

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

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

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

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

Every rock is capable of being melted, weathered, or changed by **heat** and pressure. Any rock that has been subjected to intense heat and pressure can **recrystallize** into a **metamorphic rock**. This process destroys features in the rock that would have revealed its previous history, transforming it into an entirely new form as the minerals within realign. The pressure to transform a rock may come from burial by sediment or from **compression** due to plate movements, while the heat may come from very deep burial or from contact with magma.

Metamorphic Rock Classification

Metamorphic rocks are classified differently depending on the *protolith* (parent rock) they are made from. The following chart shows common rocks and the metamorphic rocks that they can become.

Parent rock	Metamorphic rocks
shale	slate, phyllite, schist, gneiss (in order of increasing heat and pressure)
granite	gneiss
sandstone	quartzite
limestone	marble
peridotite	serpentinite

As you read through this chapter, keep in mind that once you understand the geologic events that have affected a given region, you should be able to predict the type of rocks found in that area. For example, when plates collide, compression and friction melt the **crust**. The rising magma forms igneous **intrusions** that crystallize below the surface, producing large-grained igneous rocks such as granite. The rising magma may break through the surface in the form of volcanoes, creating volcanic rocks such as basalt. Tectonic collision also leads to increased heat and pressure, creating metamorphic rocks. Basins adjacent to mountains fill with transported sediment, producing thick sequences of sedimentary rock.

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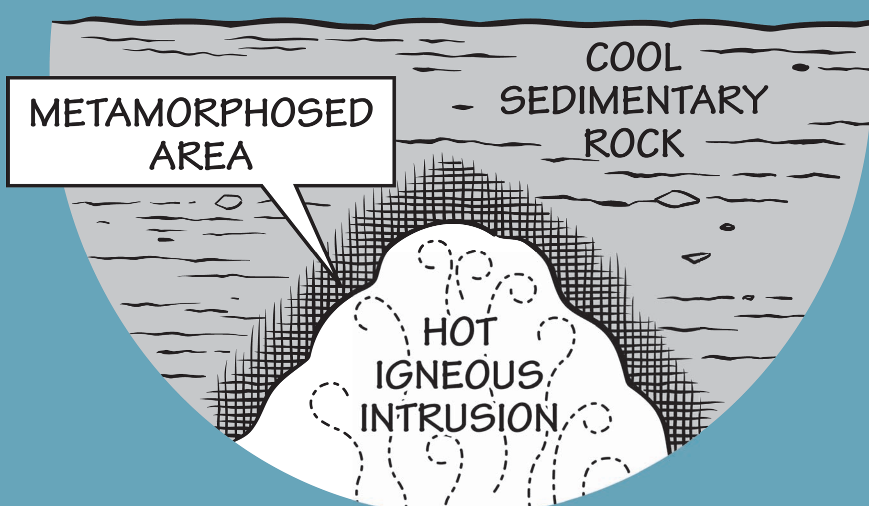
What happens to a rock when it is metamorphosed?

When rocks are subjected to high enough temperatures or pressures, their characteristics begin to change. The weight of overlying rock can cause minerals to realign perpendicularly to the direction of pressure, layering them in a pattern called *foliation*, as exemplified in gneiss and schist. Recrystallization, as seen in marble and quartzite, results as rock is heated to high temperatures, and individual grains reform as interlocking crystals, making the resulting metamorphic rock much harder than its parent rock.

Contact metamorphism describes a metamorphic rock that has been altered by direct contact with magma. Changes that occur due to contact metamorphism are greatest at the point of contact. The farther away the rock is from the point of contact, the less pronounced the change.



Regional or dynamic metamorphism describes a metamorphic rock that has been altered due to deep burial and great pressure. This type of metamorphic rock tends to occur in long belts. Different types of metamorphic rock are created depending on the gradients of heat and pressure applied.

foliation • *the arrangement of the constituents of a rock in leaflike layers.*

contact metamorphism • *the process by which a metamorphic rock is formed through direct contact with magma.*

regional (dynamic) metamorphism • *a metamorphic rock that has been altered due to deep burial and great pressure.*

2 Rocks

Review

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

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

till • *unconsolidated sediment that is eroded from the bedrock, then carried and eventually deposited by glaciers as they recede.*

outwash plain • *large sandy flats created by sediment-laden water deposited when a glacier melts.*

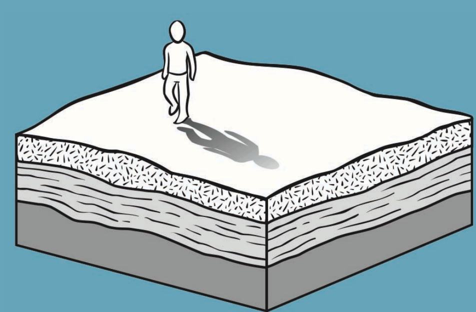
Mesozoic • *a geologic time period that spans from 252 to 66 million years ago.*

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

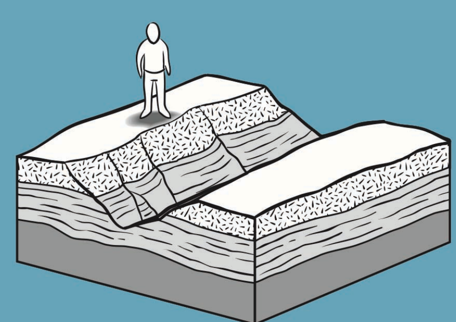
basement rocks • *the foundation that underlies the surface geology of an area, generally composed of igneous or metamorphic crystalline rock.*

Why do we see different kinds of rocks at the surface?

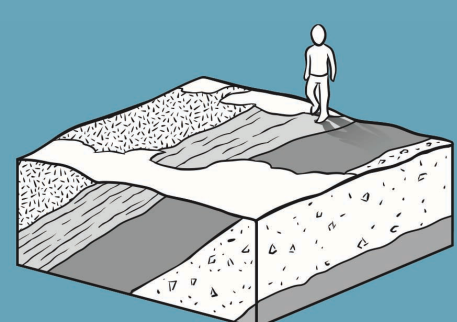
As you walk across the surface of the Earth, you will observe an amazing variety of rock types. If all rocks were flat-lying layers and there was no erosion, then we would only see one type of rock exposed on the surface. Often, however, rocks have been worn away (eroded), and the underlying layers are now exposed at the surface. Layers of rock may also be tilted, folded, or faulted to reveal the underlying rocks at the surface.



When rocks are flat-lying layers and there is no erosion, folding, or faulting, the person walking across the surface sees only one rock type.



When rocks are worn away (often by streams), the person walking across the surface sees the underlying layers of rock exposed.



When rocks are folded or tilted, the person walking across the surface sees several layers of rock exposed.

Rocks of the Central Lowland and Great Plains

Regions 1 and 2

The two **physiographic** regions of the Central Lowland and Great Plains are combined in this section due to their geological continuity. The Central Lowland, an area of low terrain that extends like a saucer with gently rising rims, stretches to meet the Great Plains on its western border in the eastern Dakotas and eastern Nebraska. In general, surface deposits in these two regions are composed of **Quaternary** glacial **tills** and **outwash** in the northernmost and easternmost plains, and **Mesozoic**-**Cenozoic** sediments in the western plains. Outcrops of older material are usually exposed by stream erosion, dissected terrain, or quarries. Erosional processes from the Missouri, Yellowstone, Little Missouri, Cheyenne, Niobrara, and Platte river systems dominate the area's active geology.

See Chapter 1: Geologic History for a geologic time scale on which you can reference the time periods described throughout this chapter.

The Great Plains and Central Lowland are underlain by a **basement** of igneous and metamorphic Precambrian rocks, some of which are up to 2.6 billion years old. These rocks are, for the most part, buried and inaccessible, with the exception of the Black Hills in southwestern South Dakota and the Sioux Arch in southeastern South Dakota.

The Sioux Arch area contains **Proterozoic** Sioux Quartzite, a formation of pink and red **orthoquartzite** with **cross-bedding**, ripples, and mudcracks. It consists largely of conglomerates formed from stream deposits, sandstones from **braided streams** and **alluvial** plains, and red to purple mudstones from tidal and lagoonal deposits. These materials, eroded from **Archean** granites, sandstones, and **iron** formations, were deposited between 1.8 and 1.6 billion years ago before being subjected to mild metamorphism.

Although the Sioux Quartzite is largely overlain by **Cretaceous** rocks and **Pleistocene** glacial materials, it appears in small outcrops in southeastern South Dakota and adjacent Minnesota, and is exposed in abundance at Sioux Falls Park along the Big Sioux River (*Figure 2.2*). The **quartzite** is quarried for building and decorative material (*Figure 2.3*), and the mudstones are also known as "pipestone" since Native Americans quarried them for pipes and carvings (*Figure 2.4*).

The most dramatic outcrops of Precambrian rocks within the Great Plains and Central Lowland are located in South Dakota's Black Hills. The Black Hills are the easternmost outlier of the Cordilleran system, **uplifted** during the **Laramide Orogeny** between 68 and 65 million years ago. The range is cored by a complex set of 3.5- to 2.5-billion-year-old Archean rocks that

Regions 1–2

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

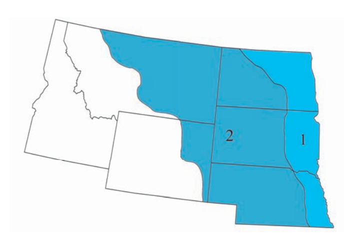
orthoquartzite • *a sandstone composed nearly entirely of well-rounded quartz grains cemented by silica.*

cross-bedding • *layering within a bed in a series of rock strata that does not run parallel to the plane of stratification.*

braided stream • *a stream consisting of multiple, small, shallow channels that divide and recombine numerous times, forming a pattern resembling strands of braided hair.*

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

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



Regions 1–2

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

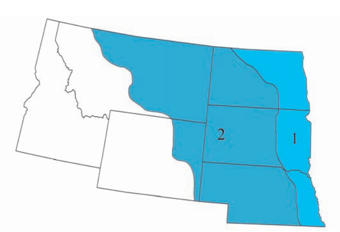
gneiss • *a metamorphic rock that may form from granite or layered sedimentary rock such as sandstone or siltstone.*

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

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

Figure 2.2: Sioux Falls Park, Sioux Falls, South Dakota.

Figure 2.3: Sioux Quartzite was used to construct the Federal Building in Sioux Falls, South Dakota.



were later deformed and metamorphosed into various **schists** and **gneisses** accompanied by the intrusion of granitic rocks. At the very center of the uplift is the notable 1.7-billion-year-old Harney Peak granite **batholith** from which Mt. Rushmore is carved (*Figure 2.5*). Related **pegmatites** known for a great variety of spectacular minerals and crystals are also found here.

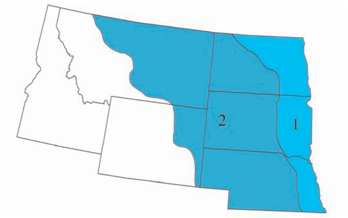
Regions 1–2

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

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

Figure 2.4: Native American pipe bowl, carved from pipestone into the shape of an owl.

Figure 2.5: Mt. Rushmore, carved from the Harney Peak granite.



