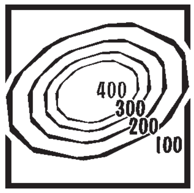

Chapter 4: Topography of the Northwest Central US

Does your region have rolling hills? Mountainous areas? Flat land where you never have to bike up a hill? The answers to these questions can help others understand the basic topography of your region. The term **topography** is used to describe the changes in elevation over a particular area and is, generally speaking, the result of two processes: deposition and **erosion**. These processes can occur over an enormous range of timescales. For example, a flash flood can erode away tons of rock in a matter of hours, yet which rock is broken down and which remains can depend on how it was formed hundreds of millions of years ago. In the Northwest Central, topography is intimately tied to **weathering** and erosion as well as to the type and structure of the underlying bedrock, but it is also a story of **plate tectonics**, volcanoes, folding, **faulting**, **uplift**, and mountain building.

Weathering includes both the mechanical and chemical processes that break down a rock. There are two types of weathering: physical and chemical. Physical weathering describes the physical or mechanical breakdown of a rock during which the rock is broken into smaller pieces, but no chemical changes occur. **Wind**, water, temperature, and pressure are the main media by which physical weathering and erosion occur. Streams are constantly eroding their way down through bedrock to sea level, creating valleys in the process. Given sufficient time, streams can cut deeply and develop wide flat floodplains on valley floors. Streams, oceans, and ice also deposit the material they erode, creating new topographical features elsewhere. The pounding action of ocean waves on a coastline contributes to the erosion of coastal rocks and sediments, while the emptying of a river can lead to the building of a **delta**.

Pressure release can cause rocks to crack. Growing plant roots can exert many pounds per square inch of pressure on rocks—think of tree roots uplifting and cracking a sidewalk. Additionally, since rocks buried miles beneath the surface are under considerable pressure, if those rocks become exposed at the Earth's surface (where the rock is under less pressure), the rock may expand and crack in a process called **exfoliation** (*Figure 4.1*). Ice can also change the landscape due to frequent episodes of freezing and thawing, causing both temperature and pressure differentials within a rock. On a small scale, as water trapped in **fractures** within the rock freezes and thaws, the fractures continue to widen (*Figure 4.2*). This alone can induce significant breakdown of large rock bodies.

Working in conjunction with physical (mechanical) weathering, chemical weathering also helps to break down rocks through changes in the chemical composition of their constituent **minerals**. Some minerals contained in **igneous**

erosion *• the transport of weathered materials.*

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

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

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.*

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

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

CHAPTER AUTHORS

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Review

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

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

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

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

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

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

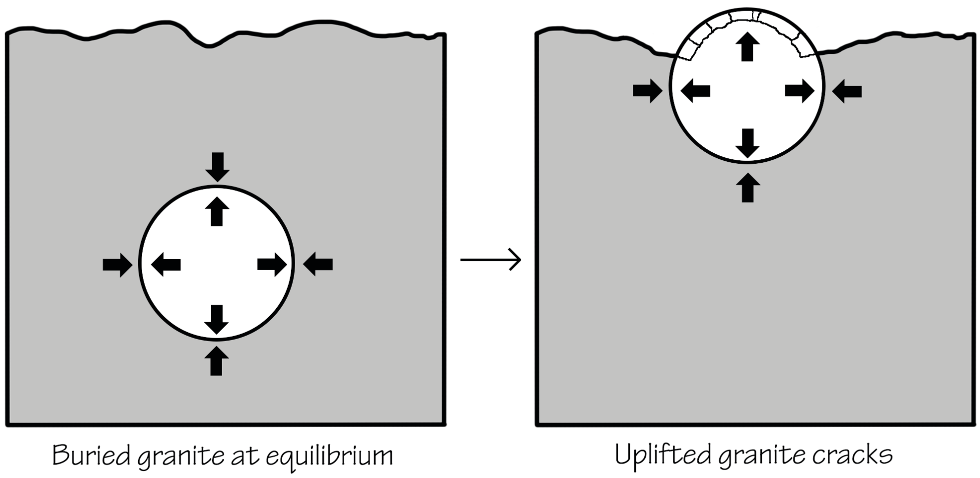


Figure 4.1: Exfoliation as a result of uplift and pressure release.

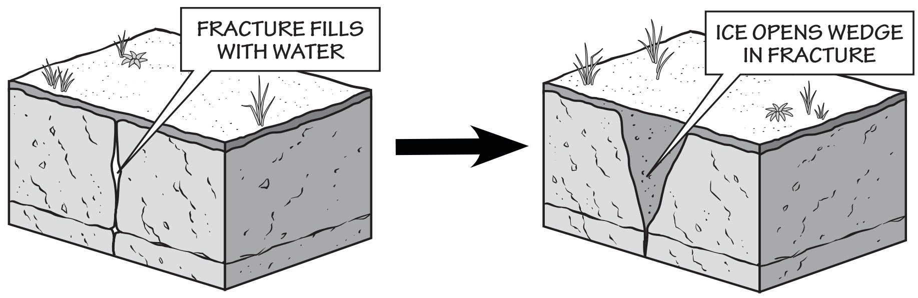


Figure 4.2: Physical weathering from a freeze-thaw cycle.

and **metamorphic rocks** that are formed at high temperatures and pressures (far below the surface of the Earth) become unstable when they are exposed at the surface or placed in contact with water, where the temperature and pressure are considerably lower. Unstable minerals transition into more stable minerals, resulting in the breakup of rock. Weak acids, such as the carbonic acid found in rainwater, also promote the disintegration of certain types of rocks. **Limestone** and **marble** may be chemically broken down as carbonic acid reacts with the **carbonate** mineral composition of these rocks, forming cavities and caverns. Other **sedimentary rocks** held together by carbonate **cement** are also particularly susceptible to chemical weathering.

Glaciers have also contributed to the Northwest Central's topography. Ice sheets from the last glaciation covered part of this area, and mountain glaciers in the Rocky Mountains were considerably more extensive than they are at present. In mountainous areas, erosion by valley glaciers leaves behind jagged peaks, bowl-like depressions called **cirques**, and long U-shaped valleys with tributary **hanging valleys**. Glaciers can both erode and deposit material. As the ice melts, piles of sediment are left behind, forming structures such as moraines, **eskers**, and **drumlins**. Glacial lakes are common, as water from the melting ice readily fills depressions. The deposition of fine **silt** that has been ground from rock by glaciers can lead to the formation of wind-blown deposits called **loess**.

See Chapter 6: Glaciers to learn more about the ways in which glacial erosion alters the landscape .

Volcanic activity has shaped the land throughout the Northwest Central. Although there are no active volcanoes there today, evidence of past activity—such as volcanic cones and craters, lava flows, **dikes**, and sills—can be seen in a variety of locations, including **tuff** beds in western and central North Dakota, and the Shoshone lava field in Idaho. Evidence of hot rock and cooling **magma**, including igneous rocks (e.g., **basalt**, **andesite**, and **rhyolite**), hot springs, and **geysers**, can be found in the Yellowstone area, which contains the ancient **caldera** of a **supervolcano**. There has been no major volcanic activity in the Yellowstone area within recorded history; the most recent Yellowstone eruption occurred around 630,000 years ago. Nevertheless, there is concern that Yellowstone may erupt again in the future.

See Chapter 10: Earth Hazards to learn about supervolcanoes.

The specific rock type found at the surface has an important influence on a region's topography. Certain rocks are able to resist weathering and erosion more easily than are others; resistant rocks that overlie weaker layers act as caps and form ridges, while surrounding layers of less resistant rock erode away. The great Western Interior Seaway of the **Cretaceous** collected and preserved sediments that became sedimentary rocks throughout the Great Plains and Central Lowland of Nebraska and the Dakotas. Sedimentary rocks weather and erode differently than do crystalline (and generally harder) igneous and metamorphic rocks, such as those found in the Rocky Mountains and the Black Hills. **Silica**-rich igneous rocks have a crystalline nature and mineral composition that resists weathering far better than do the cemented grains of a sedimentary rock. The metamorphic equivalents of sedimentary and igneous rocks are often even more resistant due to **recrystallization**. There are exceptions, however, such as **schist**, which is much weaker than its pre-metamorphic limestone or **sandstone** state.

The underlying structure of rock layers also plays an important role in surface topography. Sedimentary rocks are originally deposited in flat-lying layers that rest on top of one another. The movement of tectonic **plates** creates stress and tension within the **crust**, especially at plate boundaries. **Intrusions** beneath the surface may also cause deformation of the crust. All these different sources of geological stress can deform the flat sediment layers through folding, faulting, or overturning. These terms are collectively used to describe rock structure, and they can also be used to determine which forces have affected rocks in the past. The folding of horizontal rock beds followed by erosion and uplift brings layers of rock to the surface. Tilted rocks expose underlying layers. Faulting likewise exposes layers at the surface to erosion, due to the movement and tilting of blocks of crust along the fault plane. For example, the Basin and Range formed

Review

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

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

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

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

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

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

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

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

Topography

Review

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

Laramide Orogeny *• a period of mountain building that began in the Late Cretaceous, and is responsible for the formation of the Rocky Mountains.*

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

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

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).*

Canadian Shield *• the stable core of the North American continental landmass, containing some of the oldest rocks on Earth.*

as a result of normal faulting (*Figure 4.3A*), which occurs due to extensional stresses that create uplifted ranges and downdropped basins. The Rocky Mountains provide another regional example of folding and faulting: this range formed as a result of uplift associated with **subduction** along the western edge of the North American plate. The shallow angle of the subducting plate generated thrust (reverse) faults (*Figure 4.3B*) and the onset of the **Laramide Orogeny**.

See Chapter 1: Geologic History to learn about the processes of subduction and uplift.

