Chapter 10: Earth Hazards of the Northwest Central US

Natural hazards or earth hazards are events or processes that have significant impacts on human beings and the environment. Extreme **weather** conditions or geologic activity can cause substantial short-term or long-term changes to our environment. These changes can influence many aspects of the world around us, including crops, homes, infrastructure, and the **atmosphere**. The 4.6-billion-year-old Earth has experienced many naturally generated hazards, while other events are byproducts of human activities, created during mineral and **energy** extraction or in construction practices that modify the landscape.

The Northwest Central is subject to a variety of earth hazards. Weather hazards such as tornados, thunderstorms, and winter storms are particularly common in the Central Lowland and Great Plains, thanks to the unobstructed movement of air masses over areas of low **topographic relief**. The Rocky Mountains are susceptible to extreme winter weather such as heavy snow, blizzards, and high winds. Flooding can occur in areas of low elevation, including low-lying **glacially** sculpted terrain. Geological hazards, including avalanches, **earthquakes**, **landslides**, and rockfalls, are also common throughout the Northwest Central, especially in areas with rugged, mountainous terrain. The Columbia Plateau is susceptible to volcanic material produced by the Cascade Volcanoes to the west, and igneous activity associated with the Yellowstone **hot spot** has made its mark upon the surrounding land.

__weather__ • the measure of short-term conditions of the atmosphere such as temperature, wind speed, and humidity.

__atmosphere__ • a layer of gases surrounding a planet.

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

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

__relief__ • the change in elevation over a distance.

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

Earthquakes

Earthquakes occur when a critical amount of stress is applied to the Earth's **crust** and the crust responds by moving. According to the elastic rebound theory, rocks can bend elastically up to a point, until they finally break. The rocks then snap apart, releasing energy in the form of **seismic waves** (*Figure 10.1*). The plane defined by the rupture is known as a **fault**, and the surrounding rock layers become offset along it.

Many earthquakes, including most of those that occur in the Northwest Central US, arise along pre-existing faults. In cases such as these, stress may accumulate from lateral **compressive** pressure, as the rocks are temporarily locked in position by friction and other constraints, until sufficient strain energy has built up to cause sudden slippage along the fault (i.e., an earthquake).

There are two common ways to measure the size of earthquakes: **magnitude** and intensity. Magnitude (M) is the measure of the energy released by the earthquake, whereas the intensity is what people actually experience. The first scale used to measure magnitude was the **Richter scale** (abbreviated

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10 Earth Hazards

Earthquakes

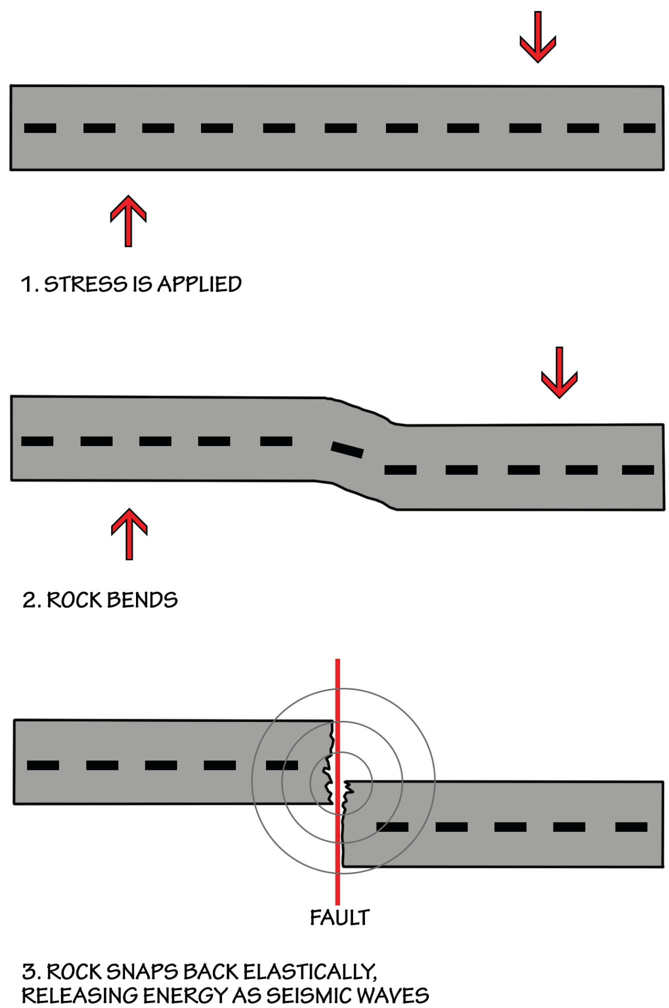

Figure 10.1: Elastic rebound.

M_L), which measures the amplitude of a seismic wave at a defined distance from the source of the earthquake. The Richter scale was designed to classify earthquakes at a local scale, but it does not do a very good job of describing the energy released by very large earthquakes. Geologists therefore developed another measurement, the Moment Magnitude scale (abbreviated M_w), which was introduced in 1979. The Moment Magnitude estimates the total energy released by an earthquake along an entire fault surface.

Both the Richter and Moment Magnitude scales are logarithmic, meaning that an M9.0 earthquake has 10 times the amplitude, and releases 32 times the energy, of an M8.0 earthquake. Accordingly, an M9.0 earth quake would have 100 times the amplitude and 1024 times the energy of an M7.0 earthquake.

Both scales may appear to reach maximum values of 10 (since the largest recorded earthquakes are slightly greater than 9), but technically there is no upper limit. The United States Geological Survey (USGS) describes earthquakes as *minor* (M3.0–3.9), *light* (M4.0–4.9), *moderate* (M5.0–5.9), *strong* (M6.0–6.9), *major* (M7.0–7.9) and *great* (M8.0 or higher). The largest recorded earthquake in US history was the 1964 Alaskan earthquake, which had an M_w of 9.2. By comparison, the largest recorded earthquake in the Northwest Central occurred in 1959 at Hebgen Lake, Montana (M7.3), near Yellowstone National Park.