Thick sequences of **Paleozoic** and Cenozoic sedimentary rocks cover the basement beneath the Great Plains. Layers of limestone and shale were deposited when shallow seas repeatedly flooded the area, while sandstones accumulated from **sandy** beaches were left behind as the seas retreated. These sedimentary layers are largely undeformed except where they have been pushed up and exposed by uplift in the Black Hills. Here, extensive cave

Mississippian • *a subperiod of the Carboniferous, spanning from 359 to 323 million years ago.*

speleothem • *an often-delicate mineral deposit in limestone or dolostone caves, formed through the dissolution of carbonate minerals.*

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

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

Permian • *the geologic time period lasting from 299 to 252 million years ago.*

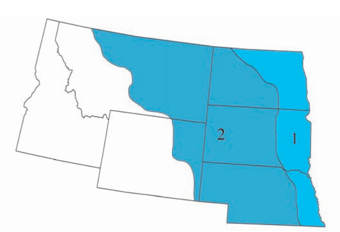
systems formed in the **Mississippian**-aged Madison limestone (locally known as Pahasapa limestone) after the layers were uplifted and subjected to surface erosion (*Figure 2.6*). The delicate formations found in these caves today, called **speleothems**, are mineral deposits that formed in more recent times.

Unless rock layers are over-turned, older rocks are found at the bottom and younger rocks are found at the top of a sedimentary sequence. This is known as the *Law of Superposition*.

Figure 2.6: Jewel Cave in the Black Hills of South Dakota. The cave was formed as acid-rich water gradually dissolved layers of limestone that had been cracked by the uplift of the Black Hills around 60 million years ago.

In easternmost Nebraska, a small area of **Carboniferous** strata is exposed at the surface thanks to erosion from the Mississippi River. The dark shales and **coal** beds in this area originate from a swampy shoreline and oxygen-poor continental shelf. Here, rivers flowing from the east deposited sediments eroded from the Appalachian Mountains. A band of **Permian** bedrock is also exposed in the southeastern portion of Nebraska, deposited there as sea levels moved back and forth across the state during the late Paleozoic.

See Chapter 3: Fossils to learn about the diverse fossils found in Nebraska's Carboniferous rocks.



Regions 1–2

Throughout the Mesozoic, shallow seas periodically covered much of North America's interior. The sedimentary deposits resulting from the water's advance and retreat became the limestones, shales, and sandstones that are now near the surface and actually outcrop in many areas of the Great Plains. For example, **Triassic** and **Jurassic** deposits of red **silts** and **clays** surround the Black Hills in a ring, providing evidence of an ancient arid coastal plain and **intertidal** mudflats. These red stones and interbedded layers of **gypsum** are part of a geological formation called the Spearfish Formation, which extends from the Dakotas into Montana, Wyoming, and Nebraska. The Belle Fourche River, which flows from Wyoming to South Dakota, cuts through and exposes these layers (*Figure 2.7*).

Figure 2.7: The Spearfish Formation is cut by the Bell Fourche River near Devils Tower National Monument, Wyoming.

During the Cretaceous period, the interior of North America was **downwarped** by tectonic processes associated with the **subduction** of oceanic **lithosphere** along the western edge of North America. As the Laramide and **Sevier orogenies** occurred to the west, the North American interior was flooded by a particularly vast inland sea called the Western Interior Seaway (*Figure 2.8*). Episodes of **transgression** and **regression** deposited thousands of feet of marine and terrestrial sedimentary rock across the Great Plains and Central Lowland. As the Cretaceous drew to a close, mountain building progressed eastward, and the vast inland sea receded for the final time. The pattern of sedimentation transitioned from marine, to near shore, and finally to on-land **gravels**, sands, and muds deposited by the action of streams and rivers flowing eastward from the elevated Rockies. These continental deposits covered the entire Great Plains progressively from north to south.

Triassic • *a geologic time period that spans from 252 to 201 million years ago.*

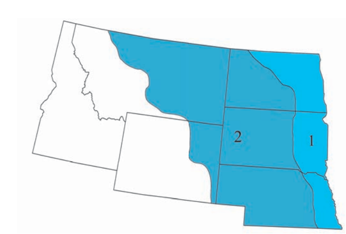
Jurassic • *the geologic time period lasting from 201 to 145 million years ago.*

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

clay • *the common name for a number of very fine-grained, earthy materials that become plastic (flow or change shape) when wet.*

intertidal • *areas that are above water during low tide and below water during high tide.*

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

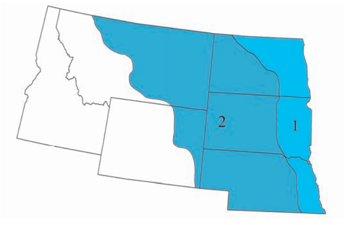


Regions 1–2

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

Inland sea **may sound like a contradiction in terms, but there is a very simple, yet important, distinction that differentiates it from other seas: an inland sea is located on continental crust, while other seas are located on oceanic crust. An inland sea may or may not be connected to the ocean. For example, Hudson Bay is on the North American plate and connects to the Atlantic and Arctic oceans, while the Caspian Sea is on the European plate but does not drain into any ocean.**

Figure 2.8: The Western Interior Seaway.



Regions 1–2

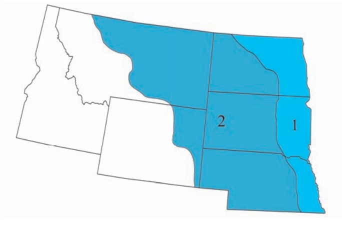
Why are there different sedimentary rocks in different environments?

Most sedimentary rock deposited in underwater settings originated from material eroded on land and washed down streams or rivers before settling to the bottom of a body of water. Intuitively, the faster the water is moving, the larger the sediments it may carry. As the water slows down, the size of sediments it can carry decreases. Furthermore, the farther the grains of sediment are carried, the more rounded they become as they are tumbled against each other. In this way, rivers emptying into a sea are effectively able to sort sediment. Near the mouth of the river, the water is still relatively high-energy, dropping only the largest pieces; farther from the shore, the dropped particles get smaller. Therefore, conglomerates and sandstones are interpreted to have been deposited on or near the shore, siltstone farther from the shore, and shale in deep water quite far from shore where currents are slow enough that even very tiny particles may settle.

Increased distance from shore and water depth can also reduce the presence of oxygen in the water, causing organic material to decompose less completely. This causes darker, carbon-rich rocks (including some that contain exploitable *fossil fuels*) to form in these areas. Limestone is made primarily of calcium carbonate, the components of which are dissolved in the water. Living creatures, like coral and *foraminifera*, take those components out of the water to make calcium carbonate shells, which, after the creatures die, accumulate to become limestone. These shelled creatures tend to fare better in clear water, so limestone usually forms far from other sources of sediment. While this process happens over much of the seafloor, if more than 50% of the sediment being deposited is from another source, the rock that forms is, by definition, not limestone.

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

foraminifera • *a class of aquatic protists that possess a calcareous or siliceous exoskeleton.*



Regions 1–2

phonolite • *an extrusive igneous rock of intermediate composition, which forms from magma with a relatively low silica content.*

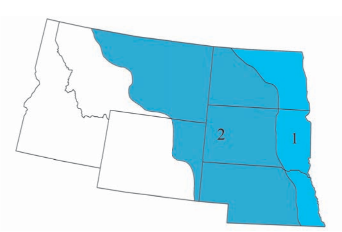
feldspar • *an extremely common, rock-forming mineral found in igneous, metamorphic and sedimentary rocks.*

columnar joint • *five- or six-sided columns that form as cooling lava contracts and cracks.*

joint • *a surface or plane of fracture within a rock.*

syenite • *a durable, coarse-grained intrusive igneous rock, which is similar to granite but contains less quartz.*

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



Tectonic activity associated with the Laramide Orogeny also generated volcanism and igneous intrusions near the area of mountain building. The famous Devils Tower, an exposed igneous intrusion that rises 386 meters (1267 feet) above the surrounding terrain, lies in Wyoming just west of the Black Hills (*Figure 2.9*). Devils Tower is composed of **phonolite**, a gray or greenish gray igneous rock containing conspicuous crystals of white **feldspar**. This igneous rock exhibits spectacular **columnar jointing**, indicating that it cooled quickly at a shallow depth. A popular interpretation for the formation of this landmark classifies it as a solidified volcanic neck, but alternate interpretations peg it as a laccolith or other shallow intrusive body. Just 6 kilometers (3.5 miles) to the northwest of Devils Tower lies a set of four summits, the Missouri Buttes, which are also composed of **jointed** phonolite of the same age (*Figure 2.10*). A similar landform in Montana, Snake Butte, is also the result of an igneous intrusion; it is composed of a coarse-grained igneous rock called **syenite**, and it also exhibits columnar jointing (*Figure 2.11*). Syenite is particularly durable, and was an important source of material used to build the Ft. Peck Dam in the 1930s.

Figure 2.9: Devils Tower, a large intrusive igneous rock formation with well-developed columnar jointing, in Crook County, Wyoming.

Volcanic eruptions in the Rockies during the **Neogene** and **Paleogene** generated ash that was carried eastward by the prevailing winds, and often fell across the Great Plains in thick layers. The Ashfall Fossil Beds in northeastern Nebraska are an example of one such location, formed after a dense **volcanic ash** fall that occurred in the late

See Chapter 3: Fossils for more about mammal fossils preserved in ash.

Regions 1–2

Columnar Jointing

As a lava flow cools, it contracts, and the resulting force may cause the rock to crack. These cracks continue down to the bottom of the flow, resulting in five- or six-sided columns. Columnar joints are not restricted to basalt flows and can form in ashflow tuffs as well as shallow intrusions. The columns are generally vertical, but may also be slightly curved.

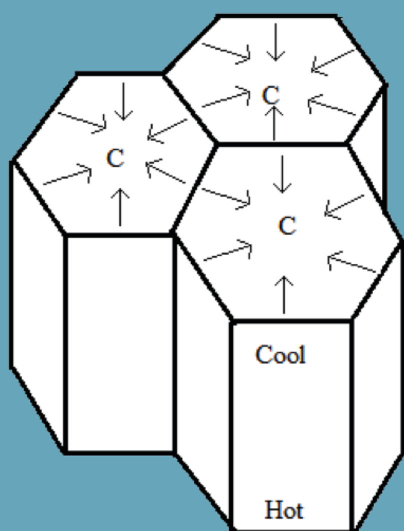
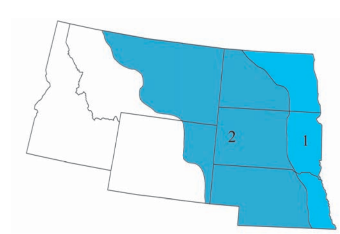


Figure 2.10: Devils Tower and the Missouri Buttes at sunrise.

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

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



Miocene. Sentinel Butte in North Dakota also contains a widespread ash and **bentonite** deposit that is up to 8 meters (25 feet) thick in some areas (*Figure 2.12*).

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

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

floodplain • *the land around a river that is prone to flooding.*

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).*

ice cap • *an ice field that lies over the tops of mountains.*

badlands • *a type of eroded topography that forms in semi-arid areas experiencing occasional periods of heavy rainfall.*

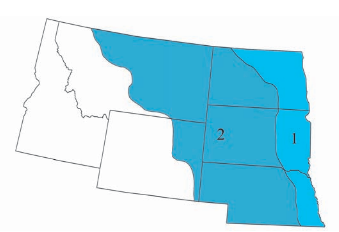


Figure 2.11: Columnar jointing at Snake Butte, an exposed igneous sill located on the Ft. Belknap Reservation in Montana.