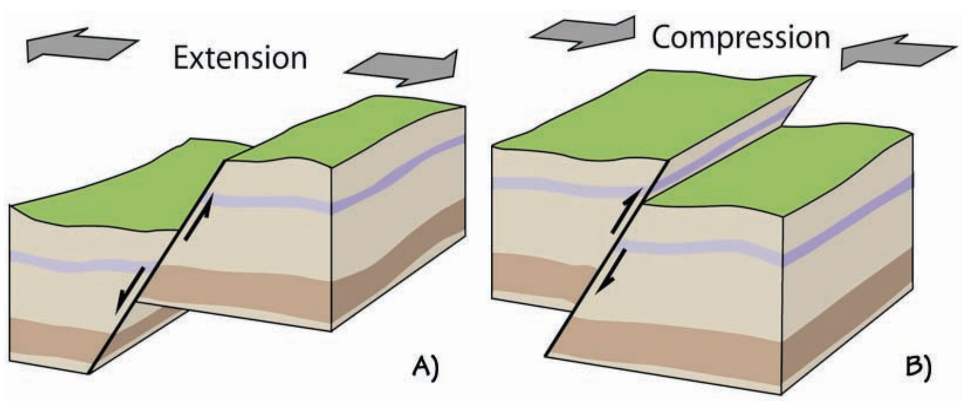


Figure 4.3: Normal faulting and thrust (reverse) faulting.

Just as we are able to make sense of the type of rocks in an area by knowing the geologic history of the Northwest Central US, we are able to make sense of its topography (*Figure 4.4*) based on rocks and structures resulting from past geologic events. Topography is a central element of the broader concepts of geomorphology or **physiography**, which also include consideration of the shape (not just the height) of land forms, as well as the bedrock, **soil**, water, vegetation, and **climate** of an area, and how they interacted in the past to form the landscape we see today. A physiographic province is an area in which these features are similar, in which these features are significantly different from those found in adjacent regions, and/or is an area that is separated from adjacent regions by major geological features. The "regions" of the Northwest Central that we use in this book are examples of major physiographic provinces.

Topography 4

Region 1

Figure 4.4: Digital shaded relief map of the Northwest Central States.

Topography of the Central Lowland
Region 1

The Central Lowland is a flat-lying region located between the Appalachian Mountains to the east and the Great Plains to the west (*Figure 4.5*). It extends from the **Canadian Shield** in the north to the Atlantic Coastal Plain in the south and is part of the North American **craton** (the older, stable part of the continent).

The Central Lowland is composed of flat-lying **Precambrian** metamorphic and igneous rocks overlain by **Paleozoic** and **Mesozoic** sedimentary rocks. The Mesozoic sediments found in the region were eroded from the Rocky, Ozark, and Ouachita mountains, then carried to and deposited in the Western Interior Seaway that covered the area. Glacial erosion and deposition during the last **ice age** modified and smoothed much of the region's surface, leaving behind thick layers of **Cenozoic** sediment and **drift**. Today, rivers running through this region, including the Missouri and Red rivers, have contributed significantly to erosion.

See Chapter 1: Geologic History to learn more about the Western Interior Seaway.

The Central Lowland has a generally smooth and flat topography, generated by glacial **scouring** during the ice age, as well as by the presence of enormous glacial lakes and erosion from catastrophic outbursts of meltwater. During

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).*

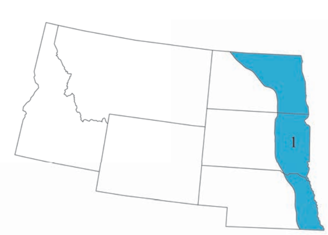
Paleozoic • *a geologic time interval that extends from 541 to 252 million years ago.*

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.*

drift • *unconsolidated debris transported and deposited by a glacier.*

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



Topography

Region 1

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

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).*

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

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

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

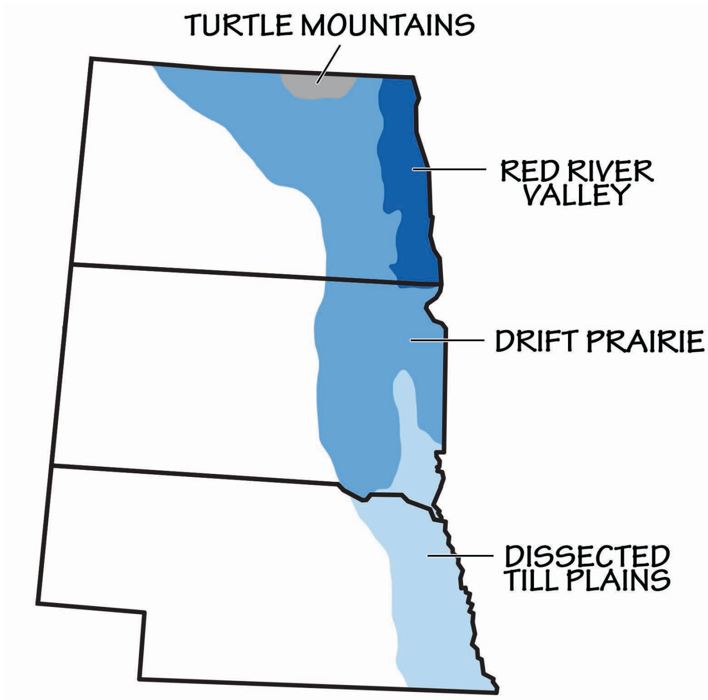


Figure 4.5: Physiographic divisions of the Central Lowland.

the **Quaternary**, a 152-meter-thick (500-foot-thick) **ice sheet** flattened the landscape, leaving behind the gently rolling hills and shallow lakes that spread throughout the Drift Prairie today (*Figure 4.6*). The ice sheet also left behind layers of **till**, **clay**, **gravel**, and wind-blown silt (loess), which contributed to the area's rich agricultural soils. The Red River Valley, directly to the east in North Dakota, is a flat lowland area that marks the former floor of glacial Lake Agassiz, which was once the largest freshwater lake in North America (*Figure 4.7*). About 160 kilometers (100 miles) west of the Red River Valley, the Missouri Escarpment—a ridge extending southeast from Canada to south-central South Dakota—separates the Drift Prairie from the Great Plains. The escarpment was formed when catastrophic floods at the end of the ice age carved a huge canyon, channeling future ice movements and flattening the surrounding area. The Missouri Escarpment is the remnant of this canyon's west and southwest wall.

See Chapter 6: Glaciers for more information about glacial landscapes and Lake Agassiz.

Escarpments **form when faulting or erosion acts to create a cliff or steep slope that separates two level or gently sloping topographical surfaces. Typically, cliffs created by faulting are called "scarps," while "escarpments" are those formed by the differential erosion of resistant layers that alternate with softer strata.**

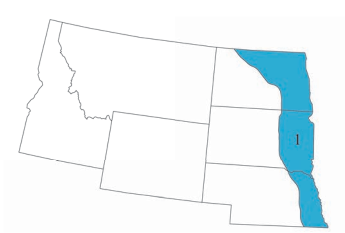
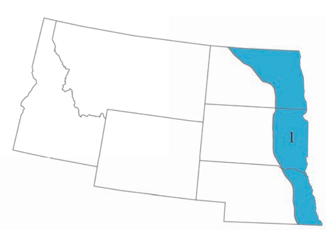


Figure 4.6: *The Drift Prairie near Bottineau, North Dakota. The rolling landscape of the Turtle Mountains is visible in the far distance.*

Figure 4.7: The extent of glacial Lake Agassiz during the Pleistocene. North Dakota's Red River Valley follows the bed of this ancient lake.



Several landforms throughout North Dakota's Central Lowland were formed as ice-thrust features—the weight and pressure of the advancing glacier displaced large bedrock slabs, shoving and thrusting large masses of rock and sediment, and depositing them a short distance from their original position. Geologists speculate that ice-thrust features occur so prominently in central and eastern North Dakota because the region's water drains northward. Ice sheets advancing from the north prevented groundwater drainage, leading to increased pressure within the ground. Eventually, the weight of the glacier caused pieces of terrain to pop out of the ground, thrusting them a short distance forward and relieving the built-up pressure (*Figure 4.8*). Ice-thrust features are often accompanied by topographic depressions (usually lakes) located to the north, from which the material was displaced. Examples include Steele Lake near Anamoose, Medicine Lake and its adjacent Grasshopper Hills, and even Devils Lake, the largest natural lake in North Dakota. The Turtle Mountains of northernmost North Dakota, a plateau lying 600 meters (2000 feet) above sea level and 90–120 meters (300–400 feet) above the surrounding land, are another example of ice-thrust terrain that was later smoothed and rounded by further glacial erosion.

See Chapter 10: Earth Hazards to learn about flooding hazards at Devils Lake.