The 1964 Alaskan earthquake and the 1906 San Francisco earthquake had roughly the same Richter magnitudes, but based on the size of the affected areas and geological movement, the Alaskan earthquake clearly released more energy than the San Francisco earthquake did. Geologists recalculated the magnitudes of these major quakes using the Moment Magnitude scale: the 1964 Alaskan earthquake, which originally had an M_L of 8.3, was found to have had an M_w of 9.2, whereas the 1906 San Francisco earthquake had M_L of 8.3 and an M_w of 7.9.

intensity *• a subjective measurement that classifies the amount of shaking and damage done by an earthquake in a particular area.*

Notable Earthquakes of the Northwest Central States

Date	Location	M_w
08-18-1959	Hebgen Lake, Montana	M7.3
10-28-1983	Borah Peak, Idaho	M6.9
06-28-1925	Clarkston Valley, Montana	M6.6
10-19-1935	Helena, Montana	M6.3
11-23-1947	Madison County, Montana	M6.3
03-28-1975	Malad City, Idaho	M6.2
07-12-1944	Sheep Mountain, Idaho	M6.1
06-30-1975	Yellowstone National Park, Wyoming	M6.1
05-16-1909	Dickinson, North Dakota	M5.5
03-28-1964	Merriman, Nebraska	M5.1

The magnitude of an earthquake, however, does not tell us how much damage it causes. The amount of shaking and damage is known as the earthquake's **intensity**, and it can be measured by the Modified Mercalli Intensity (MMI) scale. This scale uses the Roman numerals I–XII to describe the effects of the earthquake in a particular location. For example, near the epicenter of a small earthquake, or at a location far from a large earthquake, the intensity may be described with an MMI of II: "*Felt only by a few persons at rest, especially on the upper floors of buildings. Delicately suspended objects may swing.*" Unlike the Moment Magnitude scale, the MMI scale is a subjective gauge, and the USGS has attempted to improve the accuracy of MMI shake maps by soliciting data from the public. *Figure 10.2* shows the intensities felt in surrounding areas after the 1983 Earthquake at Borah Peak, Idaho, which is the largest earthquake known to have occurred in the state.

The Rocky Mountain and Columbia Plateau regions of the Northwest Central, including western Montana, northwestern Wyoming, and most of Idaho, compose one of the most seismically active areas in the United States (*Figure*

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

seismic belt • *a narrow geographic zone along which most earthquakes occur.*

seismic zone • *a regional zone that encompasses areas prone to seismic hazards, such as earthquakes or landslides.*

Figure 10.2: Intensity map of the 1983 Borah Peak earthquake.

10.3), with as many as 3000 earthquakes occurring each year (although most are too small to feel). Most of these earthquakes are caused by a combination of two phenomena: the **magmatic** activity of the Yellowstone hot spot, and the (possibly related) tectonic activity of the Basin and Range region. The resulting crustal movements cause most earthquakes to be localized in particular areas, either around the Yellowstone area or along linear **seismic belts** or **zones** (*Figure 10.4*).

See Chapter 4: Topography to learn more about the Yellowstone hot spot and the Basin and Range.

The *Intermountain Seismic Belt* is a major zone of earthquake activity that extends from the Flathead Lake region in the northwest corner of Montana, southward through Yellowstone Park, along the Idaho-Wyoming border, through Utah, and into southern Nevada. A branch of the Intermountain Seismic Belt, called the *Centennial Tectonic Belt* or *Central Idaho Seismic Zone*, extends west from the

Earth Hazards 10

Earthquakes

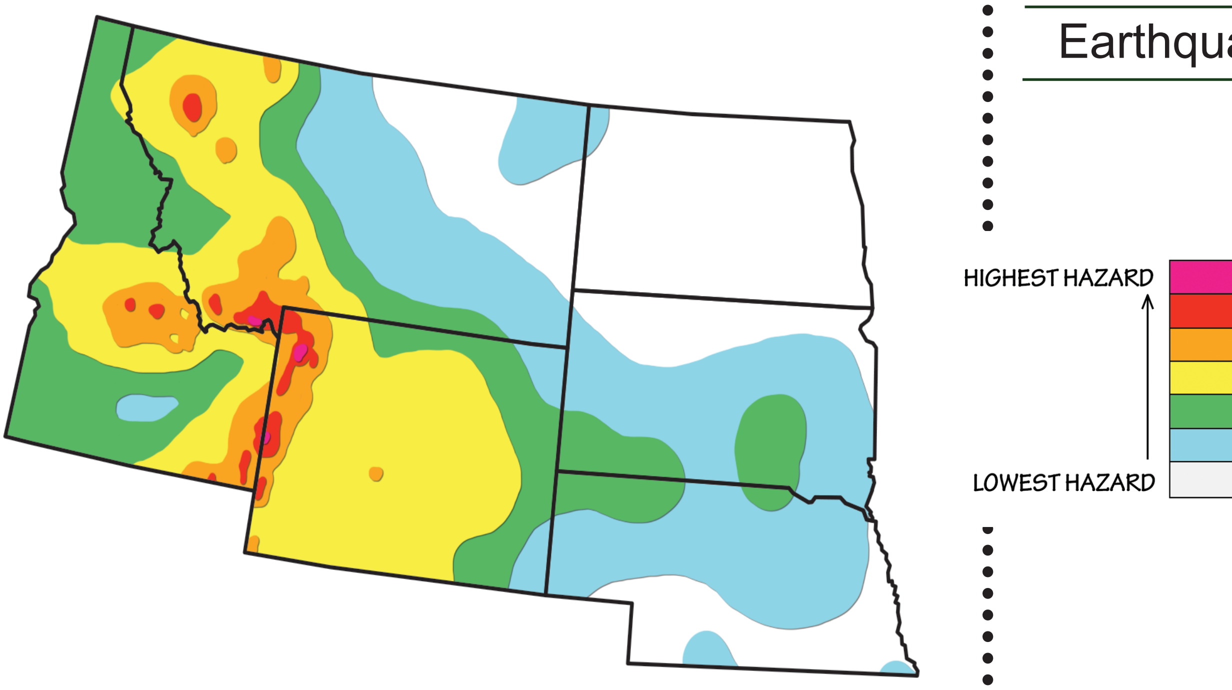

Figure 10.3: Seismic hazard map of the Northwest Central US, based on data in 2014. (See TFG website for full-color version.)