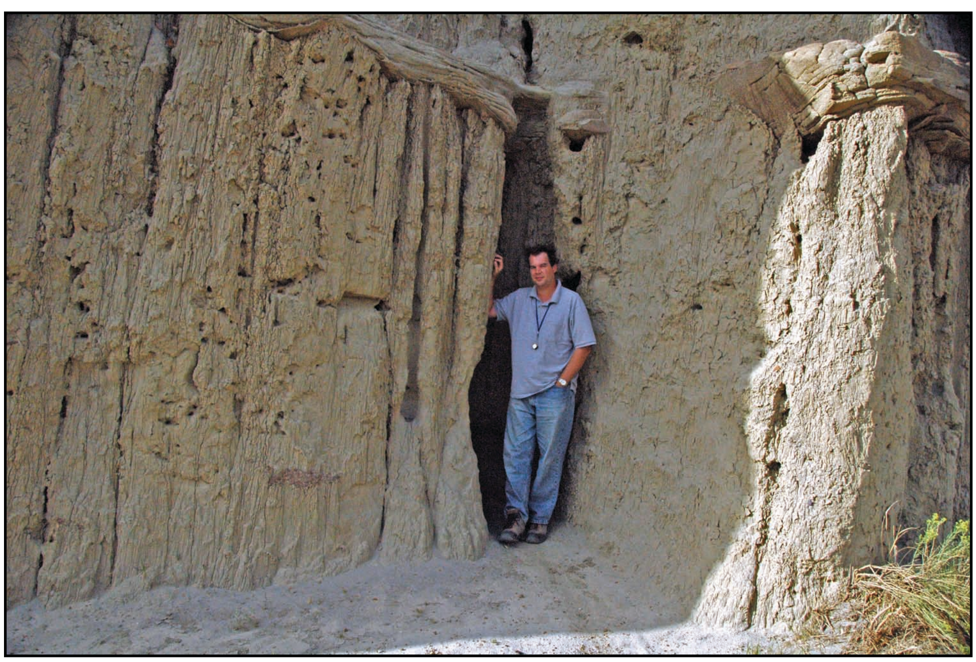


Figure 2.12: The Sentinel Butte Formation, a Paleocene ash deposit in the Little Missouri Badlands of North Dakota.

Regions 1–2

During the Cenozoic, many sediments were deposited in terrestrial environments such as lakes, rivers, and **floodplains**. These deposits cover the region's Cretaceous rocks in two large areas. The first, comprising mostly **Paleocene** sediments, is located in the northern Great Plains of Montana, Wyoming, and the Dakotas. The other area includes a large tract of late Paleocene to Neogene strata that has escaped much erosional loss, and constitutes the High Plains subdivision of the Great Plains between Nebraska and Texas. The sandstones in the High Plains Ogallala Formation house the famous Ogallala or High Plains Aquifer. Water in the Ogallala Aquifer, stored since Quaternary times, is now being withdrawn by extensive agricultural development at rates exceeding recharge in the modern **climate** regime.

See Chapter 10: Earth Hazards to learn about the effects of drought and agriculture on the Ogalalla Aquifer.

Rivers flowing eastward out of the Rocky Mountains since the early Cenozoic have eroded and carried sediment towards the plains. The process was intensified by the successive accumulation and melting of mountain glaciers and **ice caps** over many of the mountain ranges in the Rockies. These rivers, continually cutting into and removing earlier sedimentary cover, have thereby created much of the scenery and spectacular rock outcrops found in the Great Plains. Some examples include the Upper Missouri Breaks National Monument in central Montana (*Figure 2.13*), Badlands National Park in southwestern South Dakota (*Figure 2.14*), and the Scotts Bluff National Monument in western Nebraska (*Figure 2.15*). Many of these sculpted **badland** areas also contain abundant **concretions** and **nodules**, hard rounded bodies of rock formed by the precipitation of dissolved minerals, and later exposed by erosion. For example, large spherical sandstone concretions called "cannonballs" are common in the Sentinel Butte Formation of western North Dakota (*Figure 2.16*).

See Chapter 4: Topography for more on badland landscapes.

The Quaternary deposits of the Great Plains and Central Lowland are primarily related to glacial processes. During the ice age, the **Laurentide Ice Sheet** advanced several times in four main pulses and covered northern Montana and most of the Dakotas, and also penetrated into Nebraska and Kansas. The advancing **ice sheet scoured** and abraded the bedrock beneath it, breaking it down from huge boulders into fine dust, called **rock flour**. When the glaciers retreated, till and outwash were carried in meltwater and deposited in lakes or by streams. Rock flour and sand was picked up by the wind and blown for many kilometers (miles) until it settled into thick layers of **loess** (*Figure 2.17*). The Sandhills of Nebraska are perhaps the best-known example of wind-transported glacial sediments in the Great Plains.

See Chapter 6: Glaciers for more information about how glaciation altered the Northwest Central's landscape.

Paleocene • *a geologic time interval spanning from about 66 to 56 million years ago.*

concretion • *a hard, compact mass, usually of spherical or oval shape, found in sedimentary rock or soil.*

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

Laurentide Ice Sheet • *an ice sheet that covered most of Canada during the last major glaciation.*

ice sheet • *a mass of glacial ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).*

scouring • *erosion resulting from glacial abrasion on the landscape.*

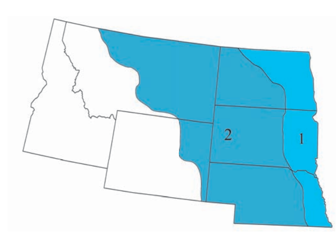


Figure 2.13: The Upper Missouri Breaks in central Montana are composed of Mesozoic and Cenozoic shales, sandstones, and volcanic materials.

Figure 2.14: The Brule Formation, exposed in Badlands National Park, is a sequence of fine-grained mudstones, claystones, and siltstones interbedded with freshwater carbonate rock, volcanic ash, and sandstone. These sediments were deposited during the Oligocene, 34-30 million years ago.

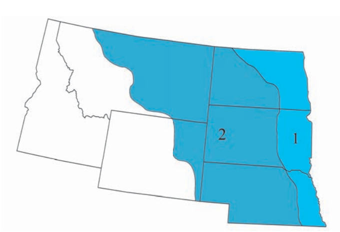


Figure 2.15: Scotts Bluff exposes 225 meters (740 feet) of Paleogene-Neogene terrestrial sediments, including sandstone, limestone, and volcanic material.

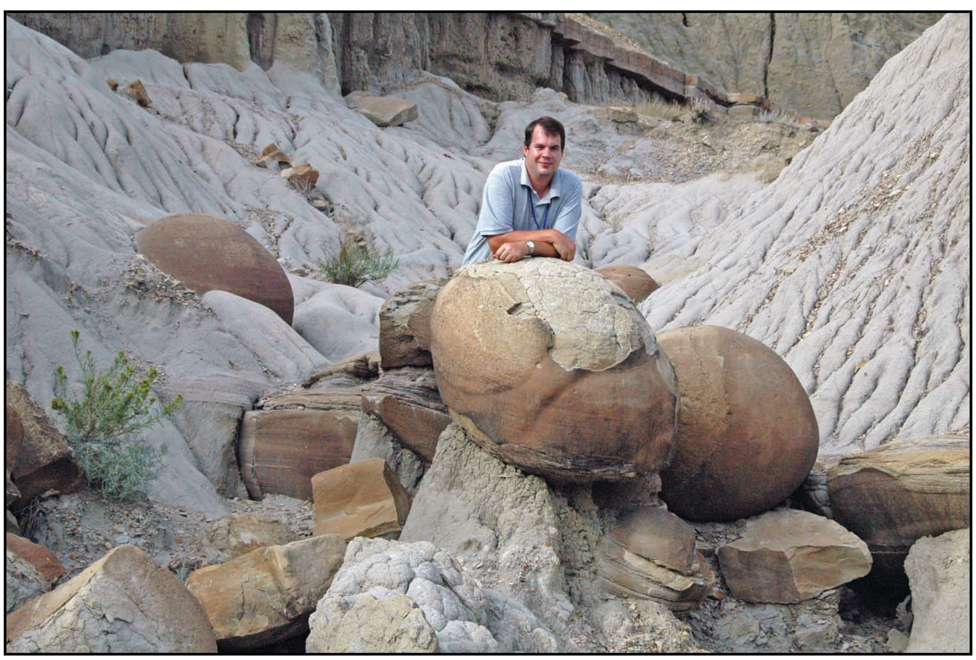
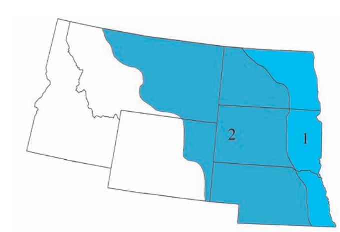


Figure 2.16: Cannonball concretions in the Sentinel Butte Formation, Theodore Roosevelt National Park, North Dakota.



2

Rocks

Regions 1–3

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.*

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

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.*

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

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

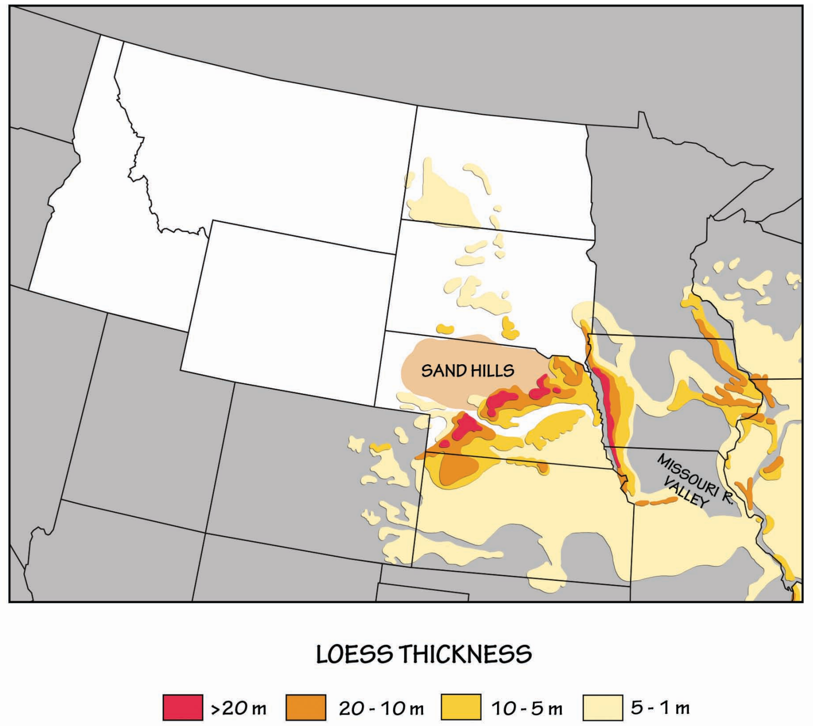


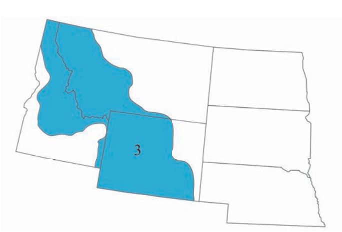
Figure 2.17: Loess deposits in the central US. (See TFG website for full-color version.)