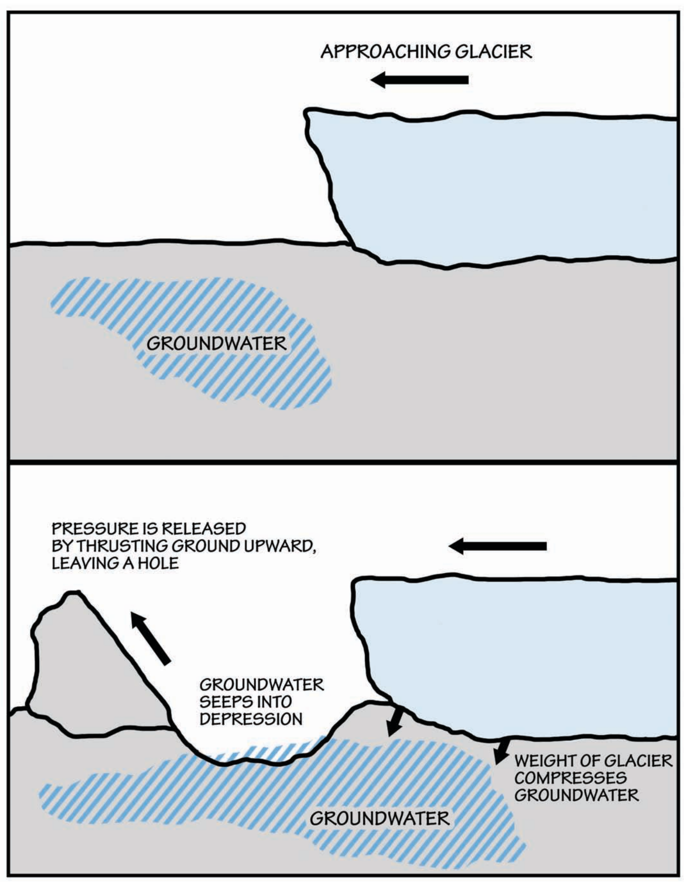
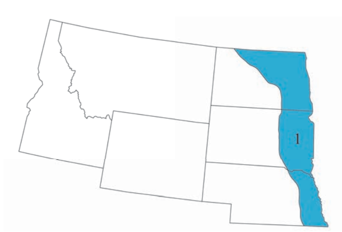


Figure 4.8: Ice-thrust features are created when pressure from the weight of an advancing glacier is released by thrusting a piece of terrain forward.



Topography 4

Regions 1–2

The Dissected Till Plains, extending from southeast South Dakota through Nebraska, are an area of rolling hills ripe with fertile soil. The area was initially scoured and flattened during the **pre-Illinoian** glacial stage; during the **Wisconsinian**, great quantities of loess accumulated there. Glacial runoff later led to erosion that sculpted the area into valleys and hills. Today, the Missouri River cuts across the plains at the border between Nebraska and South Dakota and runs south along Nebraska's eastern border, forming wide **floodplains** that support a complex environment of sandbars and wetlands (*Figure 4.9*).

Figure 4.9: Sandbars in the Missouri River, viewed from Mulberry Bend Scenic Outlook near Dixon, Nebraska.

Topography of the Great Plains
Region 2

The Great Plains is a lowland area underlain by flat-lying sedimentary rocks, and located between the Central Lowland and Rocky Mountain regions. Despite its name, the Great Plains region is not entirely flat, changing in elevation from 1830 meters (6000 feet) on its western edge to 460 meters (1500 feet) on its eastern edge. The Black Hills and the Sand Hills are hilly areas in the western and southern parts of the Great Plains, and the Badlands (located in the central part of the Great Plains) contain tall cliffs, plateaus, and deep canyons. The Great Plains' physiographic subdivisions include the Missouri Plateau, the Black Hills, and the High Plains (*Figure 4.10*). The Missouri Plateau can be further divided into glaciated and unglaciated sections; the Plains Border, a subsection of the High Plains, extends from Nebraska into Kansas.

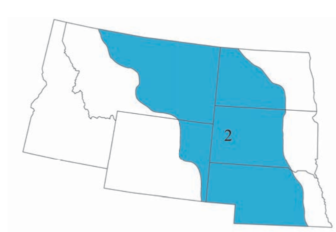
Similarly to the Central Lowland, the Great Plains region has a **basement** of flat-lying Precambrian metamorphic and igneous rocks, overlain by Paleozoic and Mesozoic sedimentary rocks. The Mesozoic sediments consist largely of materials eroded from the Rocky and Ozark mountains and deposited in the Western Interior Seaway, which covered this area during the Cretaceous. Today, the Missouri River runs through this region (*Figure 4.11*), where it both deposits

pre-Illinoian glaciation *• a grouping of the Midwestern glacial periods that occurred before the Wisconsinian and Illinoian glaciations.*

Wisconsinian glaciation *• the most recent interval of glaciation, which occurred during the Pleistocene, 85,000 to 11,000 years ago.*

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

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



4 Topography

Region 2

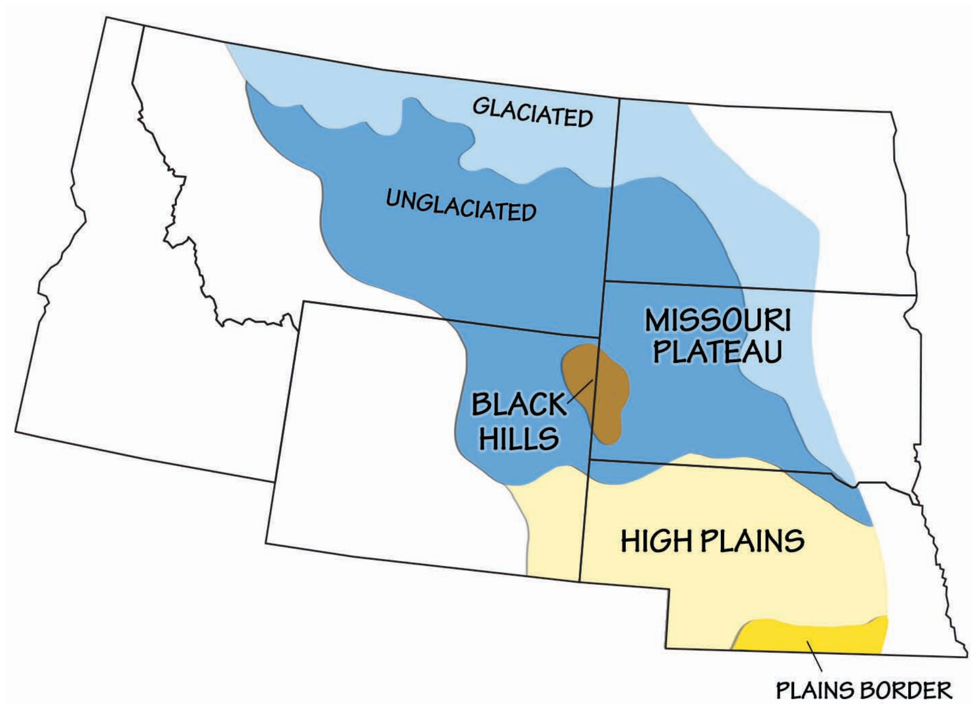
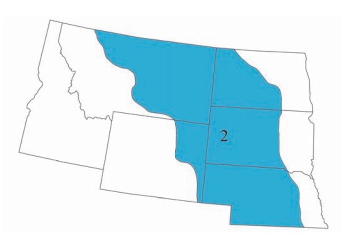


Figure 4.10: The physiographic regions of the Great Plains.

Figure 4.11: The Missouri River watershed. (See TFG website for full-color version.)



and erodes sediments. Glacial sediments can be found in the northern Great Plains, which was covered by ice sheets during the last glaciation. Additionally, some glacial sediment has been transported southward by the Missouri River and its tributaries.

The Missouri Plateau

The unglaciated portion of this area is a rugged expanse of semiarid terrain characterized by landforms sculpted from eroded sedimentary rock and glacial sediment, including **badlands** and dunes. Older surface features such as **buttes** and well-developed river systems also provide breaks in the generally flat topography. A butte can form when resistant **capstone** allows for the surrounding rock to be eroded away at a faster pace than the rock beneath the resistant layers (*Figure 4.12*). Over time, the differing rates of erosion will create a flat-topped hill with steep slopes. Such formations are a hallmark of an old erosional surface, since large buttes often take millions of years to form. On the Missouri Plateau, these topographical features are created from sedimentary rock that formed during erosional and depositional events associated with the uplift of the Rocky Mountains and the sedimentation of the Western Interior Seaway.

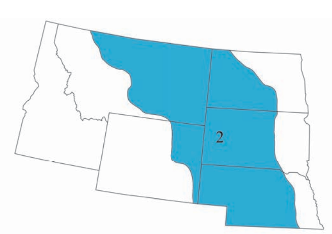
badlands • *a type of eroded topography that forms in semi-arid areas experiencing occasional periods of heavy rainfall.*

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

capstone • *a harder, more resistant rock type that overlies a softer, less resistant rock.*

Figure 4.12: Red Butte, near Casper, Wyoming, rises high above the easily erodible red Spearfish Shale thanks to a resistant capstone of white gypsum.

Badland topography forms in semiarid areas that experience occasional periods of heavy rainfall. Here, sloping ground composed of sandstones and calcareous sediments underlain by clay or other soft materials is eroded over time into an intricate series of gullies and ravines. Different layers of rock weather at different rates, resulting in a variety of sculpted spurs and buttresses. Harder layers crop out of softer sediments to form ledges, and isolated erosion-resistant patches



fossil • *preserved evidence of ancient life.*

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

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

porosity • *the percentage of 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.*

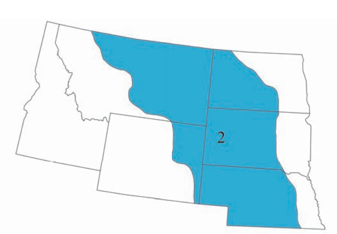
protect the sediments beneath, forming tall pillars of softer rock with a hard capstone. In the Northwest Central US, badlands can be found in Wyoming, Nebraska, Montana, and the western Dakotas, and are well known for their mammal **fossils**. Several scenic badlands areas have been set aside as protected land, including Theodore Roosevelt National Park in North Dakota (*Figure 4.13*), Badlands National Park in South Dakota (*Figure 4.14*), Makoshika State Park in Montana, and Toadstool Geologic Park in Nebraska.

See Chapter 3: Fossils for more information about the mammal fossils of the Great Plains.

Figure 4.13: Badlands in Theodore Roosevelt National Park, Billings and McKenzie counties, North Dakota.