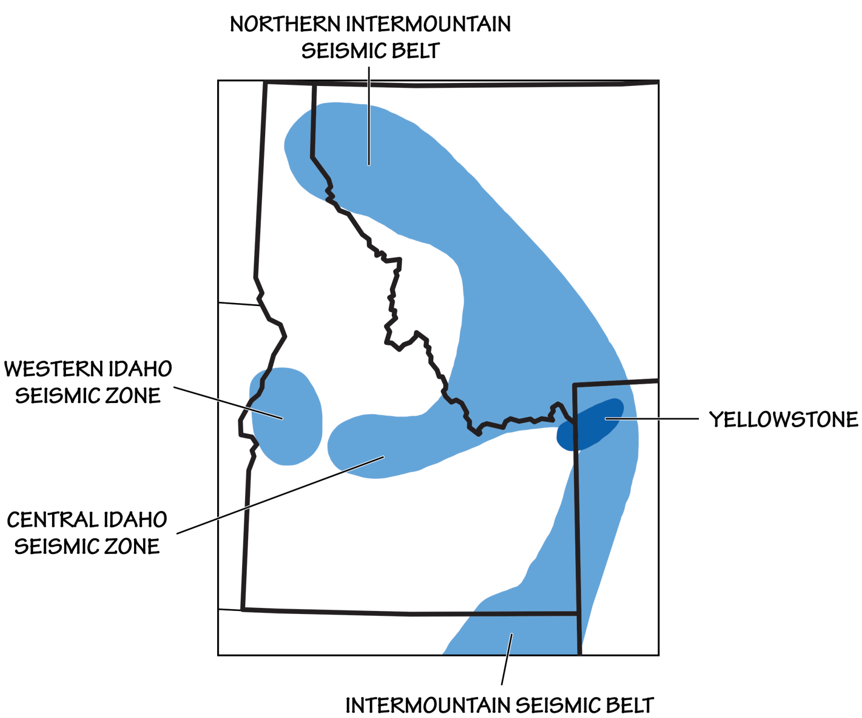

Figure 10.4: Major seismic belts and zones of the Northwest Central US.

Earthquakes

northwest corner of Yellowstone National Park through southwestern Montana and into central Idaho. This zone includes at least eight major active faults, and was the site of the two most severe earthquakes in the Rocky Mountains: the Hebgen Lake and Borah Peak earthquakes (*Figure 10.5*). The M7.3 Hebgen Lake earthquake, which occurred near the Montana-Wyoming Border in 1959, caused a major landslide that resulted in 28 fatalities as well as damming a river and destroying roads and buildings (*Figure 10.6*). The M6.9 Borah Peak earthquake occurred in Idaho in 1983, and caused extreme surface faulting as well as $12.5 million worth of damage to infrastructure in the surrounding Challis-Mackay area. A 34-kilometer-long (21-mile-long) **fault scarp** formed along the slopes of the Lost River Range; in other areas, the ground was shattered into huge blocks up to 100 meters (330 feet) in width.

fault scarp *• an escarpment directly beside a fault line, where the ground on one side of the fault has moved vertically with respect to the other side, creating step-like topography.*

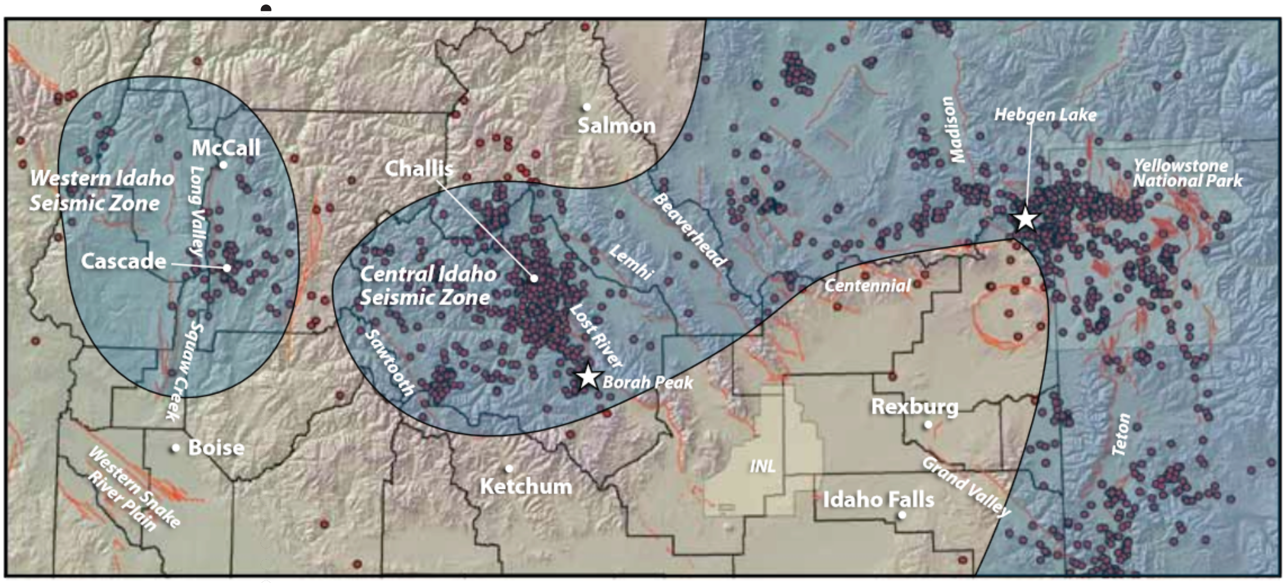

Figure 10.5: Earthquake occurrences in the Central Idaho Seismic Zone and Western Idaho Seismic Zone between 1973 and 2009. Earthquake epicenters are shown in red. The locations of Borah Peak and Hebgen Lake are marked by stars. (See TFG website for full-color version.)