Rocks of the Rocky Mountains
Region 3

The rocks of the Rocky Mountain region are the most varied in the Northwest Central, ranging from Archean gneisses—some of the oldest rocks found in the US—to Paleozoic **reefs**, **oil** shales, volcanic fields, and glacial till. This great variety of rock types is mainly a result of the Laramide and Sevier orogenies, which uplifted numerous discrete blocks of terrain along thrust **faults** that accommodated compressional shortening and thickening of the crust. The overlying sediments were subsequently eroded to expose deeper Precambrian rock as well as Mesozoic and Paleozoic sedimentary formations. The thrust-faulted uplift also produced adjacent basins, which subsequently accumulated sediments eroded from the surrounding mountains.

See Chapter 1: Geologic History to learn more about mountain building during the Laramide and Sevier orogenies.

The oldest rock found so far in the Rocky Mountain region is a 3.65- to 3.8-billion-year-old granitic gneiss found in the Wind River Range. Other Archean-aged rocks, including gneisses, **amphibolites**, schists, and iron formations, are found throughout the uplifted ranges of Wyoming, Montana, and Idaho, including



the Teton, Bighorn, Beartooth, and Wind River mountains (*Figure 2.18*). These rocks were formed when **cratons** collided between 3.6 and 3 billion years ago, producing belts of metamorphosed and deformed rock. In southwest Montana, the mountains contain excellent examples of metamorphosed sedimentary rocks with interesting occurrences of minerals (blue **calcite**, rubies, and more), schists, **marble**, quartzite, iron formations, and greenstone. At the southern end of the Wind River Mountains, a **greenstone belt** hosts **gold** deposits, and the Granite Mountains host a thick iron formation with metamorphosed sediments, greenstone, gold deposits, and good examples of **komatiites**.

A gneiss is a very highly metamorphosed rock with alternating bands of dark and light minerals. The dark bands are mafic and higher in magnesium and iron, while the lighter bands are felsic and higher in silicates. These bands may form because extreme temperature and pressure cause a *chemical reaction* that forces the different elements into separate layers. Banding may also occur when a set of varied protoliths are subjected to extreme *shearing* and sliding forces, causing them to stretch into stacked sheets.

Figure 2.18: Cathedral Peak in the Wind River Range, Wyoming, is composed of Archean-aged granitic gneiss.

Region 3

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

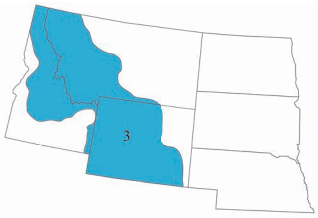
marble • *a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite.*

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

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

komatiite • *mafic volcanic rocks richer in magnesium and erupted at a higher temperature than basalts.*

chemical reaction • *a process that involves changes in the structure and energy content of atoms, molecules, or ions but not their nuclei.*



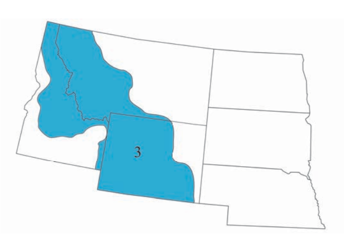
2 Rocks

Region 3

Snowy Pass Supergroup • *a 2.4–2.5 billion year old series of sedimentary rocks, located in the Medicine Bow Range in southern Wyoming.*

Belt Supergroup • *a 1.45-billion-year-old series of sedimentary rocks, found in the Northern Rocky Mountains, that contain sandstones and mudstones.*

orogeny • *a mountain-building event generally caused by colliding plates and compression of the edge of the continents.*



Greenstones

A greenstone belt is a term used to describe a series of interlayered volcanic and sedimentary rocks that have been metamorphosed into meta-sedimentary rocks and amphibolite. The rocks are called "greenstones" due to the presence of metamorphic minerals that give the rock a greenish-grey color. Many geologists believe these belts are the result of deposition in volcanic arc environments. An unusual volcanic rock type—komatiite—is often found in Archean greenstone belts. Komatiites are mafic volcanic rocks richer in magnesium and erupted at a higher temperature than basalts. They are restricted to the Archean, when the mantle temperatures were higher at the depths where magma is generated. Komatiites often exhibit "spinifex texture," which is an unusual crystallization-cooling texture that produces large, long crystals.

Spinifex texture in a komatiite from the Komati Formation greenstone in South Africa. Similar rocks are common in the Archean greenstones of Wyoming.

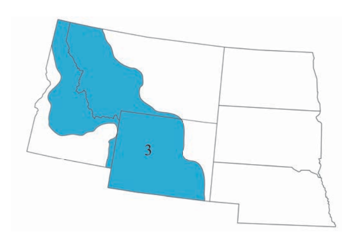
Two main groups of Proterozoic rocks record the early formation of the North American continent: the **Snowy Pass Supergroup** and the **Belt Supergroup**. The Snowy Pass Supergroup, 2.4–2.5 billion years old, is located in the Medicine Bow Range in southern Wyoming. These strata—thick sequences of sandstone, conglomerate, and limestone—were deposited in a continental shelf environment on the passive margin of proto-North America. The sediments were later metamorphosed by an **orogenic** episode accompanied by volcanic activity. Today, the Medicine Peak quartzite forms high cliffs along the ridge of the Medicine Bow Range (*Figure 2.19*). Metamorphosed limestones in the Snowy Range also host 2.3-billion-year-old **stromatolites**, or mats of colonial **cyanobacteria** (*Figure 2.20*).

Figure 2.19: Medicine Bow Peak, a ridge of 2.4-billion-year-old quartzite (metamorphosed sandstone) in the Medicine Bow Range, Wyoming.

Figure 2.20: Stromatolite in metamorphosed Proterozoic dolostone from the Nash Formation, Medicine Bow Range, Wyoming.

stromatolite • *regularly banded accumulations of sediment created by the trapping and cementation of sediment grains in bacterial mats.*

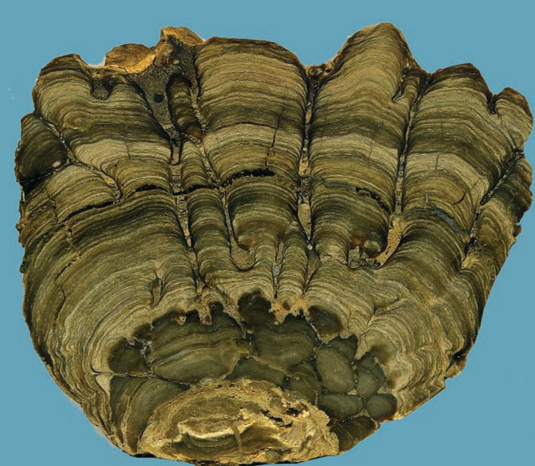
cyanobacteria • *a group of bacteria, also called "blue-green algae," that obtain their energy through photosynthesis.*



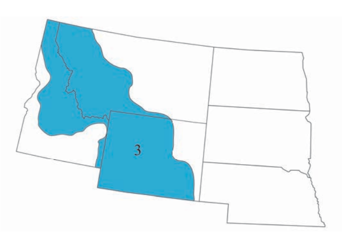
Stromatolites

Stromatolites are regularly banded accumulations of sediment created by the trapping and cementation of sediment grains in bacterial mats (especially photosynthetic cyanobacteria). Cyanobacteria emit a sticky substance that binds settling clay grains and creates a chemical environment that leads to the precipitation of calcium carbonate. The calcium carbonate then hardens the underlying layers of bacterial mats, while the living bacteria move upward so that they are not buried. Over time, this cycle of growth combined with sediment capture creates a rounded structure filled with banded layers.

Stromatolites peaked in abundance around 1.25 billion years ago, and likely declined due to predation by grazing organisms. Today, stromatolites exist in only a few locations worldwide, such as Shark Bay, Australia. Modern stromatolites form thick layers only in stressful environments, such as very salty water, that exclude animal grazers. Even though there are still modern stromatolites, the term is often used to refer specifically to fossils. For more information, see Chapter 3: Fossils.



A stromatolite from the Green River Formation (Eocene) of southwestern Wyoming.



Region 3

The Belt Supergroup is located in northwestern Montana and adjacent Idaho, and is composed of a sequence of low-grade metamorphic sandstones, siltstones, mudstones, shales, and limestones over 10 kilometers (6 miles) thick. These rocks come in many **colors**—orange, yellow, rusty, red, purple, and green with white quartzite. They were deposited in a large sedimentary basin between 1.4 and 1.1 billion years ago, and they preserve many fossils as well as sedimentary structures including **ripple marks**, mudcracks, and raindrops. Rocks from the Belt Supergroup are best seen in Glacier National Park, Montana, where they have been exposed by an extensive system of thrust faults and folds related to the subduction of the Farallon plate beneath western North America in the late Cretaceous. The Belt Supergroup is of particular note due to its age and excellent preservation. It is extremely rare for sedimentary rocks of over a billion years in age to not have been warped, tilted, metamorphosed, or otherwise altered. The Belt Supergroup is also famous for its abundant and well-preserved stromatolites. In addition, ancient **tillites** (glacial deposits) found in Idaho represent major glaciation events that occurred during the Proterozoic (*Figure 2.21*).

See Chapter 4: Topography for more about the Lewis Overthrust, which exposes rocks of the Belt Supergroup.

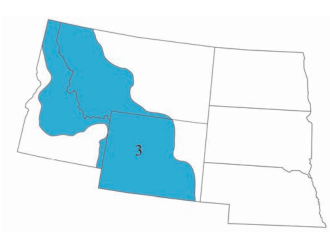
See Chapter 6: Glaciers to learn about Proterozoic glacial periods.

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

ripple marks • *surface features created when sediment deposits are agitated, typically by water currents or wind.*

tillite • *glacial till that has been compacted and lithified into solid rock.*

Figure 2.21: Diamictite, a type of tillite from the Pocatello Formation near Pocatello, Idaho. This rock is thought to have been deposited during the "Snowball Earth" Proterozoic glacial period.



Region 3

Cambrian • *a geologic time period lasting from 541 to 485 million years ago.*

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

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

aeolian • *pertaining to, caused by, or carried by the wind.*

While most of the ranges and uplifts in the Rocky Mountains are cored by Archean rocks, two major areas are not. The Snake and Salt River Ranges of western Wyoming and adjacent Idaho, and the range just west of Choteau, Montana, consist of Paleozoic and Mesozoic units faulted and uplifted during the Sevier Orogeny. The ranges of central Idaho are primarily made up of the three major lobes of the Idaho Batholith, a set of late Cretaceous granitic intrusions (*Figure 2.22*).