The Sandhills of Nebraska are **sand** dunes that were created by wind-blown glacial material (*Figure 4.15*). During the last glaciation in the late **Pleistocene**, winds blowing along the edge of the ice sheet concentrated layers of sand and glacial loess in central Nebraska. This unique area, which covers 52,000 square kilometers (20,000 square miles), is the largest sand dune formation in the country. The dunes' **porous** composition allows them to absorb rainwater, helping to recharge the Ogalalla Aquifer that underlies the area and supplies fresh water to much of Nebraska.

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



Region 2

Figure 4.14: Badlands National Park, near Jackson, South Dakota.

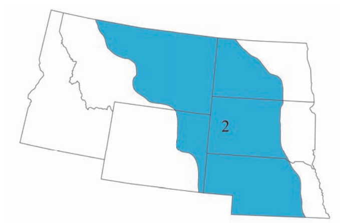
Figure 4.15: The Sandhills in Hooker County, Nebraska, as seen from Nebraska Highway 97.

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

kettle *• a lake formed where a large, isolated block of ice became separated from the retreating ice sheet.*

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

The glaciated portion of the Missouri Plateau contains typical glacial features such as **moraines** and **kettle** ponds. The Prairie Pothole Region, an expanse of tallgrass prairie filled with thousands of shallow **pothole** wetlands (*Figure 4.16*), covers most of this area, extending from Alberta and Saskatchewan all the way down into Iowa. These potholes were formed as a result of glacial activity during the Wisconsinian glaciation, and the wetlands they support provide a haven for more than 50% of North America's migratory waterfowl. Today, however, more than half of the Prairie Pothole Region has been drained and converted for use in agriculture.



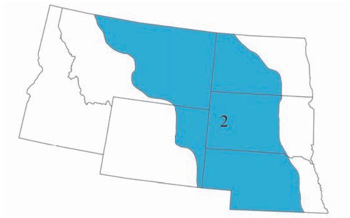
Topography

Region 2

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

Figure 4.16: Prairie pothole terrain near Wing, North Dakota.

Figure 4.17: The Black Hills of South Dakota, as viewed from Harney Peak.



The Black Hills

The Black Hills are an isolated mountain range that outcrops within western South Dakota and northeast Wyoming (*Figure 4.17*). The mountains contain a core of 1.8-billion-year-old Precambrian **granite**, generated during the formation of the North American craton. This core is surrounded by a ring of metamorphic rock and layers of Paleozoic and Mesozoic sediment, including sandstone and limestone. The Black Hills were uplifted during the Cretaceous, as the Laramide Orogeny warped the landscape. Since then, the softer overlying sediment has been largely eroded, exposing remnants of the mountains' granitic core. This granite has been used as the base material for two notable sculptures: Mount Rushmore and the Crazy Horse Memorial. The highest elevation in the Black Hills is Harney Peak, which stands at 2208 meters (7244 feet) above sea level.

The High Plains

The High Plains, part of the vast North American Interior Plains, is a low area with flat **relief** that reflects 500 million years of cratonic stability in the continent's interior. Much of this area was submerged by the Cretaceous Western Interior Seaway, leading to the deposition of sediment that overlies the area's igneous and metamorphic core.

__relief__ • the change in elevation over a distance.

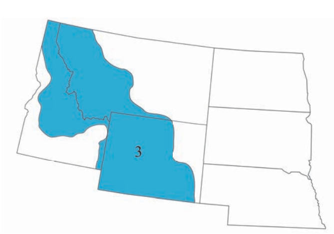
__compression__ • flattening or squeezing as a result of forces acting on an object from all or most directions.

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

Topography of the Rocky Mountains
Region 3

The Rocky Mountain region, west of the Great Plains, is divided into the Northern, Middle, and Southern Rockies as well as the Wyoming Basin (*Figure 4.18*). The Rocky Mountains, which extend north into Canada and south into New Mexico, formed during the late Mesozoic when crustal **compression** led to deformation and thrust faulting. The mountains consist of igneous, sedimentary, and metamorphic rocks that were uplifted during the **Sevier** and Laramide orogenies, around 80 to 55 million years ago. Today, the tallest mountains in the Rockies are found in the state of Colorado, where over 50 mountains have an elevation greater than 4270 meters (14,000 feet). In the Northwest Central,

Figure 4.18: Physiographic subregions of the Rocky Mountains.



Region 3

downwarp *• a segment of the Earth's crust that is broadly bent downward.*

intermontane *• between or among mountains.*

watershed *• an area of land from which all water under or on it drains to the same location.*

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

Figure 4.19: The Grand Tetons, some of the tallest mountains in Wyoming, as viewed from the Snake River Overlook. Grand Teton, the highest peak, is 4199 meters (13,775 feet) in elevation.

however, the tallest of the Rockies are located in Wyoming (*Figure 4.19*), where five peaks have an elevation of over 4000 meters (13,120 feet).

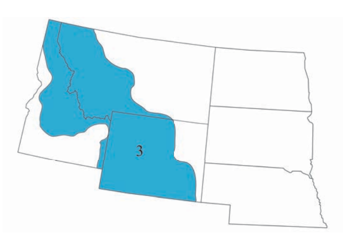
The Rocky Mountains have undergone extensive erosion thanks to the forces of weathering and glaciation. During the Cenozoic, thousands of feet of sediment were eroded from the Rockies and transported eastward into adjacent basins, which formed as a result of **downwarping** during the mountains' formation. The erosion of the Rockies has filled these basins, forming many flat-lying **intermontane** areas. Glacial erosion during the Quaternary created the jagged peaks and bowls that we see today.

The Continental Divide runs along the crest of the Rocky Mountains. It separates North America's **watersheds** into those that flow east and south into the Atlantic Ocean and the Gulf of Mexico, and those that flow west toward the Pacific Ocean.

A *hydrological divide* is a boundary between two drainage basins or watersheds.

The Northern Rocky Mountains

The Northern Rocky Mountains are found in northeastern Washington, northern Idaho, western Montana and northwestern Wyoming. These mountains are lower than those to the south, reaching heights of around 3660 meters (12,000 feet). In Idaho and western Montana, the Northern Rockies are composed of a series of mountain ranges, including the Clearwater, White Cloud, Salmon River, Sawtooth, and Lost River mountains. These ranges formed as a result of the uplift and erosion of the Idaho Batholith, a mass of granitic **plutons**



that formed during the Cretaceous when the oceanic Farallon plate subducted beneath the west coast of North America. The **batholith**, which underlies about 39,900 square kilometers (15,400 square miles) of central Idaho (*Figure 4.20*), was uplifted and exposed between 65 and 50 million years ago. Since then, weathering and erosion have sculpted the batholith's granitic rock into rough peaks (*Figure 4.21*).

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).*

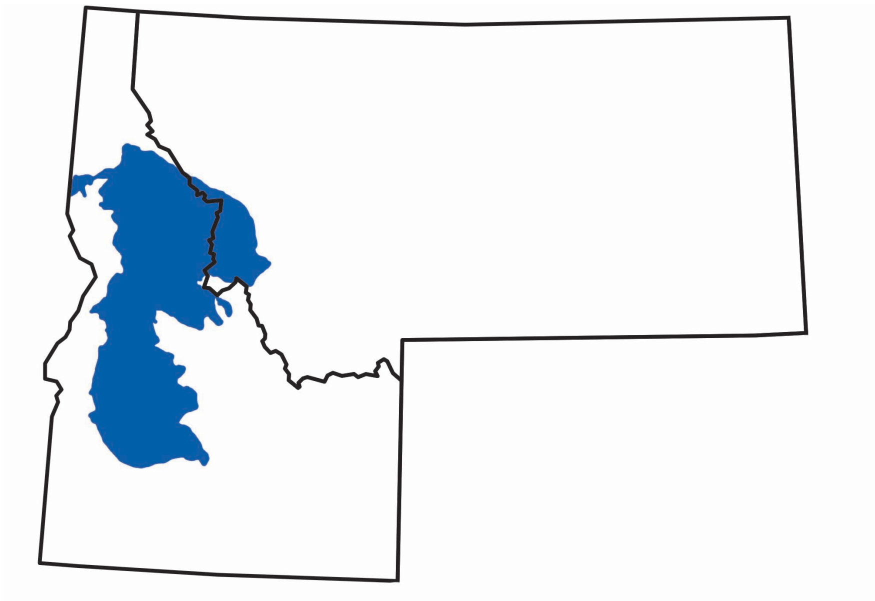


Figure 4.20: Extent of the Idaho Batholith.

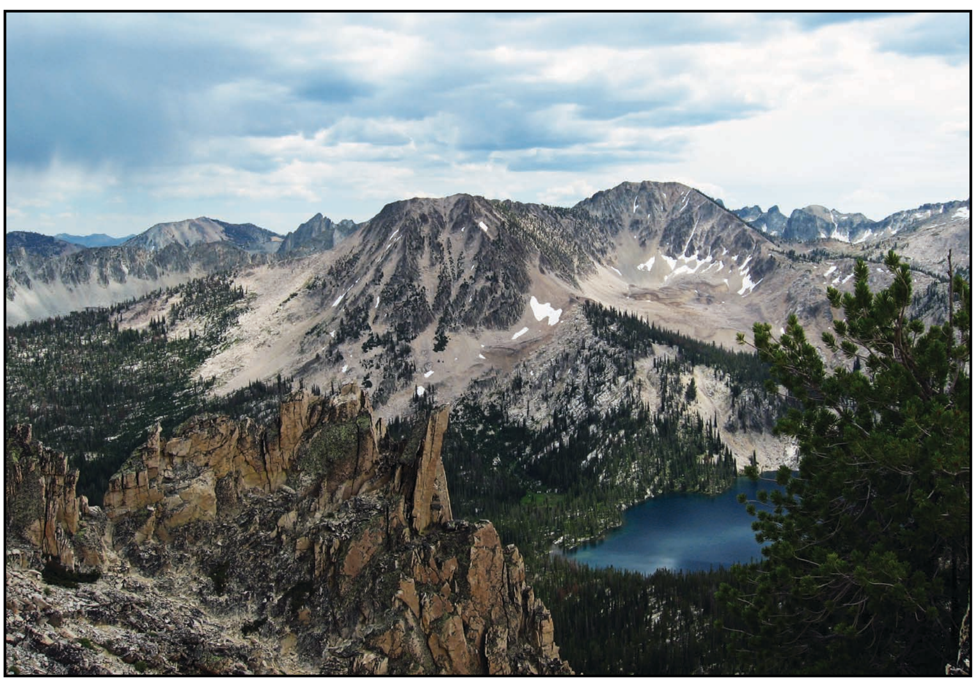
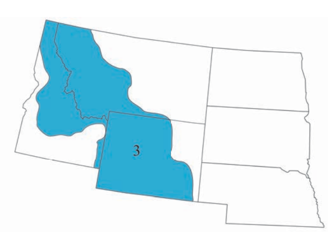
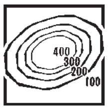


Figure 4.21: The Sawtooth Mountains above Toxaway Lake in the Sawtooth Wilderness, Idaho. These mountains are formed of granite from the Idaho Batholith.