A geologically distinct region called the *Western Idaho Seismic Zone* lies between McCall and Boise. It is characterized by prominent north-south-trending basins and ranges that contrast strikingly with the surrounding area. A complex **suture** zone between **accreted terranes** and the ancient North American tectonic **plate** underlies the region and may influence the north-south orientation of the Zone's faults. Major active faults in the Western Idaho Seismic Zone include the Squaw Creek fault and the Long Valley fault zone, which is notable for earthquake swarms. During a swarm, thousands of small shallow earthquakes occur over several weeks to months within a relatively small region.

The *Lewis and Clark Zone* is a **megashear** in the Earth's crust, up to 48 kilometers (30 miles) wide, which runs some 386 kilometers (240 miles) through north Idaho and northwestern Montana. Geologic studies have shown that the North American plate has been **sheared** along this zone repeatedly over the

suture *• the area where two continental plates have joined together through continental collision.*

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

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

Figure 10.6: Earthquake damage to State Highway 287 and the Hilgard Lodge near Hebgen Lake, Montana.

past billion years, meaning that the rocks have been continuously **fractured** due to compressive stress. The most obvious manifestation of the zone is a set of parallel valleys that follow brittle fault zones across the grain of the northern Rocky Mountains from Helena and Missoula, Montana to Coeur d'Alene, Idaho. These valleys provided a natural transportation corridor through the mountains used in part by Lewis and Clark in 1806 and the Mullan Trail of the 1850s, and today by Interstate 90. Along the Lewis and Clark Zone in Idaho, many mining-related seismic events, called **rockbursts**, have occurred. Rockbursts are spontaneous, violent fractures of rock in deep mines. The sizable magnitudes of these events, their alignment with the direction of horizontal strain, and their location within the Lewis and Clark Zone suggest that tectonic stress release may be involved in causing them.

See Chapter 1: Geologic History to learn about the tectonic events that formed the North American continent and generated fractures and faults.

Earthquakes have many different effects on the rocks in which they occur, including breaking and movement along faults, **uplift**, and displacement. Earthquakes around Yellowstone National Park have altered the area's extensive **hydrothermal systems** and may help to keep open the fractures and conduits that supply hot water to the surface. For example, both the 1959 Hebgen Lake and 1983 Borah Peak earthquakes caused measurable changes in the output of Old Faithful geyser and other hydrothermal features. Yellowstone is one of the most active seismic zones in the United States, and commonly experiences

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

megashear *• a large shear formed when rocks have been continuously fractured due to compressive stress.*

shearing *• the process by which compressive stress causes the fracturing and faulting of brittle rocks.*

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

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

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

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

earthquake swarms (*Figure 10.7*). The largest swarm occurred in 1985, with more than 3000 earthquakes recorded on the northwest side of the park during a three-month period. Scientists believe these swarms are caused by shifting and changing pressures in the crust due to the migration of hydrothermal fluids, a common occurrence around volcanoes.

See Chapter 4: Topography to learn more about hydrothermal features at Yellowstone National Park.

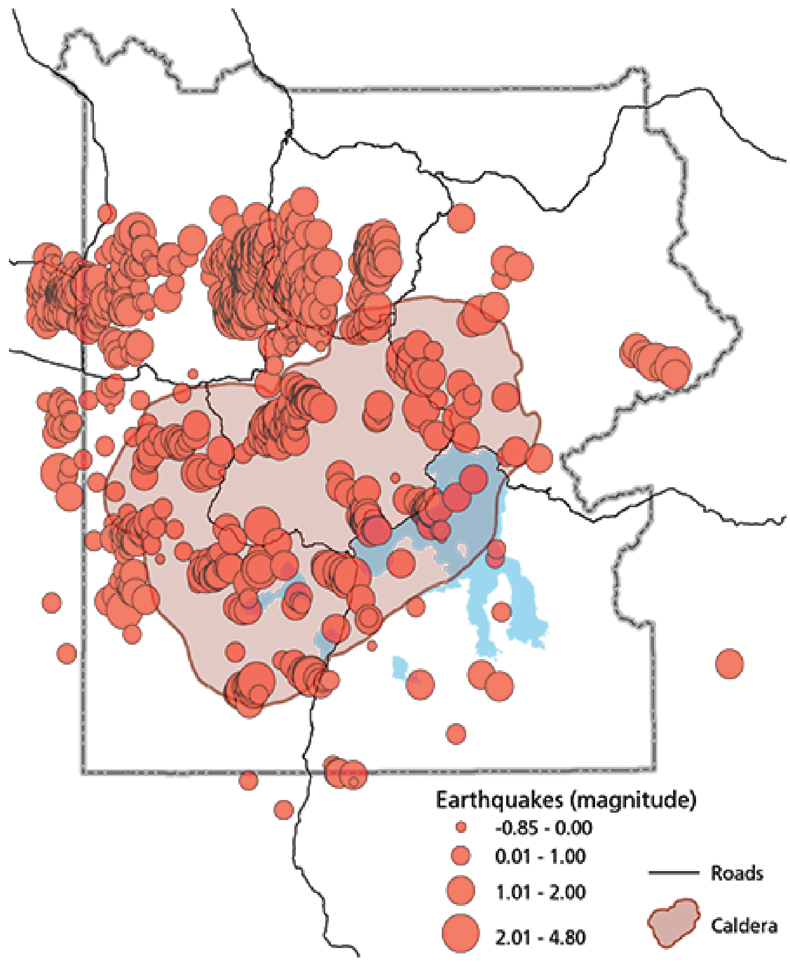

Figure 10.7: Earthquakes in Yellowstone National Park, 2014. Approximately 2000 earthquakes occurred during the course of the year. (See TFG website for full-color version.)