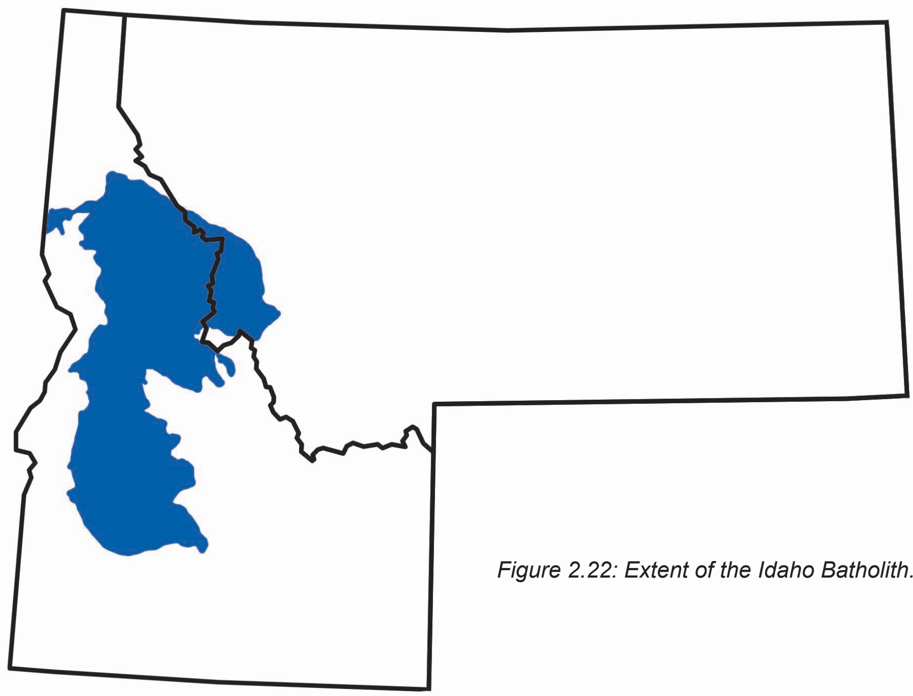
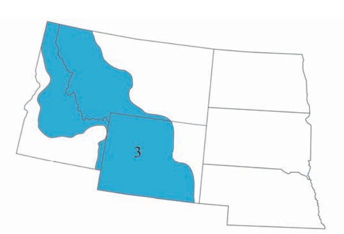


Figure 2.22: Extent of the Idaho Batholith.

The **Cambrian** to Mississippian rocks of the Rocky Mountain region are a succession of sandstones, limestones, and shales that were deposited on the continental shelf of what was then the western shore of North America (*Figure 2.23*). From the **Pennsylvanian** through the Permian, a transition to shallow and evaporating seas deposited sandstones, mudstones, limestones, and **phosphate**-rich rocks. During the Triassic, a hot and arid landscape stretched across the region, as the shallow seas of the previous era retreated. This led to the deposition of continental rocks on nearshore marine environments and vast floodplains: red beds, sandstones, mudstones, and limestones. Others were deposited by **aeolian** processes; the Nugget Sandstone, found in parts of southwest Wyoming, exhibits cross-bedding and was deposited by wind on a Jurassic shoreline or desert. The bright red and orange colors of many Mesozoic siltstones and sandstones are caused by the presence

See Chapter 3: Fossils for more information about Wyoming's Mesozoic fossils.



of iron **oxides** (*Figure 2.24*). During the Cretaceous, shales, sandstones, and coals formed when the epicontinental Western Interior Seaway covered the area (*see Figure 2.8*).

Figure 2.23: Ridges of the Mississippian-aged Madison Limestone, exposed by thrust faulting along the Rocky Mountain Front in Montana.

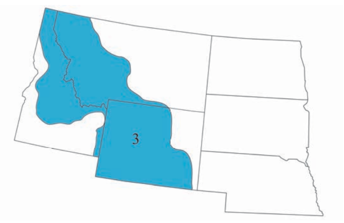
oxidation *• a chemical reaction involving the loss of at least one electron when two substances interact.*

intermontane *• between or among mountains.*

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

Between the main ranges of the Rockies, there are a series of **intermontane** basins and mesas (*Figure 2.25*); surface rocks here are predominantly of Cretaceous and early Cenozoic age. Most of the rocks were formed when eroded sediment from the uplifted mountains was deposited by rivers into alluvial fans in lakes, basins, and swamps. These deposits eventually formed conglomerates, sandstones, mudstones, shales, **evaporites**, coal, and limestone. Thick blankets or wedges of Paleogene and Neogene sediments were deposited on the flanks of uplifted mountains. Paleozoic, Triassic, and Jurassic rocks crop out where they are uplifted at the margins of uplifts and ranges, but are typically buried within the basins.

The most important intermontane basins in the Rocky Mountain region are the Green River, Bighorn, Wind River, and Red Desert basins. These areas were centers for the deposition of thick layers of shale and mudstone into lakes, later forming evaporite beds as the lakes dried. The best known of these basin deposits are the sediments of the Green River Basin, which include well known fossil beds, oil shales, and large coal deposits. It is also the world's largest source of trona, a non-marine evaporate mineral, along with related minerals including sodium bicarbonate (baking soda). Because of the basins' isolated



2 Rocks

Region 3

butte *• an isolated hill with steep, often vertical sides and a small, relatively flat top.*

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

Figure 2.24: An outcrop of Triassic sandstone near Thermopolis, Wyoming.

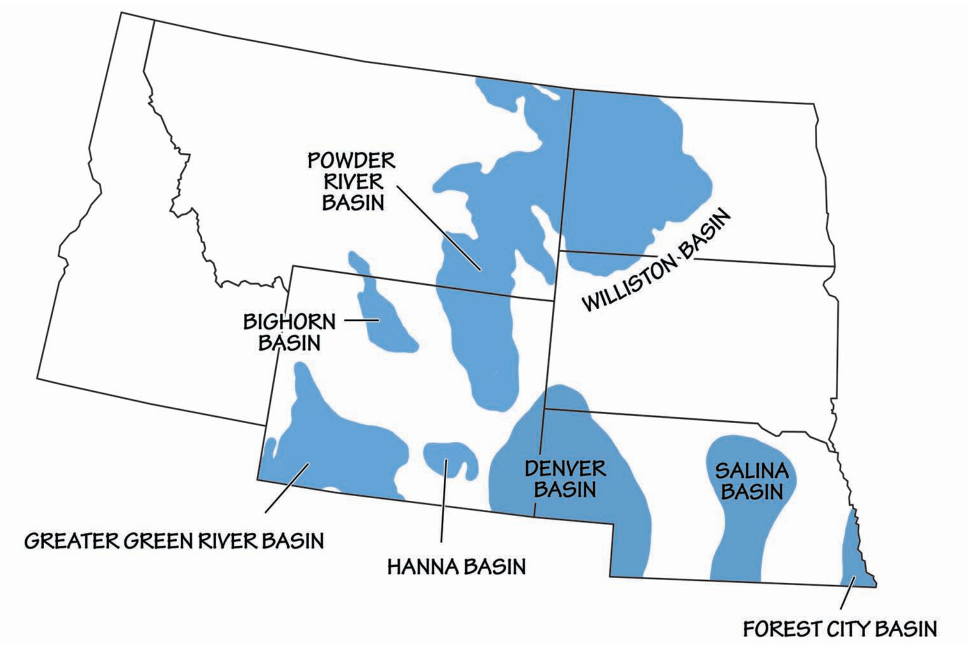
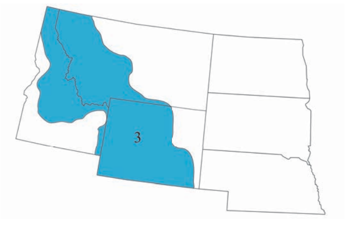


Figure 2.25: Geologic basins of the Northwest Central US.



nature, early Cenozoic deposits are mainly basin-specific, with individual units often restricted to a particular basin or set of related basins. Some basins also contain igneous outcroppings—for example, Boars Tusk, an isolated **butte** within the Green River Basin, is the heavily eroded **lamproite** core of a 2.5-million-year-old volcano (*Figure 2.26*).

Figure 2.26: Boars Tusk, located within Sweetwater County, Wyoming, is the core of an extinct volcano.

During the Neogene, large volcanic eruptions related to the Yellowstone **hot spot** periodically buried parts of the region in thick layers of ash, forming **tuff** (*Figure 2.27*). Active **Eocene** volcanism and plutonism produced the Absaroka Volcanic Field in northwestern Wyoming, as well as smaller fields and intrusive bodies in Montana and Idaho. The Absaroka volcanics are up to 1500 meters (5000 feet) thick, and are composed of **andesites**, **dacites**, basalts, tuffs, and mudflows with minor related igneous intrusions (*Figure 2.28*).

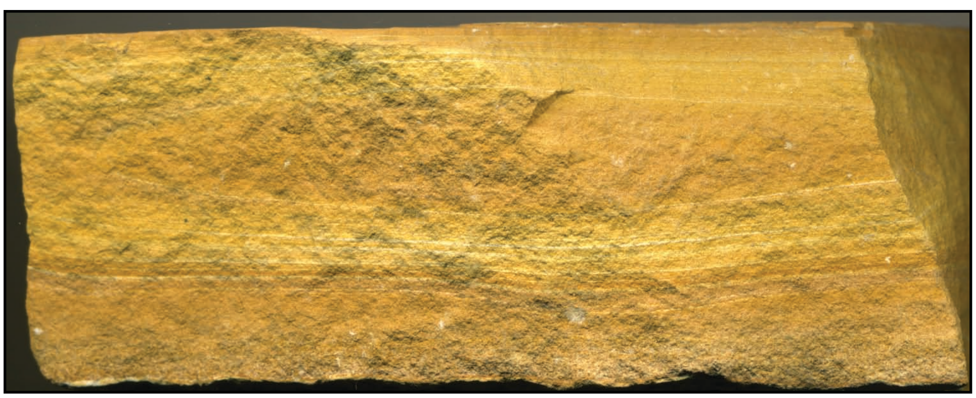


Figure 2.27: Volcanic ashfall tuff from the Eocene, Green River Formation, Wyoming.

A *pluton* is a large body of igneous rock that formed under the Earth's surface through the slow crystallization of magma. The term comes from Pluto, the Roman god of the underworld.

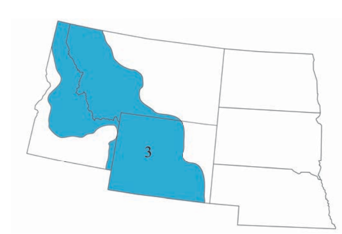
hot spot • *a volcanic region thought to be fed by underlying mantle that is anomalously hot compared with the mantle elsewhere.*

tuff • *a pyroclastic rock made of consolidated volcanic ash.*

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

andesite • *a fine-grained extrusive volcanic rock, with a silica content intermediate between that of basalt and dacite.*

dacite • *a fine-grained extrusive igneous rock, with a silica content intermediate between that of andesite and rhyolite.*



Region 3

cirque • *a large bowl-shaped depression carved by glacial erosion and located in mountainous regions.*

moraine • *an accumulation of unconsolidated glacial debris (soil and rock) that can occur in currently glaciated and formerly glaciated regions.*

caldera • *a collapsed, cauldron-like volcanic crater formed by the collapse of land following a volcanic eruption.*

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

geyser • *a hot spring characterized by the intermittent explosive discharge of water and steam.*

earthquake • *a sudden release of energy in the Earth's crust that creates seismic waves.*

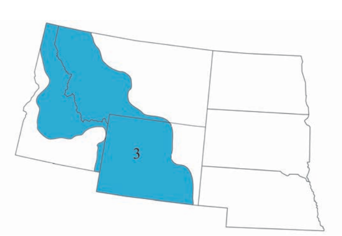


Figure 2.28: An andesite dike intrudes through a volcanic debris flow conglomerate exposed by a roadcut in the Absaroka Range, Wyoming.