Region 3

The Northern Rocky Mountains of Montana are also home to the Cordilleran fold-and-thrust belt, an area of deformed rock created by crustal compression during the collision of the oceanic Farallon plate with the North American plate. Blocks of older rock were thrust forward on top of younger strata, resulting in the Lewis Overthrust, a 320-kilometer-long (200-mile-long) overthrust fault that extends from central Montana into southern Alberta, Canada. Glacier National Park in northern Montana contains many outcrops related to this fault belt, including the 2770-meter-high (9080-foot-high) Chief Mountain (*Figure 4.22*).

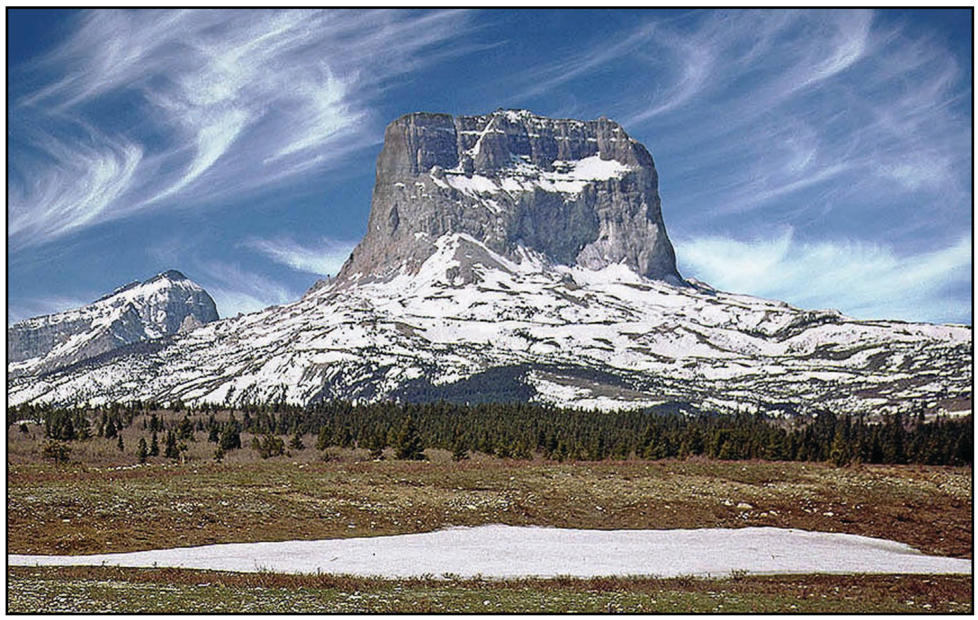


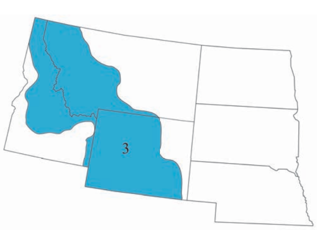
Figure 4.22: Chief Mountain, located in Montana's Glacier National Park, is a block of Precambrian rock that rests directly atop younger Cretaceous shales as a result of thrust faulting along the Lewis Overthrust. The surrounding thrust sheet has been eroded, leaving behind the mountain as an isolated block.

The Middle Rocky Mountains

The Middle Rocky Mountains consist of multiple mountain ranges, including the Wasatch, Teton, Absaroka, Bighorn, and Wind River mountains.

The Wasatch and Teton mountains were uplifted during the Cenozoic as a result of faulting, possibly due to processes related to extension in the Basin and Range region. Both ranges stretch in a north-south direction, and both border the Basin and Range: the Tetons stretch along the border of Wyoming and Idaho, and the Wasatch Range extends from the southeastern edge of Idaho down through Utah. The Wasatch Mountains (called the Bear River Mountains where they enter Idaho) formed from Cretaceous thrust faulting and the erosion of granitic batholiths followed by more recent uplift. The Teton Mountains are the

See Region 5: Basin and Range later in this chapter to learn more about the unique processes that formed its topography.



youngest range in the Rockies, formed as the rocks along one side of a normal fault were uplifted due to crustal extension between nine and six million years ago. Rocks along the other side of the fault were downdropped, creating a valley that is today known as Jackson Hole. Thanks to the fault at the base of the range, the Tetons lack foothills on their eastern side, and rise sharply up to 2100 meters (7000 feet) above the valley floor.

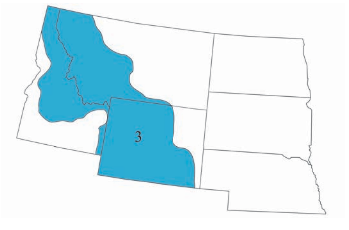
The Bighorn and Wind River mountains both have Precambrian rocks at their cores, with overlying Paleozoic and Mesozoic sedimentary rocks that were uplifted and exposed during the Cretaceous. The Wind River Mountains, formed by Mesozoic-Cenozoic thrust faulting, are the highest mountains in Wyoming with 40 peaks standing over 3960 meters (13,000 feet) high. Fault lines also cut through the flanks of the Bighorns, and the range's western face is pierced by gorges (*Figure 4.23*).

Figure 4.23: Tensleep Canyon, Washakie County, Wyoming.

The Absaroka Range stretches across the Montana-Wyoming border, and forms the eastern boundary of Yellowstone National Park. The Absarokas are the remnants of a 23,000-square-kilometer (9,000-square-mile) **Eocene** volcanic field filled with poorly consolidated volcanic debris, igneous intrusions, and tuffs. These volcanic rocks are not related to igneous activity at the Yellowstone **hot spot**, which occurred more recently. This largely looser material has been easily eroded over time, leading to the Absarokas' steep slopes and sharp, jagged topography (*Figure 4.24*). While much of the range was covered in ice during the last glaciation, weathering has destroyed most remnants of glacial landforms.

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

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



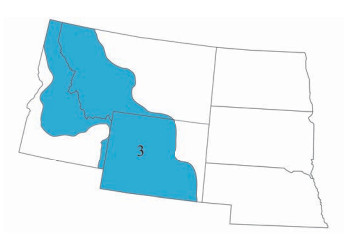
mantle • *the layer of the Earth between the crust and core.*

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

Figure 4.24: An aerial view of the Absaroka Range near Livingston, Montana.

The Yellowstone Plateau is found in the Middle Rockies of western Wyoming, and is the location of Yellowstone National Park and the Yellowstone hot spot. Hot spots can occur under both continental and oceanic crust, and they provide evidence that the Earth's tectonic plates move. Since hot spots are nearly stationary in the **mantle**, they remain in place as the plates slowly move over them, forming a chain of volcanic features that increase in age as one moves away from the hot spot. North America first overlapped with the Yellowstone hot spot in what is now Washington State, where it is thought to have produced the Columbia River flood basalts. As the North American plate continued to move, the hot spot wound up beneath the current Oregon-Nevada border, and began to generate a succession of violent, caldera-producing explosions interspersed with calmer basalt flows. We can easily trace the continent's movement by following the path of calderas across Idaho to the northwestern corner of Wyoming and Yellowstone National Park (*Figure 4.25*). The most recent Yellowstone caldera was produced by an explosive volcanic eruption 630,000 years ago (*Figure 4.26*). Geothermal activity continues in the area today, as evidenced by geysers, hot springs, steam vents, and mud volcanoes.

Geysers and other water features form from the circulation of hot groundwater, channeled through fracture zones from the ancient Yellowstone eruptions. Magma from the Yellowstone hot spot heats up the overlying rocks and the water that flows through them. The fracture zones connect this underground **heat** source to the surface and produce geysers (*Figure 4.27*), hot springs (*Figure 4.28*), steam vents, and mud volcanoes.