Volcanism

While there are no active volcanoes in the Northwest Central US today, past volcanism has left its mark on the area. Igneous activity continues today in and around Yellowstone National Park in northwestern Wyoming, which overlies a hot spot in the Earth's mantle. During the Cenozoic, as the North American

Volcanism

plate traveled over this mantle plume, the crust melted and produced a trail of volcanic rock that crosses southern Idaho, forming the Snake River Plain and ending at Yellowstone National Park. The trail of volcanic eruptions from the hot spot works its way east along this path. For example, the rocks at Craters of the Moon National Monument in southeastern Idaho formed during eight major eruptive periods between 15,000 and 2000 years ago. During this time, **lava** associated with the Yellowstone hot spot erupted from the Great Rift, a series of deep cracks that start near Craters of the Moon's visitor center and stretch 84 kilometers (52 miles) to the southeast. Over the course of eruption, the lava field grew to cover 1600 square kilometers (618 square miles).

See Chapter 2: Rocks for more information about the rocks formed by eruptions of the Yellowstone hot spot.

The recent geological history of volcanism at Yellowstone has led the area to be classified as a **supervolcano**—a volcano capable of producing more than 1000 cubic kilometers (240 cubic miles) of ejecta. Supervolcanoes can occur when magma rises under the crust from a hot spot, but is unable to break through. Eventually, the crust ruptures when it can no longer contain the built-up pressure. Although the Yellowstone area contains no active volcanoes today, the Yellowstone hot spot was the source of several prehistoric supereruptions (*Figure 10.8*): the Huckleberry Ridge, 2.1 million years ago, which produced 2450 cubic kilometers (588 cubic miles) of ejecta; the Mesa Falls flow, 1.3 million years ago, which produced 280 cubic kilometers (67 cubic miles) of ejecta; and the Lava Creek flow, 630,000 years ago, which produced 1000 cubic kilometers (240 cubic miles) of ejected material. The Mount St. Helens

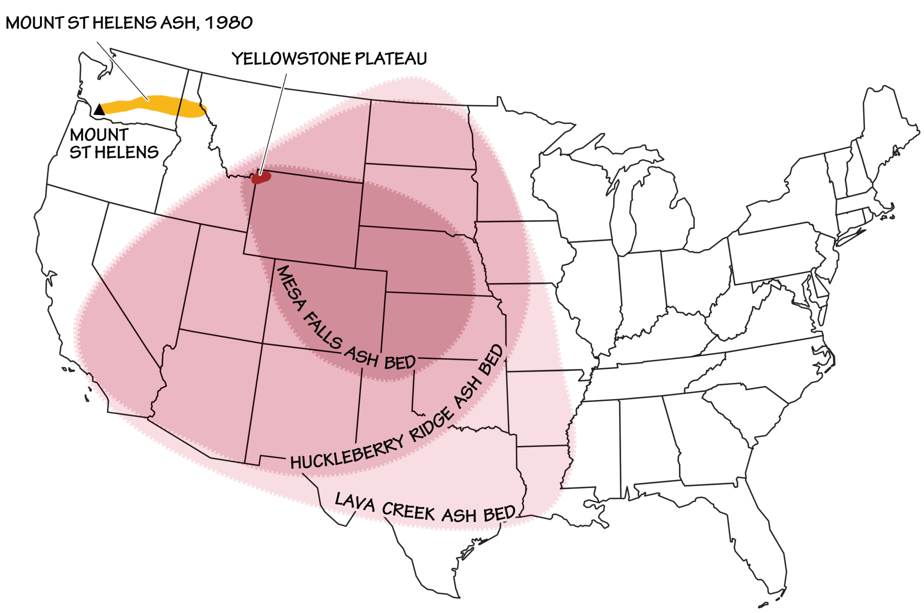

Figure 10.8: The extent of the three most recent ashfalls from Yellowstone supervolcano eruptions, as compared to the eruption of Mount St. Helens in 1980.

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

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

mass wasting • *a process in which soil and rock move down a slope in a large mass.*

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

erosion • *the transport of weathered materials.*

eruption in 1980, by contrast, produced only 0.19 cubic kilometers (0.046 cubic miles) of ejecta. While there is concern about another supereruption occurring at Yellowstone, the probability of an explosive eruption within the next few thousand years is very low.

Landslides

The term "landslide" refers to a wide range of **mass wasting** events that result in rock, **soil**, or fill moving downhill under the influence of gravity (*Figure 10.9*). These events occur when friction between the earth material (i.e., rock and soil) and the slope is overcome, allowing the earth material to fail and move downslope. Landslides may be triggered by high rainfall, earthquakes, **erosion**, deforestation, groundwater pumping, or **volcanic** eruptions. They may occur rapidly, such as in some mud and **debris flows**, or they can be as slow as soil **creep**: slow land movement that usually does not cause loss of life, but can still destroy roads and buildings. In mountainous areas, avalanches, landslides,