Pleistocene glaciation produced glacial till and outwash materials in the region's mountains and basins. Alpine glaciers, rather than continental ice sheets, carved **cirques** and deposited **moraines** in mountain valleys.

Greater Yellowstone Area

Yellowstone National Park and its surrounding area are the latest and current manifestation of the Yellowstone hot spot, whose trail from Oregon to Wyoming produced the Snake River Plain in Idaho. The most recent **caldera** eruption associated with this hot spot occurred 640,000 years ago, and more recent minor eruptive activity produced **rhyolitic** domes and basalt flows. The Yellowstone area is rich with volcanic features, such as calderas, resurgent domes, lava flows, and hydrothermal explosion craters. Yellowstone also has the world's greatest number of **geysers**, along with hot springs, fumaroles, and mudpots. **Earthquakes** are common here, and many are related to faults connected with the movement of magma, groundwater, thermal expansion, or contraction of the ground.

See Chapter 10: Earth Hazards to learn more about natural hazards associated with the Yellowstone hot spot and supervolcano.

Due to the Yellowstone area's history of volcanism, rocks in the park are primarily volcanic. Major explosive caldera eruptions in the Yellowstone area occurred 2.1, 1.3, and 0.63 million years ago, with multiple minor eruptions occurring between the major caldera-forming eruptions. The volume of material ejected during these major eruptions has led to Yellowstone's classification as a **supervolcano** (*Figure 2.29*). A wide range of volcanic rock types and textures are present in the park, including basalts, rhyolites, obsidian (volcanic glass), agglomerates (volcanic flows that picked up cobbles or fragments of other volcanic rocks), and ashflows. In some areas, volcanic ashflows are mixed with sedimentary conglomerates, sandstones, and mudstones from stream and mudflow deposits.

The rocks formed during Yellowstone's past eruptive events can be seen in exposures throughout the park. The Huckleberry Ridge ash bed, laid down during the caldera explosion of 2.1 million years ago, is exposed in the walls of Golden Gate Canyon (*Figure 2.30*). An eruption around 590,000 years ago produced the Canyon Rhyolite flow, which can be seen in the Grand Canyon of the Yellowstone River on the eastern side of the park (*Figure 2.31*). Here, the rhyolites in the canyon walls have been altered by oxidation and acidic groundwater, resulting in striking yellows, pinks, and lavenders. Obsidian Cliff formed from a rhyolite lava flow that occurred 180,000 years ago (*Figure 2.32*); it contains abundant obsidian and was an important source of tool-making material for prehistoric peoples in the area.

Rhyolite and Basalt

Both rhyolite and basalt are lavas, but they behave differently due to their different densities and melt structures. Rhyolite is composed of felsic minerals including quartz, orthoclase, and biotite, and is high in silica and *aluminum*. This composition results in a very viscous magma. The lavas in volcanoes with felsic (rhyolitic) compositions are too viscous to flow easily; pressure builds up beneath them until they erupt explosively. The most explosive volcanoes form calderas, and the ash from such an explosion can travel many miles. The eruptions that occurred at the Yellowstone hot spot were rhyolitic in nature.

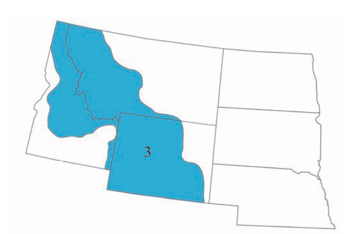
Basalt is composed of the mafic minerals plagioclase and *pyroxene*, and may contain *olivine*. These minerals are high in iron and magnesium, and produce a very fluid magma. Volcanoes with mafic or basaltic compositions tend to produce fluid lava flows comparable to those associated with the eruptions presently seen in Hawai'i. The voluminous Columbia Flood Basalts (see Region 4: the Columbia Plateau) are the result of a basaltic eruption.

supervolcano *• an explosive volcano capable of producing more than 1000 cubic kilometers (240 cubic miles) of ejecta.*

aluminum *• a metallic chemical element (Al), and the most abundant metal in the Earth's crust.*

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

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



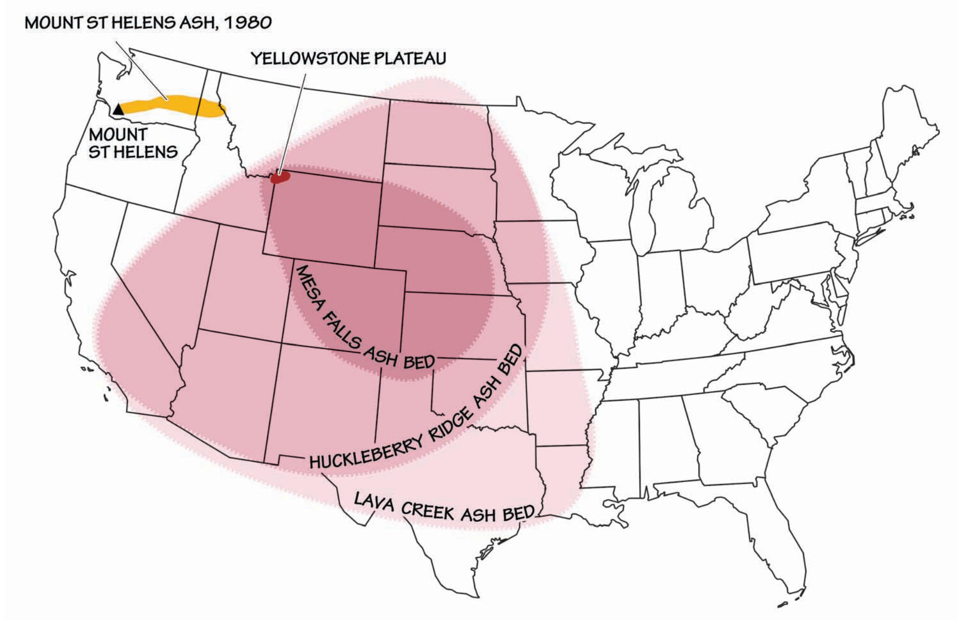


Figure 2.29: The extent of the three most recent ashfalls from Yellowstone supervolcano eruptions, as compared to the eruption of Mt. St. Helens in 1980.

Figure 2.30: The pink- and yellow-hued rocks exposed in Golden Gate Canyon are composed of Huckleberry Ridge Tuff, formed from an ashfall after a Yellowstone supervolcano eruption 2.1 million years ago.

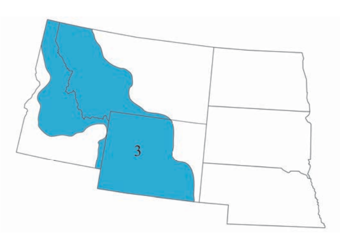
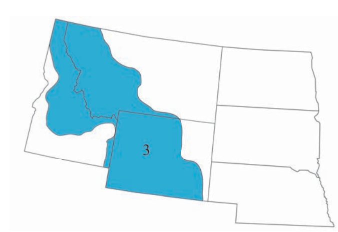


Figure 2.31: Brightly colored rhyolites are exposed in the Grand Canyon of the Yellowstone.

Figure 2.32: Thick veins of obsidian run through the rhyolite of Obsidian Cliff. Note the sunglasses used for scale.



Region 3

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

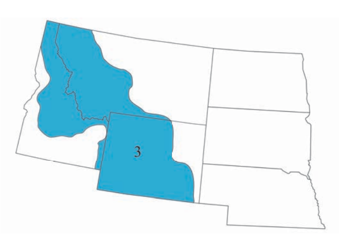
silica *• a chemical compound also known as silicon dioxide (SiO_2).*

Cordilleran Ice Sheet *• one of two continental glaciers that covered Canada and parts of the Western US during the last major Pleistocene ice age.*

Figure 2.33: The travertine terraces of Mammoth Hot Springs in Yellowstone National Park precipitated over thousands of years as hot water from the spring cooled and deposited calcium carbonate. Over two tons of carbonate minerals in solution flow through the hot springs every day.

The thermal features of Yellowstone are driven by heat from the cooling magma body beneath the caldera. Groundwater circulates through the hot rock, rises in hot springs, or erupts as geysers if there is a pressure buildup within the water. Fumaroles are openings that emit gaseous steam. Mudpots occur where hot water mixes with clay that has weathered from volcanic rock; the thick mud bubbles and spatters as it boils or releases gas. The **hydrothermal solutions** that circulate within Yellowstone's geysers and hot springs dissolve minerals from the bedrock, precipitating them out at the surface to form intricate structures made of **silica** or travertine (*Figure 2.33*).

During the Quaternary, the **Cordilleran Ice Sheet** covered part of the Rocky Mountains, and a small ice sheet covered Yellowstone. This glaciation event left behind glacial till, creating moraines and outwash deposits from sediments deposited by meltwater. Geyser and hot spring activity continued beneath the ice cover. The combination of ice, meltwater ponds and lakes, and underground heat sources caused hydrothermal explosions—these are not volcanic eruptions, but rather occur when water contained in near-surface rock at superheated temperatures flashes to steam and violently disrupts the confining rock. In the case of the Pocket Basin, located in the western part of the park, an ice-dammed lake existed over a heat source, and a hydrothermal explosion was triggered by an abrupt decrease in confining pressure when the dam failed and the lake drained. This event created a crater-like basin, in which steam works its way through silica-bearing volcanic silt to create mudpots (*Figure 2.34*)



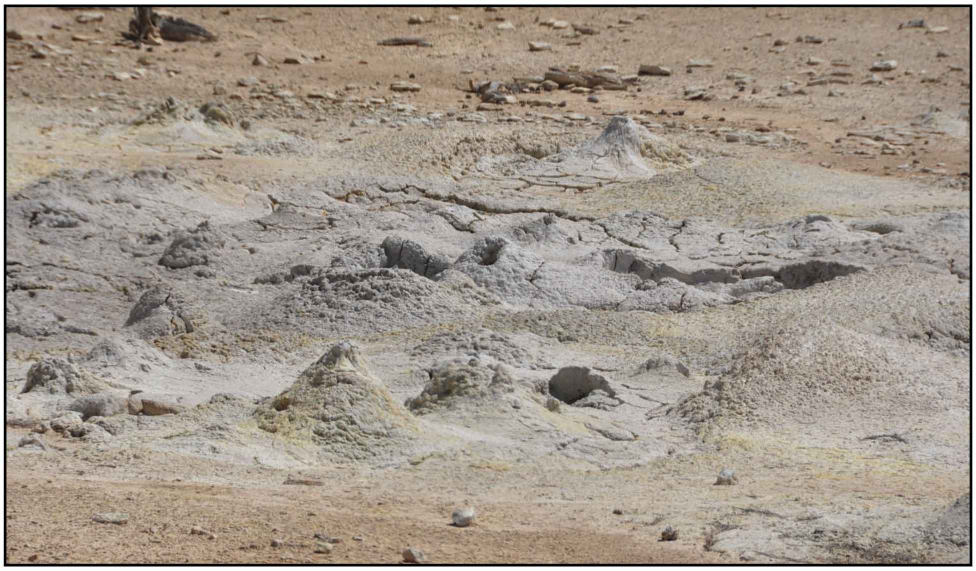


Figure 2.34: Mudpots in the Pocket Basin, Yellowstone National Park. The mud is composed of hot water mixed with volcanic clay.