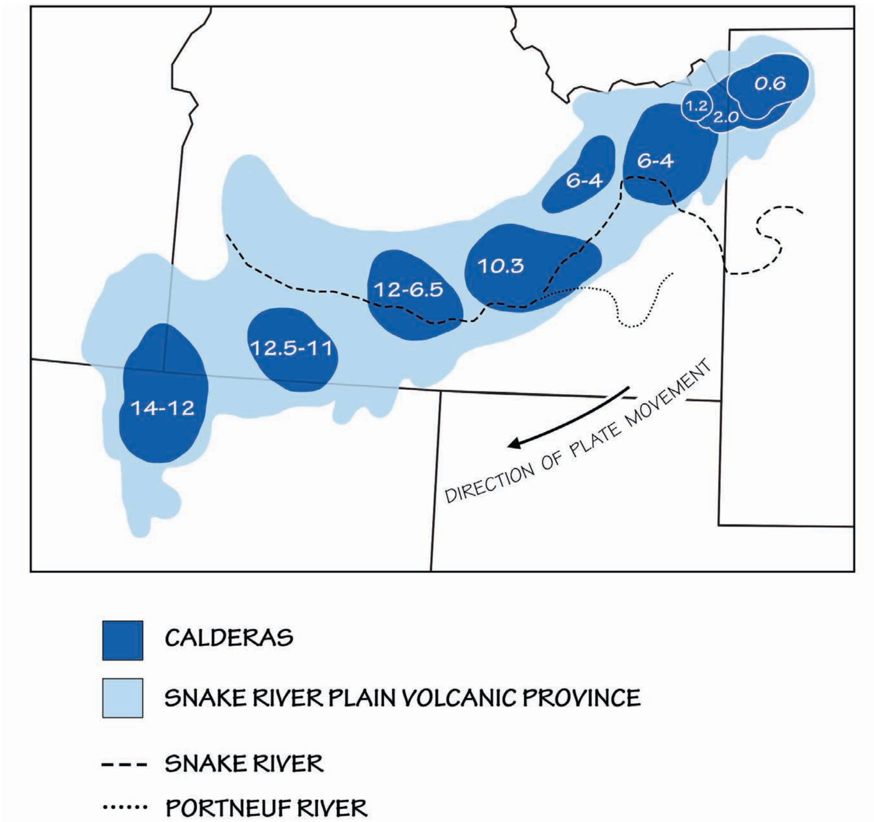
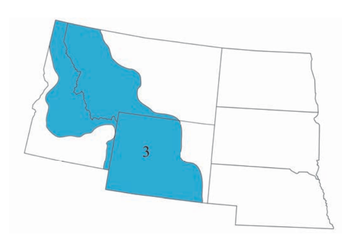


Figure 4.25: The path of the Yellowstone hot spot over the past 16 million years, including the Snake River Plain (part of the Columbia Plateau region) and Yellowstone National Park. During this time, the North American plate has been moving southwest over the hot spot.

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

How do geysers work?

When superheated water enters underground fractures, it becomes highly pressurized, preventing it from cooling. The fractures that create geysers contain a restriction near the surface that prevents water from circulating to the surface and diffusing heat, as in a hot spring. If a deep pocket of water begins to bubble, causing water to leak out of the fracture's mouth, pressure in the *system* is reduced. The water flashes into steam, and the geyser erupts; after the eruption is over, the process of pressurization begins again.



4 Topography

Region 3

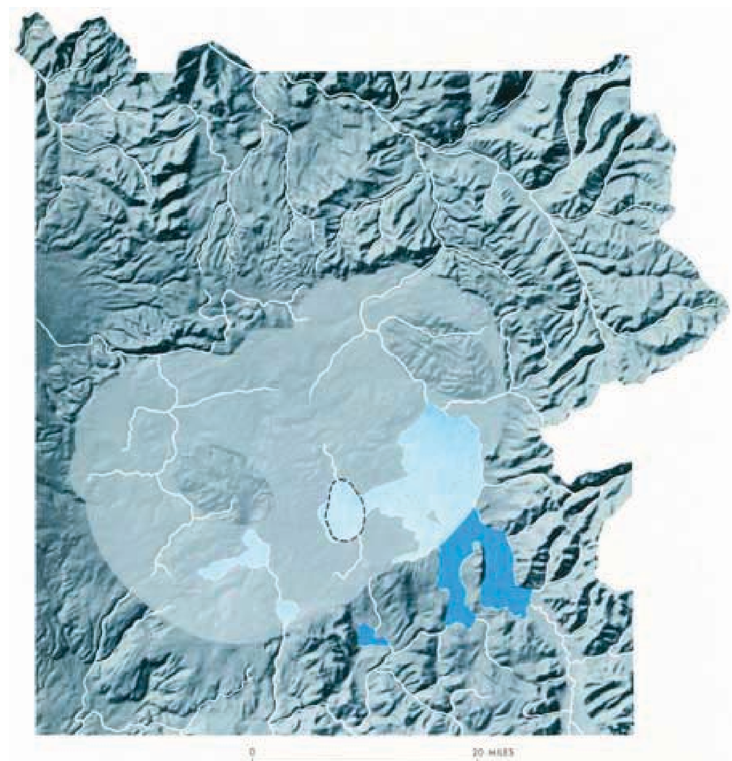
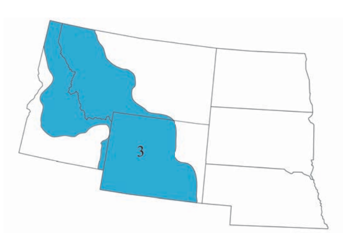


Figure 4.26: Extent of the Yellowstone caldera in Yellowstone National Park (Wyoming, overlapping into Montana and Idaho), created 630,000 years ago. The small area enclosed by the dotted line represents a small, younger caldera created during an eruption 174,000 years ago, and now filled by part of Yellowstone Lake.

Figure 4.27: Old Faithful geyser erupting at Yellowstone National Park. The geyser is one of the most predictable in the world, with intervals of 60 to 90 minutes between each eruption, which can shoot 32,000 liters (8400 gallons) of boiling water as high as 56 meters (185 feet) and last for up to five minutes.



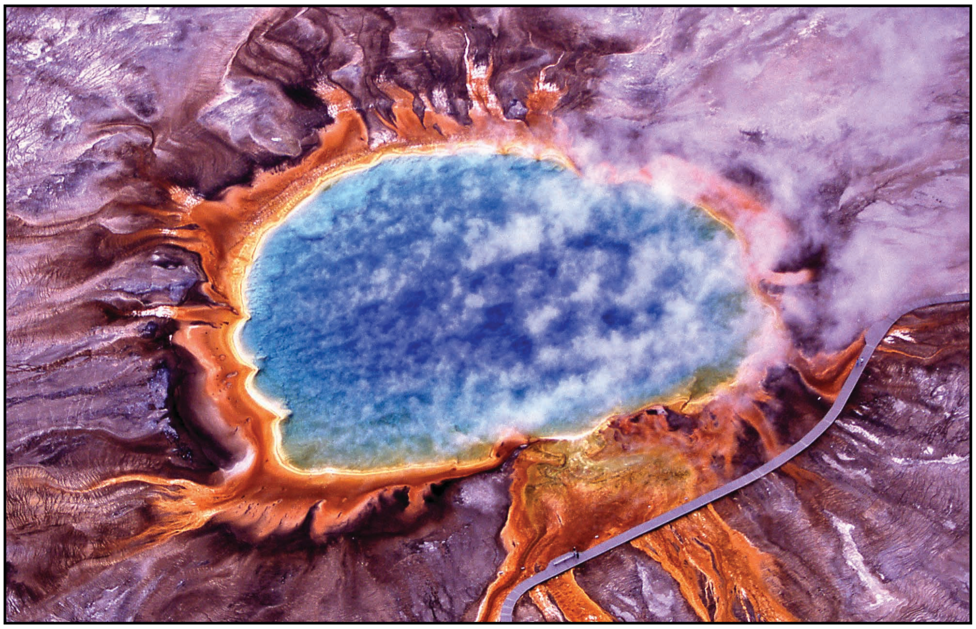


Figure 4.28: An aerial view of the Grand Prismatic Spring at Yellowstone National Park, the largest hot spring in North America, with an average diameter of 85 meters (275 feet). The spring's bright colors are caused by bacteria that live in the water.

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

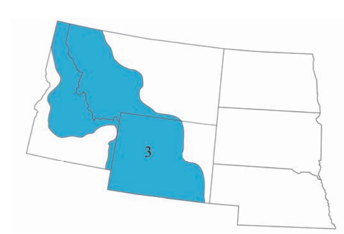
hectare *• a metric unit of area defined as 10,000 square meters.*

The Wyoming Basin

The Wyoming Basin is one of many intermontane basins that formed during the uplift of the Rocky Mountains. When the Rockies underwent weathering and erosion, layers of sediment thousands of feet thick were deposited in these basins.

The Wyoming Basin is particularly notable because it contains the Great Divide Basin—a major closed drainage basin, or area of land from which water does not drain into an ocean, but rather is retained and diffuses out by evaporation or seepage. This basin straddles the Continental Divide, and includes the Red Desert, an arid steppe and desert landscape encompassing 24,000 square kilometers (9320 square miles) of south central Wyoming. The desert receives only about 20 centimeters (8 inches) of annual precipitation, and most of its water comes from melting snowpack in the spring. This brief influx of moisture forms standing water that leads to temporary wetlands, intermittent streams, and mud flats in wet years, and which evaporates to form **salt** pans during drought. The Red Desert also contains the Killpecker Sand Dunes, one of North America's largest dune fields, spanning 44,110 **hectares** (109,000 acres) of the Great Divide Basin (*Figure 4.29*). The dunes formed from glacial sediments that collected along the banks of the Big Sandy and Little Sandy rivers to the northeast. Over the past 20,000 years, westerly winds have moved the sand toward its present location.

Winds are named for the direction from which they originate. For example, a "westerly wind" blows from the west and moves toward the east.



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

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

Figure 4.29: An aerial view of the Killpecker Sand Dunes in Wyoming.

The Southern Rocky Mountains

The bulk of the Southern Rockies are located in Colorado and New Mexico, and only three small prongs extend north into Wyoming, east of the Wyoming Basin. These are the Laramie Mountains, the Medicine Bow Mountains, and the Sierra Madre. All three ranges consist of a core of uplifted Precambrian metamorphic rock flanked by younger sedimentary strata. The Medicine Bow Mountains contain abundant **stromatolite** remains.