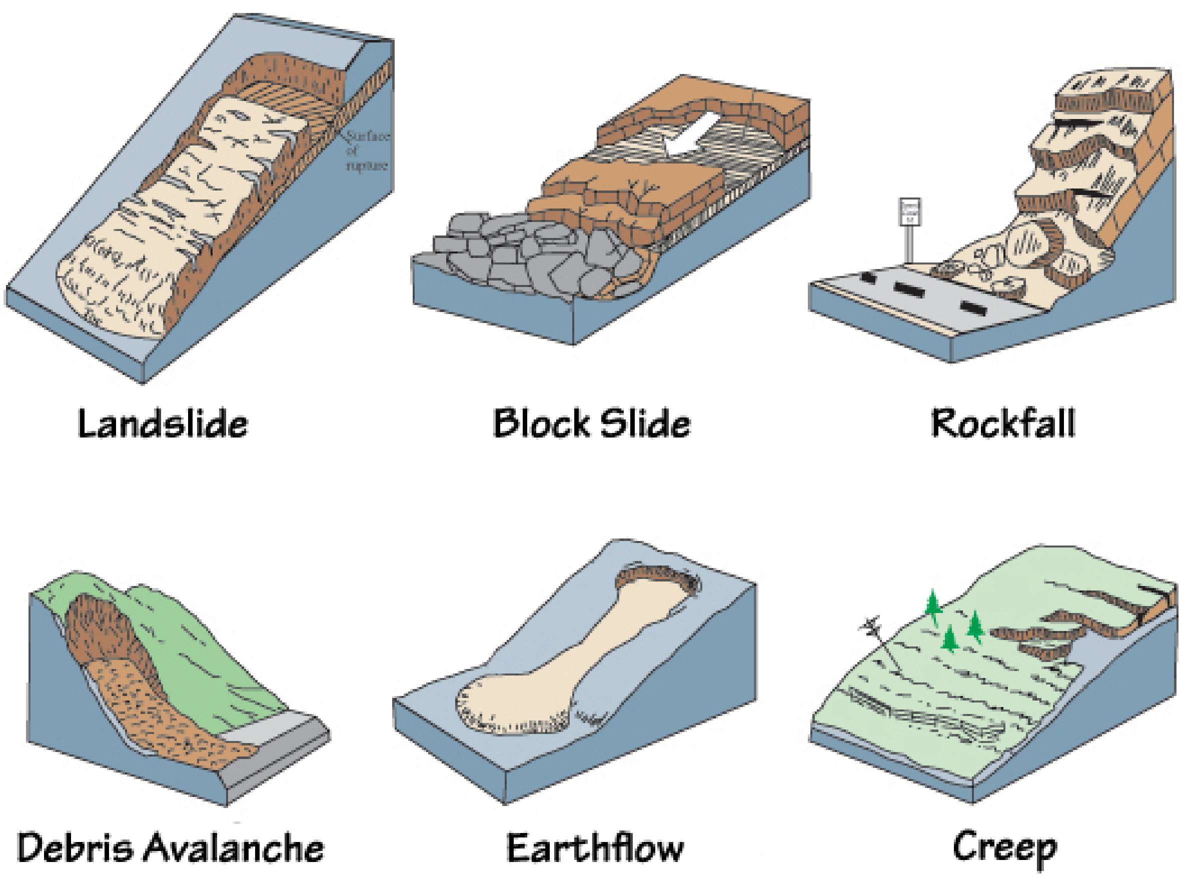

Figure 10.9: Common types of landslides.

and rockfalls can be dangerous, moving downslope and then crossing roads and moving into areas that contain homes and other buildings. In the Rocky Mountains, every year at least one road will be temporarily closed as the result of an avalanche, earth movement, or rockfall event. Mass wasting events can also dam streams and rivers, creating lakes. If such dams fail, a flood will result somewhere downstream.

Landslides are common in mountainous regions of the Northwest Central thanks to a combination of steep terrain, poorly consolidated sediments, and tectonic activity (*Figure 10.10*). They often occur in high glacial valleys with little vegetative cover. In the winter, many of the same mountainous areas that are prone to landslides during the year are subject to avalanches—rapid flows of snow, ice, and rock. Avalanches occur when the strength of the snow is overcome, or when a weak layer in the snow fails. These snow failures can result from storms, warming weather, sunny slopes, earthquakes, and people moving over the snow. Thousands of avalanches occur every winter in the mountains of Idaho, Montana, and Wyoming.

volcanism • *the eruption of molten rock onto the surface of the crust.*

debris flow • *a dangerous mixture of water, mud, rocks, trees, and other debris that can move quickly down valleys.*

creep • *the slow movement or deformation of a material under the influence of pressure or stress.*