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

Rocks of the Columbia Plateau
Region 4

The Columbia Plateau, also known as the Columbia Basin, is the site of one of the largest outpourings of lava that the world has ever seen. The Columbia Plateau flood basalts are a notable example of a "Large Igneous Province," where vast volumes of basalt are erupted over a relatively short period of time. Such a high volume of basaltic lava is erupted that the lava flows flood the land's surface. Between 15 and 6 million years ago, basaltic lava flooded approximately 163,000 square kilometers (63,000 square miles), covering large parts of Washington, Oregon, and Idaho (*Figure 2.35*). The thickness of the lava flows reached 1800 meters (6000 feet), burying almost all of the older rock in the area. Geological evidence suggests that many of these flows advanced over preexisting topography at a rate of five kilometers per hour (three miles per hour). This was made possible by the fact that basaltic lava erupts at a temperature of greater than 1100°C (2000°F), yielding a very hot and fluid form of lava that would have quickly inundated existing landforms. The Columbia Plateau in western Idaho is uniformly covered with basalt, although over geological time, a large degree of faulting and warping has altered once nearly uniform elevations to a range of 60 to 1500 meters (200 to 5000 feet). The basalt flows found in this region commonly exhibit spectacular examples of columnar jointing.

Large areas of flood basalt are generally associated with **mantle** hot spots. In this case, they are associated with the

See Chapter 1: Geologic History to learn more about the progression of the Yellowstone hot spot.

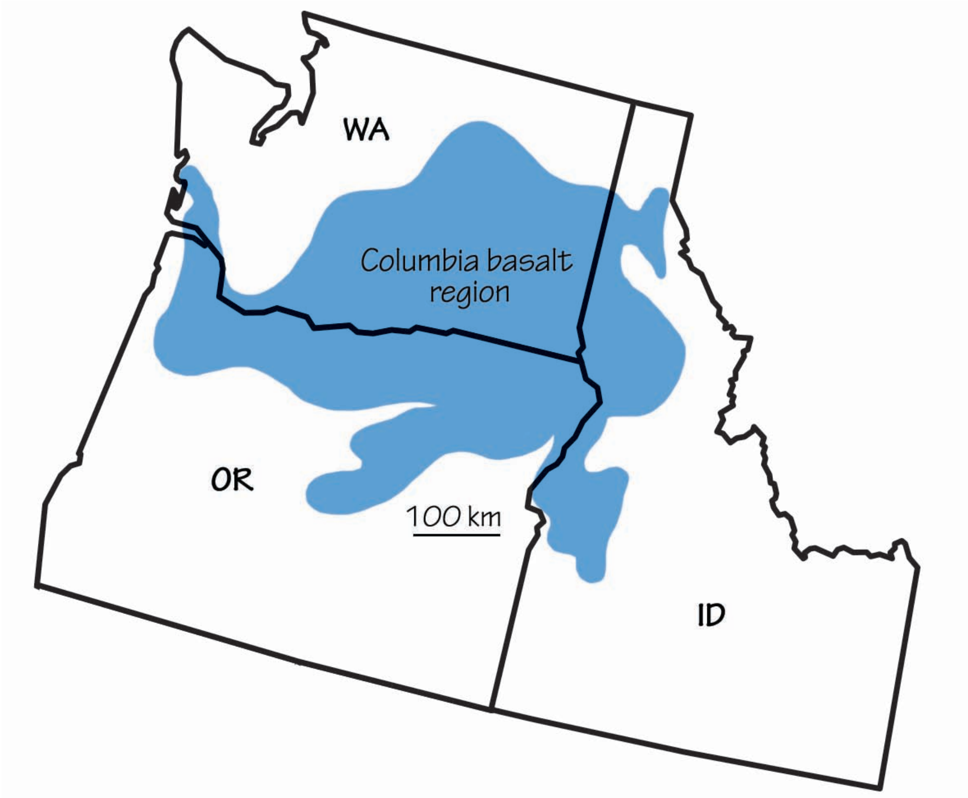


Figure 2.35: Extent of the Columbia Basin Flood Basalt.

Yellowstone hot spot, whose trail from Oregon to Wyoming has produced the Snake River Plain. As the North American plate passed over the hot mantle plume, melting the base of the crust and producing large volumes of magma, the hot spot's eruptive center moved northeastward across Idaho.

The rocks of the Snake River Plain cut across both the older Rocky Mountain and Basin and Range regions of Idaho. The plain is deeply filled with 30 to over 300 meters (100 to over 1000 feet) of rhyolite and basalt. Thick layers of rhyolite are generally capped by basalt on the surface—smaller basaltic eruptions tended to continue long after a major rhyolitic caldera eruption. Deeper rocks are seen in drillhole cores, but there are many places where the surface basalts or lava fields can be seen. Craters of the Moon National Monument is a lava field where basalts have been erupted over the last 15,000 years; the youngest flow there is only 2000 years old (*Figure 2.36*). Visitors can see flows, lava tunnels, spatter cones, and other volcanic features. Hell's Half Acre, Shoshone, Cerro Grande, and Wapi are also well known lava fields in the plain.

In addition to lava flows, eruptions from the Yellowstone hot spot often generated enormous clouds of ash created when rhyolite magma was erupted as tiny molten particles. The ash was buoyed through the air by hot gases and blanketed hundreds of kilometers (miles) of land. As it condensed, it solidified into thick layers of tuff (*Figure 2.37*).

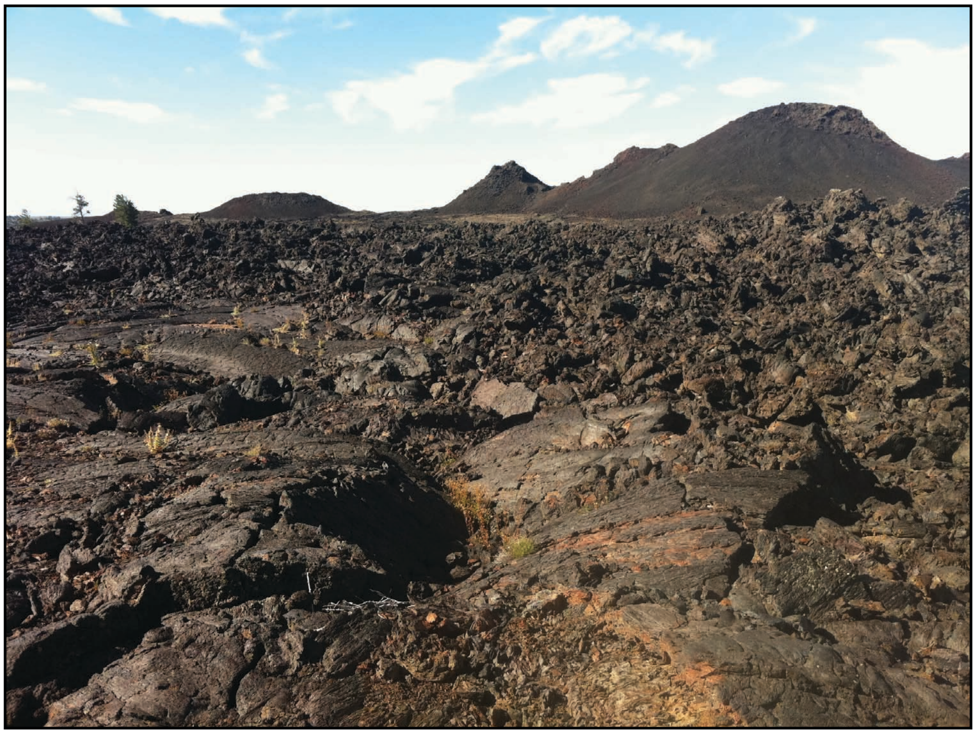


Figure 2.36: A lava field at Craters of the Moon National Monument, Idaho.

Figure 2.37: The Owyhee Canyonlands of southwestern Idaho cut through the Snake River Plain's volcanic units, revealing layers of basalt, rhyolite, and welded tuff.

pahoehoe *• a type of lava resulting from the rapid motion of highly fluid basalt. It cools into smooth glassy flows, or can form twisted, ropey shapes.*

‘a‘a *• a dense and blocky lava flow, made up of a massive front of hardened fragments.*

Types of Volcanic Flows

Pahoehoe **flows are fluid, fast flowing basaltic rivers of lava resulting in smooth, ropey surfaces. In contrast, *‘a‘a* flows are blocky, rubbly, slow-moving basaltic flows of cooling lava. They advance as cooled fragments tumble down the steep front and are buried by the advancing flow, producing a rough, spiny surface. Pillow lavas are formed when lava enters water, such as a lake, river, or ocean. The surface of the lava mass entering the water is cooled instantaneously, insulating the inner mass, which cools more slowly to form an irregular ovoid with a glassy external surface and a fine crystalline core.**

A pahoehoe lava flow at Craters of the Moon National Monument.

Not all features of Idaho’s Columbia Plateau are related to igneous activity. As the Cordilleran Ice Sheet retreated back into Canada at the end of the ice age, meltwater ponded in lakes of all sizes. One of the largest glacial lakes was Glacial Lake Missoula in Montana, which was dammed by the ice sheet. When the ice dam failed, the lake was released in a catastrophic flood. The

See Chapter 6: Glaciers for more information about Glacial Lake Missoula.

resultant landforms from this violent flood event carved deep channels into the terrain and left giant ripple marks, **potholes**, and boulders in the Channeled Scablands of northern Idaho and western Washington.

pothole • a shallow, rounded depression eroded in bedrock by a glacier.

Rocks of the Basin and Range
Region 5

A tiny corner of the Basin and Range region— a huge physiographic region that extends from southeastern Oregon to west central Mexico—extends into the Rocky Mountains of southeastern Idaho. While the formation of the Basin and Range is a recent event that began only 30 million years ago, the bedrock that makes up the region's up-thrust ranges and down-dropped basins is very old. In this tiny area of Idaho, rocks can be found from nearly all periods of the **Phanerozoic**. This is largely because the region's most recent geologic activity involved crustal extension that has exposed many deeper, older layers. During the Paleogene, magma upwelling from the mantle weakened the lithosphere, lowering its **density**. This stimulated uplift, stretching the bedrock in an east-west direction. The crust along the Basin and Range stretched, thinned, and faulted into some 400 separate mountain blocks. Movement along the faults led to a series of elongated peaks and down-dropped valleys, also called horst and graben landscapes. In a manner similar to books toppling when a bookend is removed from a shelf, the blocks slid against each other as they filled the increased space (*Figure 2.38*).

Phanerozoic • a generalized term used to describe the entirety of geological history after the Precambrian, from 541 million years ago to the present.