See Chapter 2: Rocks to learn more about stromatolites.

Topography of the Columbia Plateau
Region 4

The Columbia Plateau lies to the west of the Rocky Mountains in eastern Washington, Oregon, and Idaho. This region, also called the Columbia Basin, is a broad, volcanic plain composed of basalt. Basalt solidifies from **lavas** that are very fluid when hot, and the basalt lava in this area erupted along a series of fractures in eastern Oregon between 17 and 14 million years ago. The basalt was so voluminous and fluid that it completely filled the preexisting topography, forming a broad, flat plain that tilts downward to the west. Geologists believe

that some of these lava flows were 30 meters (100 feet) high, and flowed at speeds of up to 5 kilometers (3 miles) per hour. The Columbia Plateau also includes an area of volcanic materials erupted from the Yellowstone hot spot onto the relatively flat Snake River Plain. In the Northwest Central, the Columbia Plateau can be divided into the Walla Walla Plateau, the Payette Section, and the Snake River Plain (*Figure 4.30*).

See Chapter 3: Fossils to learn more about the Clarkia Lake flora, a Columbia Plateau lagerstätte in Idaho.

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

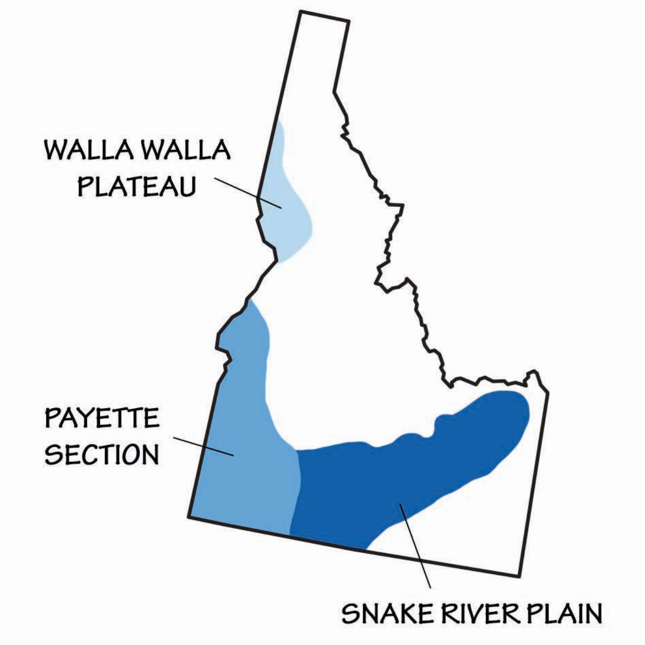


Figure 4.30: Physiographic subregions of the Columbia Plateau.

The Walla Walla Plateau is covered by flood basalt, and, in fact, one basalt flow in western Idaho, the Imnaha basalt, is 900 meters (2950 feet) thick. Some rivers were able to cut through the basalt, forming deep canyons (*Figure 4.31*). The presence and thickness of sediment varies on this plateau since some of the small rivers in this area were dammed by the basalt flows, forming lakes where sedimentation could occur. In some places, thick layers of wind-blown glacial sediment were deposited, eroding to form hills.

See Chapter 2: Rocks for more information about flood basalts.

The Payette Section is a flat-lying area dominated by the drainage basin of the Payette River (a tributary of the Snake River with two major tributaries of its own: the North and South forks). The Snake River Plain is a low-lying, relatively

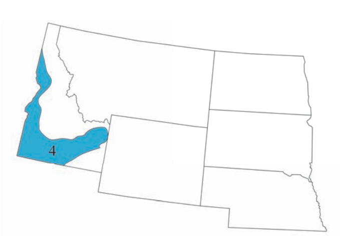


Figure 4.31: Hells Canyon, near Wallowa along the Oregon-Idaho border, cuts deeply through the Columbia Flood Basalt.

flat area underlain by volcanic rocks. This low-lying area, formed from eruptions of the Yellowstone hot spot as the North American plate moved westward (*see Figure 4.25*), forms an obvious feature on maps and satellite imagery. The majority of the features on the plain's surface are lava flows and **cinder** cones, with a few volcanic domes (*Figure 4.32*). As one moves toward the western edge of the Snake River Plain, ash flows and tuff become more common.

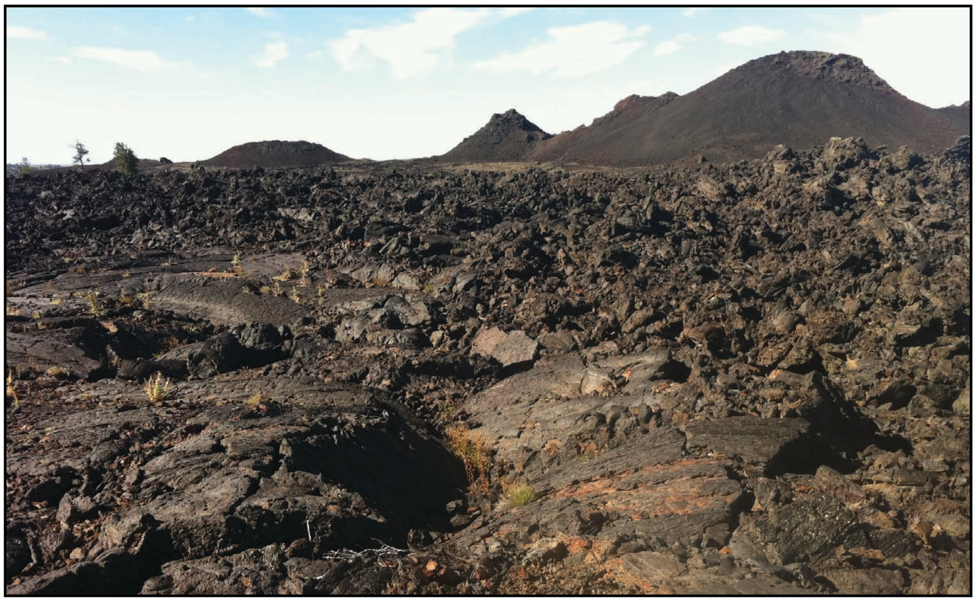


Figure 4.32: Craters of the Moon National Monument encompasses three major lava fields, spanning about 1000 square kilometers (400 square miles) along Idaho's Snake River Plain. The area's volcanic features include volcanic domes, basaltic flows, lava tubes, open rifts, and ash flows.

Topography of the Basin and Range
Region 5

Only a small portion of the Basin and Range is found in the Northwest Central US, located in the southeastern corner of Idaho. The entire Basin and Range region stretches from Idaho through all of Nevada, southeastern California, and southeastern Oregon, and reaches as far as western Texas.

The Basin and Range is characterized by rapid changes in elevation alternating from flat and dry basins to narrow and faulted mountains. This pattern of many parallel, north-south mountain ranges found throughout the region inspired geologist Clarence Dutton to famously observe that the topography of the Basin and Range appeared “like an army of caterpillars crawling northward. ”The formation of this topography is directly related to tectonic forces that led to crustal extension (pulling of the crust in opposite directions). After the Laramide Orogeny ended in the **Paleogene**, tectonic processes stretched and broke the crust, and the upward movement of magma weakened the **lithosphere** from underneath. Around 20 million years ago, the crust along the Basin and Range stretched, thinned, and faulted into some 400 mountain blocks. The pressure of the mantle below uplifted some blocks, creating elongated peaks and leaving the lower blocks below to form down-dropped valleys. The boundaries between the mountains and valleys are very sharp, both because of the straight faults between them and because many of those faults are still active.

These peaks and valleys are also called horst and graben landscapes (*Figure 4.33*). Such landscapes frequently appear in areas where crustal extension occurs, and the Basin and Range is often cited as a classic example thereof. In the Basin and Range, the crust has been stretched by up to 100% of its original width. As a result of this extension, the average crustal thickness of the

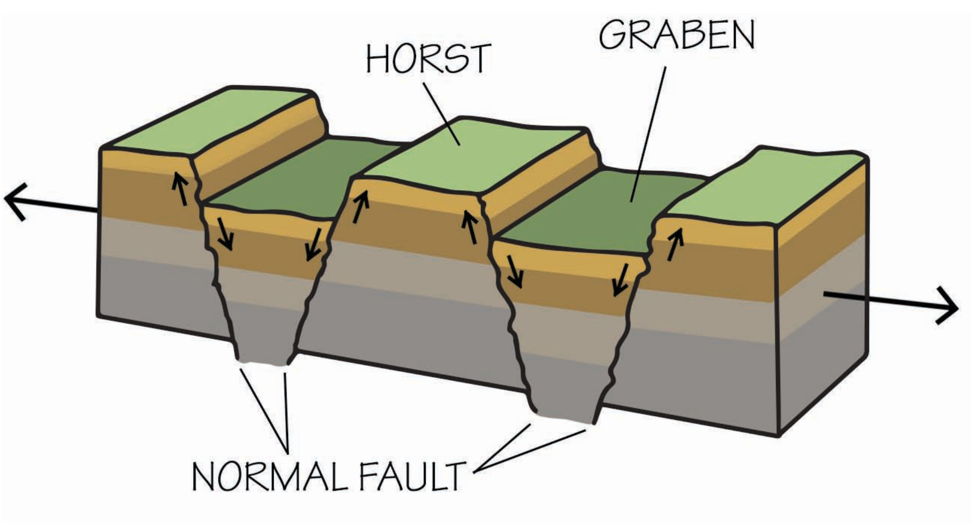
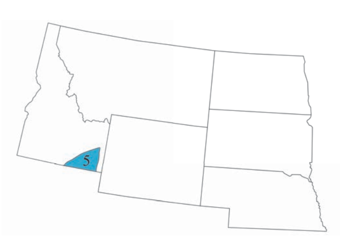


Figure 4.33: A horst and graben landscape occurs when the crust stretches, creating blocks of lithosphere that are uplifted at angled fault lines.