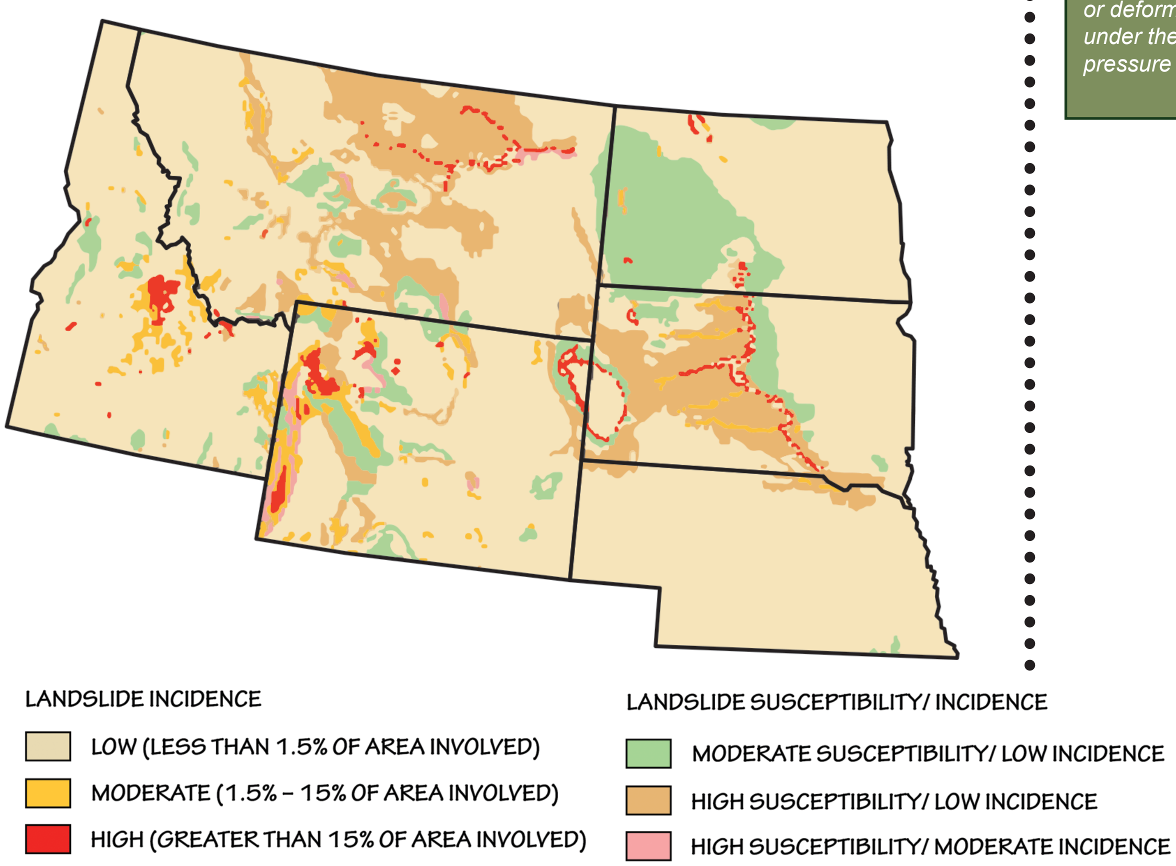

Figure 10.10: Landslide incidence and risk in the Northwest Central. (See TFG website for full-color version.)

10 Earth Hazards

Landslides

In Montana, landslides are among the state's most common geologic hazards. The largest landslide in Montana history, triggered by the Hebgen Lake Earthquake of August 1959, carried 80 million tons of mud, rock, and debris down Sheep Mountain at an estimated 160 kilometers per hour (100 miles per hour) (*Figure 10.11*). The slide killed 28 people and buried sections of Montana Highway 287 beneath almost 122 meters (400 feet) of rock, as well as formed a major dam across the Madison River (*Figure 10.12*). Landslides are also common occurrences in the mountains of Wyoming. In 1925, more than 38 million cubic meters (50 million cubic yards) of waterlogged soil was dislodged from a mountainside, crossed the Gros Ventre River, and moved 90 meters (300 feet) up the other side of the valley. The landslide blocked the river, creating Lower Slide Lake. Two years later, the dam failed, and the subsequent flash flood killed six people and destroyed a nearby town.

Figure 10.11: Damage from the Hebgen Lake Landslide is still visible today in Madison Valley, Montana.

In Idaho, a variety of geological features combine to increase the likelihood of slope failure. Throughout the Snake River Plain and Columbia Plateau, **basalt** is interbedded with unconsolidated sediments, fractured **metamorphic rocks**, and loose volcanic material along deep canyons. Rocks fractured by folding and faulting are common, and ice-age floods deposited loose **gravel** and **sand** as well as undercut slopes. All these factors contribute to slope instability, and tremors from earthquakes associated with Idaho's several fault lines often produce landslides throughout the state. Intense storms and heavy winter rains, generated by moisture carried eastward from the Pacific Ocean, can also waterlog soils and lead to mudflows or debris flows.

See Chapter 6: Glaciers to learn more about ice-age lakes and outburst floods.

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

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.*

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

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

tree • *any woody perennial plant with a central trunk.*

Landslides

Figure 10.12: The landslide dam that led to the formation of Quake Lake (also known as Earthquake Lake). Today, the lake is 58 meters (190 feet) deep and 10 kilometers (6 miles) long.

Mudflows or earthflows are fluid, surging flows of debris that have been fully or partially liquefied by the addition of water. They can be triggered by heavy rainfall, snowmelt or high levels of ground water flowing through cracked bedrock. High groundwater pressures and soil liquefaction due to nearby roadwork are thought to have generated the 1998 mudflow in Bonners Ferry, Idaho, in which 306,000 cubic meters (400,000 cubic yards) of earth materials flowed across Highway 95 and a Union Pacific railway track, burying more than a million dollars' worth of equipment (*Figure 10.13*).

Debris flows are a dangerous mixture of water, mud, rocks, **trees**, and other debris that moves quickly down valleys. The flows can result from sudden rainstorms or snowmelt that creates flash floods. In Glacier National Park, Montana, debris flows regularly occur where rock fragments like **talus** have built up on steep slopes and cliff faces. These debris flows can travel hundreds of meters (feet), and regularly impact trails and roads within the park.

Slumps and creep are common problems in parts of the Northwest Central with a wetter **climate** and/or the presence of unstable slopes, such as North Dakota's Red River Valley, the Fort Randall Reservoir in South Dakota, and the Niobrara River in Nebraska. These areas contain expansive soils generated from **clay**-rich **shales**. Certain clay **minerals** can absorb water and swell up to twice their original volume—an amount of expansion that can exert enough force to cause damage, such as cracked foundations, floors,

See Chapter 8: Soils for more information about Vertisols, soils rich in swelling clays.

talus • *debris fields found on the sides of steep slopes, common in periglacial environments.*

slump • *a slow-moving landslide in which loosely consolidated rock or soil layers move a short distance down a slope.*