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

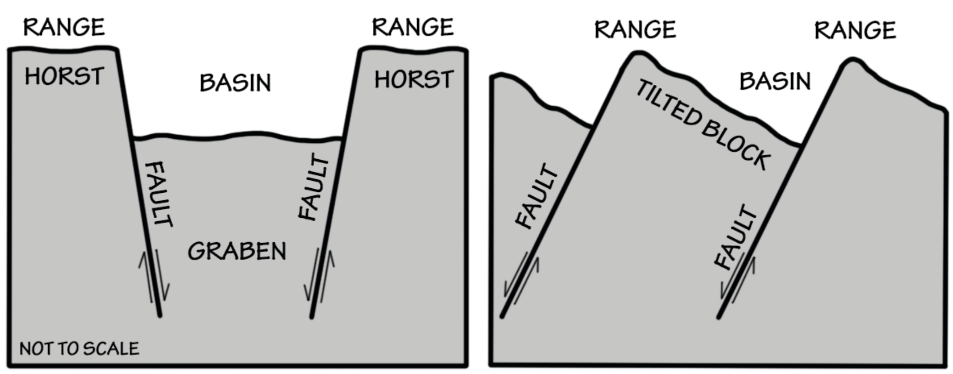
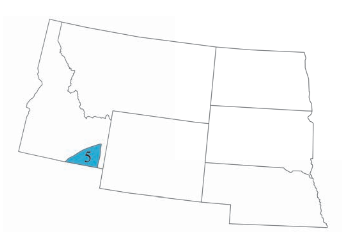


Figure 2.38: Alternating basins and ranges were formed during the past 17 million years by gradual movement along faults. Arrows indicate the relative movement of rocks on either side of a fault.

Since the region's formation, the bedrock of the basins has been covered by young deposits, including loose sediment washed down from the mountains and evaporite deposits left behind in dried-out lakes. The ranges, however, particularly the Sevier Orogenic Belt (also known as the "Overthrust Belt"), expose rocks whose ages span from Precambrian to Cenozoic. The Basin and Range's Paleozoic rocks, a succession of sandstones, limestones, and shales, were deposited on the western shore of North America during the Cambrian to



the Mississippian. This was followed during the Pennsylvanian to the Permian by a transition to shallow and evaporating seas, which deposited sandstones, mudstones, limestones, and phosphate-rich rocks. Mesozoic rocks include red beds, sandstones, mudstones, and limestones of the Dinwoody, Nugget, Twin Creek, Morrison, and Stump Formations. Good outcrops of these rocks can be seen in uplifted ranges such as the Bear and Aspen Range. These Paleozoic and Mesozoic sediments were thrusted during the Sevier Orogeny, then involved in the Basin and Range style of extension during the Paleogene. Valleys formed by this extensional faulting were filled with later Cenozoic sediments.

Younger rocks from the Cretaceous and the Cenozoic cover the valley floor, filling the region's basins (*Figure 2.39*). These rocks are mainly conglomerates, sandstones, and mudstones originating from erosion of the nearby uplifts. In the case of the Idaho Basin and Range, the basin fills also include Cenozoic volcanic rocks produced by nearby volcanic activity on the Snake River Plain. Pleistocene deposits include glacial till, outwash, and glacial lake deposits. These gravels, sands, silts, and tills are mostly associated with glaciers in the adjacent Teton and Snake River Ranges of Wyoming.

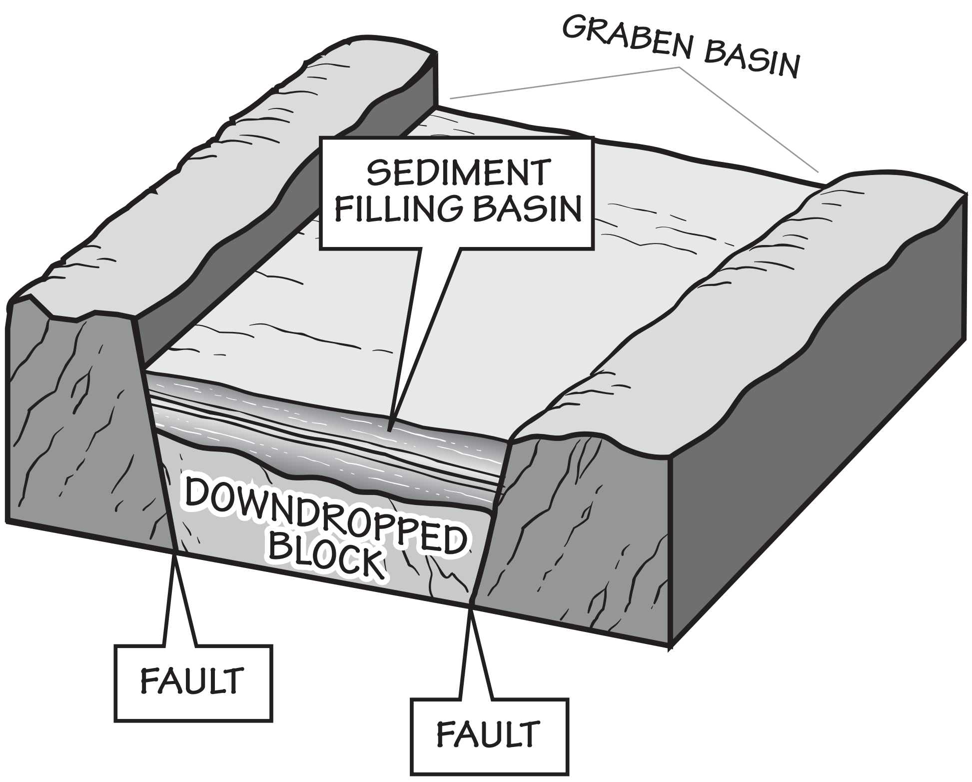


Figure 2.39: Basin fill in the Basin and Range.

State Rocks, Minerals, and Gems

Idaho
Idaho has no state rock or mineral.

State **gem**: star garnet
These dark purple silicate crystals are found in great quantity in only two places in the world: India, and Idaho's panhandle. Star garnets have a unique property that causes them, when polished, to display a reflection that looks like a four- or six-pointed star.

Montana
Montana has no state rock or mineral.

State gems: Montana **agate** and sapphire.
Montana agates are usually light yellow or clear in color, and contain bands and inclusions of red and black iron and other mineral oxides. They are found in Pleistocene-aged gravel deposits around the Yellowstone River and its tributaries. Montana sapphires are found in four major areas: the Missouri River, the Sapphire Mountains, Yogo Gulch, and Deer Lodge. These gemstones appear in a greater variety of colors than sapphires found anywhere else in the world, leading to Montana's nickname as the "Treasure State."

Nebraska
State rock: prairie agate
Prairie agate is a semiprecious variety of **chalcedony** known for its lack of the coarse banding present in most types of agate. It is found in abundance in the Ogalalla National Grasslands.

State gem: blue agate
This dark blue variety of chalcedony often exhibits blue and white banding. Blue agates formed from wind-blown silt and claystone deposited during the **Oligocene** and are found in northwestern Nebraska.

North Dakota
North Dakota has no state rock, mineral, or gem.

South Dakota
South Dakota has no state rock.

State mineral: rose **quartz**
This silicate mineral is found in great quantities throughout the Black Hills. It was first discovered there in 1875, and the Scott Rose Quartz Mine was opened in 1902.

State gem: Fairburn agate

State Rocks

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

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

chalcedony • *a crystalline silicate mineral that occurs in a wide range of varieties.*

Oligocene • *a geologic time interval spanning from about 34 to 23 million years ago.*

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

State Rocks

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

These colorful silicate minerals are named for a locality near Fairburn, South Dakota, where they were originally discovered. The Fairburn agate is notable for its variety of colorful, strikingly contrasted, thin red, pink, white, and yellow bands.

Wyoming

Wyoming has no state rock or mineral.

State gem: nephrite **jade**
This green stone was first described in the Granite Mountains of central Wyoming in 1936. Wyoming's jade is considered to be some of the world's finest nephrite, and it appears in many varieties and colors.

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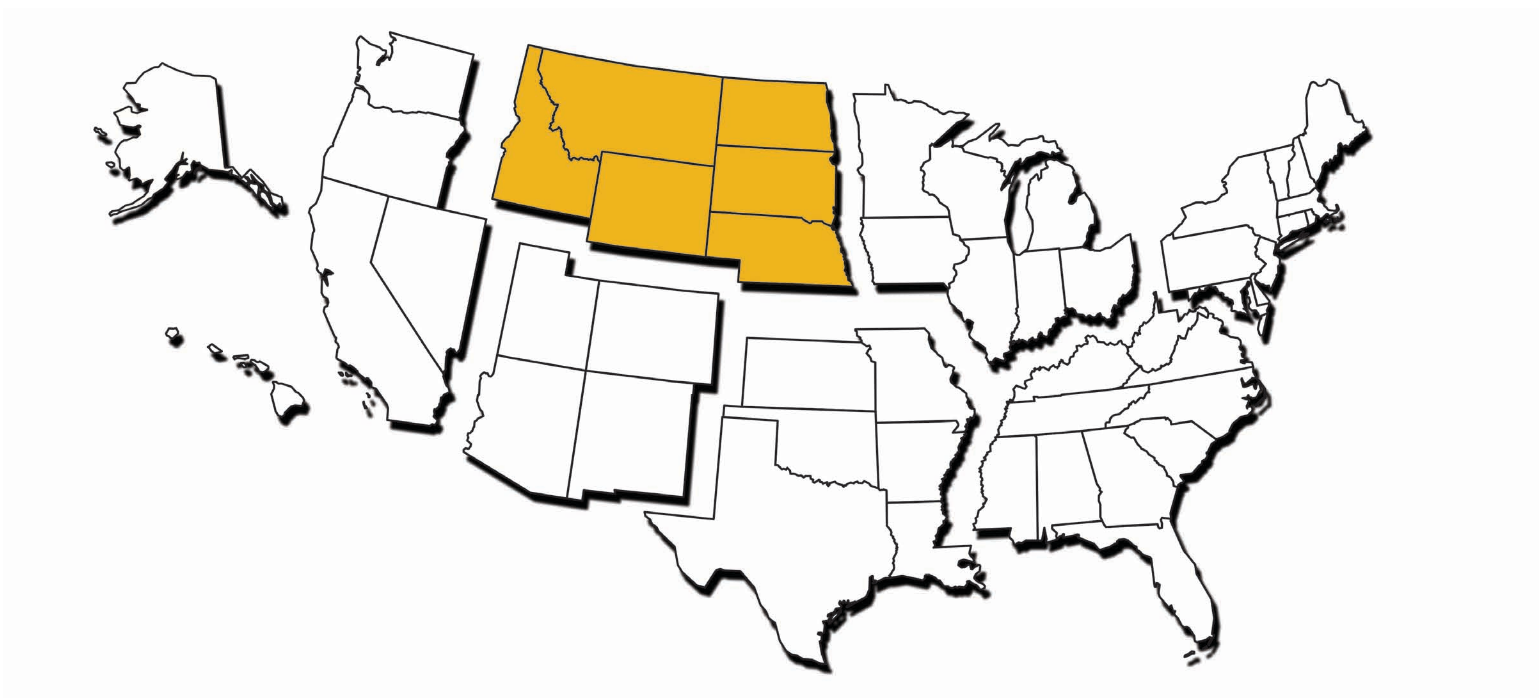

Edited by Mark D. Lucas, Robert M. Ross, & Andrielle N. Swaby

Paleontological Research Institution
2015

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

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

First printing September 2015

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

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

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

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

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

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

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