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

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



Elevations

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

magnitude (earthquake) *• a logarithmic scale used to measure the seismic energy released by an earthquake. Magnitudes range from 1 to 10, with M3 earthquakes classed as minor and earthquakes of M8 or greater being classified as great.*

Figure 4.34: The Portneuf Range, Bannock County, Idaho.

Basin and Range region is 30–35 kilometers (19–22 miles), compared with a worldwide average of around 40 kilometers (25 miles).

In Idaho, the Basin and Range encompasses long, parallel mountain ranges, including the Bannock and Portneuf ranges (*Figure 4.34*). The crustal extension of the Basin and Range has increased strain and tension throughout the region, leading to a dynamic variety of active fault zones that create an abundance of **earthquakes**.

See Chapter 10: Earth Hazards for more information about earthquakes in Idaho.

Highest and Lowest Elevations (by State)

Idaho

Idaho's highest point is Borah Peak, a 3861-meter-high (12,668-foot-high) mountain in the central Lost River Range, Custer County. The mountain was named in 1937 for Idaho senator William Borah, who had been in office for almost 27 years. In 2010, a **magnitude** 7.1 earthquake rocked Borah Peak, lifting it an additional two meters (seven feet) and scarring its west face. The Snake River in Nez Perce County is Idaho's lowest point, flowing at 216 meters (710 feet) above sea level.

Montana

At 3904 meters (12,807 feet) in elevation, Granite Peak is Montana's highest point and a popular mountain climbing destination. The mountain, part of the Beartooth range located 16 kilometers (10 miles) north of the Wyoming border, is considered the second most difficult state high point to climb. At the Montana-Idaho border, the Kootenai River tumbles over Kootenai Falls to land at an elevation of 555 meters (1820 feet), Montana's lowest point.

Topography

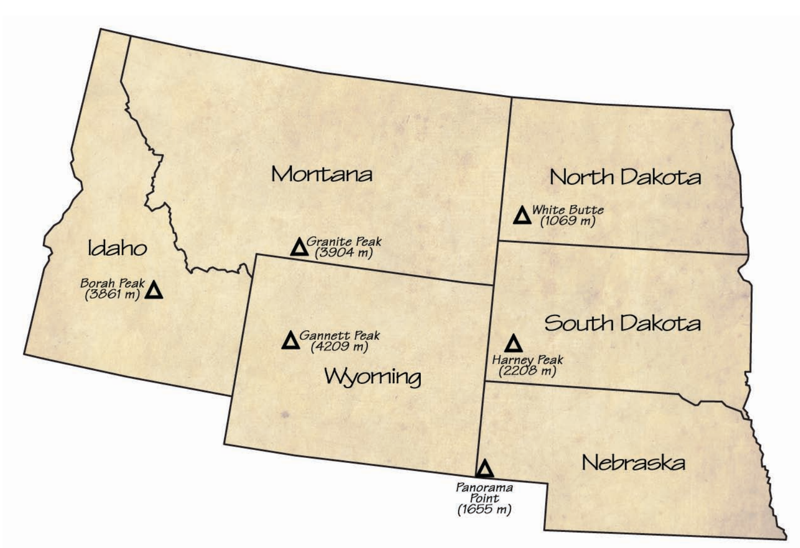
Elevations

Nebraska
Panorama Point, located near the juncture of Colorado, Nebraska, and Wyoming, is the state's highest point, with an elevation of 1655 meters (5,429 feet). Despite its name, this "point" is neither a peak nor a hill, but simply a rolling portion of the High Plains, marked only by an engraved stone and guest register. Nebraska's lowest point, at 256 meters (840 feet) above sea level, is located along the Missouri River in Richardson County.

North Dakota
White Butte, located in North Dakota's southwestern badlands, is the highest point in the state, rising to 1069 meters (3506 feet) in elevation. The butte, about 10 kilometers (6.5 miles) south of the town of Amidon, is on privately owned land, but a trail allows visitors to access the landmark. The lowest part of North Dakota, at 229 meters (751 feet) in elevation, is found along the Red River where it flows into Manitoba.

South Dakota
South Dakota's highest point is Harney Peak, an exposed granitic edifice in the Black Hills just six kilometers (four miles) southwest of Mount Rushmore. The mountain, which has an elevation of 2208 meters (7244 feet), was first seen by European-Americans when General George Armstrong Custer climbed it in 1874. South Dakota's lowest point is Big Stone Lake, which lies at 294 meters (965 feet) above sea level and is located in the northeastern corner of the state on the Minnesota border.

Wyoming
Rising to an elevation of 4209 meters (13,809 feet) above sea level, Gannett Peak is the highest point in Wyoming—and the entire Northwest Central—as well as the highest mountain in the Rockies outside of Colorado. Gannett Glacier, the largest glacier in the American Rocky Mountains, flows from Gannett Peak's north slopes. The Belle Fourche River, which reaches an elevation of 945 meters (3099 feet) at the South Dakota border, is Wyoming's lowest point.



Resources

Books

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Trimble, D. E., 1980, *The Geologic Story of the Great Plain*, US Geological Survey Bulletin 1493, http://library.ndsu.edu/exhibits/text/greatplains/text.html.

Wyckoff, J., 1999, *Reading the Earth: Landforms in the Making*, Adastra West, Mahwah, NJ, 352 pp.

Maps

Color Landform Atlas of the US, http://fermi.jhuapl.edu/states/states.html. (Low resolution shaded relief maps of each state.)

Topoquest, https://www.topoquest.com/.

Websites

Basin and Range Physiographic Province, National Park Service, http://www.nature.nps.gov/geology/education/concepts/concepts_basinrange.cfm. (Includes Idaho.)

Colorado Plateaus Province, National Park Service, http://www.nature.nps.gov/geology/education/concepts/concepts_coloradoplateau.cfm.

OpenLandform Catalog, Education Resources, OpenTopography, http://www.opentopography.org/index.php/resources/lidarlandforms. (High resolution topographic images that may be useful in teaching.)

Rocky Mountain System Physiographic Provinces, National Park Service, http://www.nature.nps.gov/geology/education/concepts/concepts_rockies.cfm.

South Dakota's Physiographic Regions, by Douglas Malo, http://www3.northern.edu/natsource/EARTH/Physio1.htm.

Teaching Geomorphology in the 21st Century, On the Cutting Edge, Strong Undergraduate Geoscience Teaching, SERC, http://serc.carleton.edu/NAGTWorkshops/geomorph/index.html. (A set of resources for college level, some of which may be adaptable to secondary education.)

Teaching with Google Earth, On the Cutting Edge, Starting Point: Teaching Entry Level Geoscience, SERC, http://serc.carleton.edu/introgeo/google_earth/index.html.

United States Geography, by S. S. Birdsall & J. Florin, http://countrystudies.us/united-states/geography.htm.

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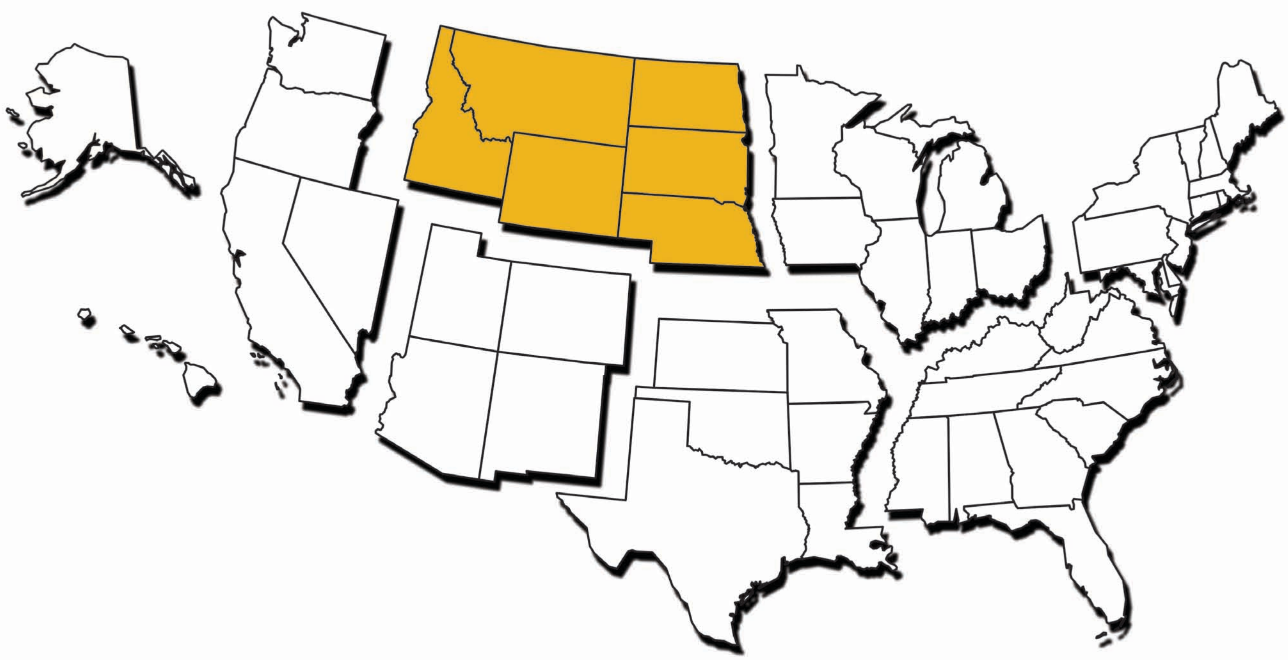
The **Teacher-Friendly** Guide™

to the Earth Science of the Northwest Central US



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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.