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).*

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

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

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

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

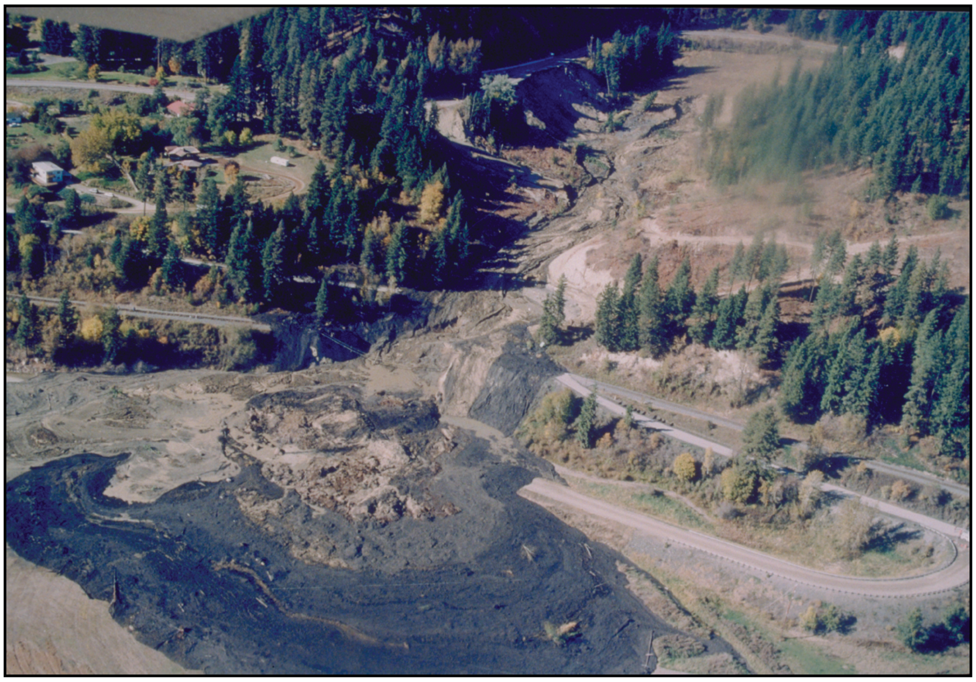

Figure 10.13: Mudflow in Bonners Ferry, Idaho.

and basement walls. An estimated $9 billion of damage to infrastructure built on expansive clays occurs each year in the United States. In addition, when the clay dries and contracts, the particles settle slightly in the downhill direction. This process can cause soil creep, a slow movement of land that causes fences and telephone poles to lean downhill, while trees adjust by bending uphill (*Figures 10.14 and 10.15*). Human development can exacerbate this process when homes are built along river bluffs, disturbing vegetation that would otherwise stabilize the slope and adding water to the land in the form of yard irrigation or septic systems.

Slumping occurs when expansive minerals are present on steeper slopes, and involves the downward movement of a larger block of material along a surface that fails when the weight of the saturated soils can no longer be supported. Thanks to rain and heavy spring snowmelt runoff, slumps are a significant problem in some areas of North Dakota. In 2011 alone, this type of mass wasting caused more than $3 million of damage to roads and trails in Theodore Roosevelt National Park. Slumping is common near roads and highways throughout the state, thanks to the presence of steeper hills, roadcuts, and construction (*Figures 10.16 and 10.17*).

While expansive soils can be found all over the US, nearly every state in the Northwest Central has bedrock units or soil layers that are possible sources, with central Montana, North Dakota's Red River Valley, and South Dakota's **Cretaceous** shales being the most susceptible (*Figure 10.18*). Significant or repeated changes in moisture, which can occur in concert with other geologic hazards such as earthquakes, floods, or landslides, greatly increase the hazard potential of expansive soils. The key to reducing this hazard is to keep the

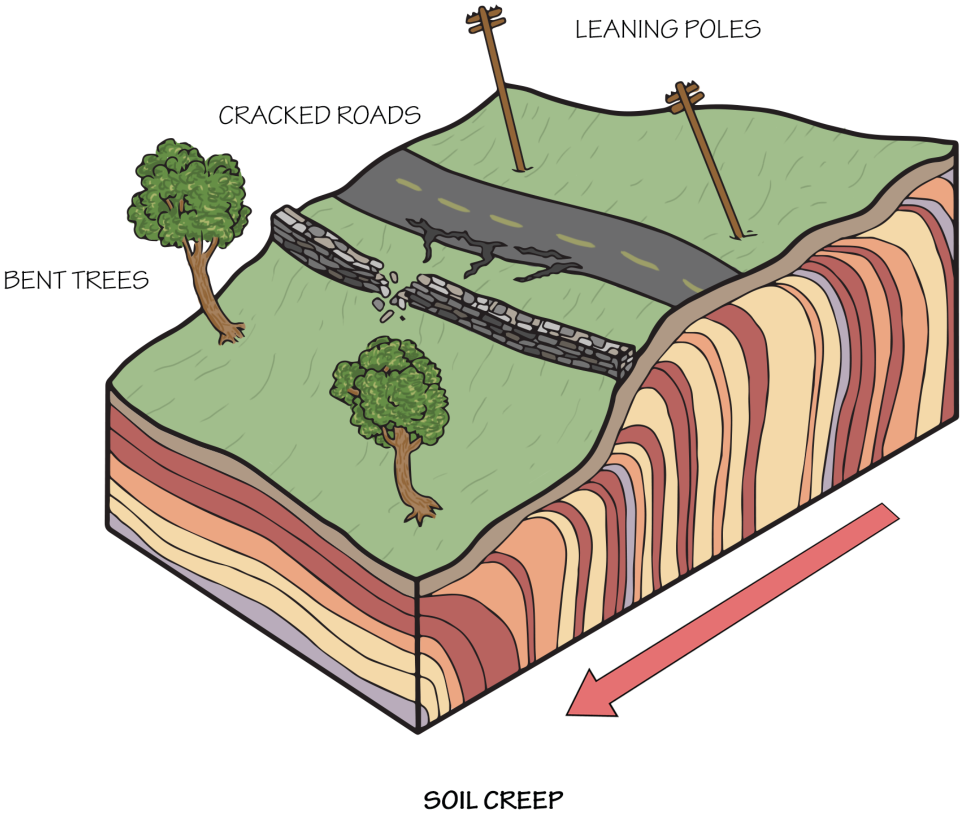

Figure 10.14: Some influences of soil creep on surface topography.

Figure 10.15: These fenceposts along the Sheyenne River Valley in North Dakota lean downhill under the influence of soil creep, while the trees near them bend uphill to compensate.

Landslides

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

karst topography • *a kind of landscape defined by bedrock that has been weathered by dissolution in water, forming features like sinkholes, caves, and cliffs.*

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

Figure 10.16: This slump near Interstate 29 in Fargo, North Dakota occurred in clay-rich materials used to construct the nearby overpass.

Figure 10.17: This slump occurred along a North Dakota roadcut after a spring thaw melted piles of snow on the upper bank, saturating the clay-rich soil and increasing its weight.

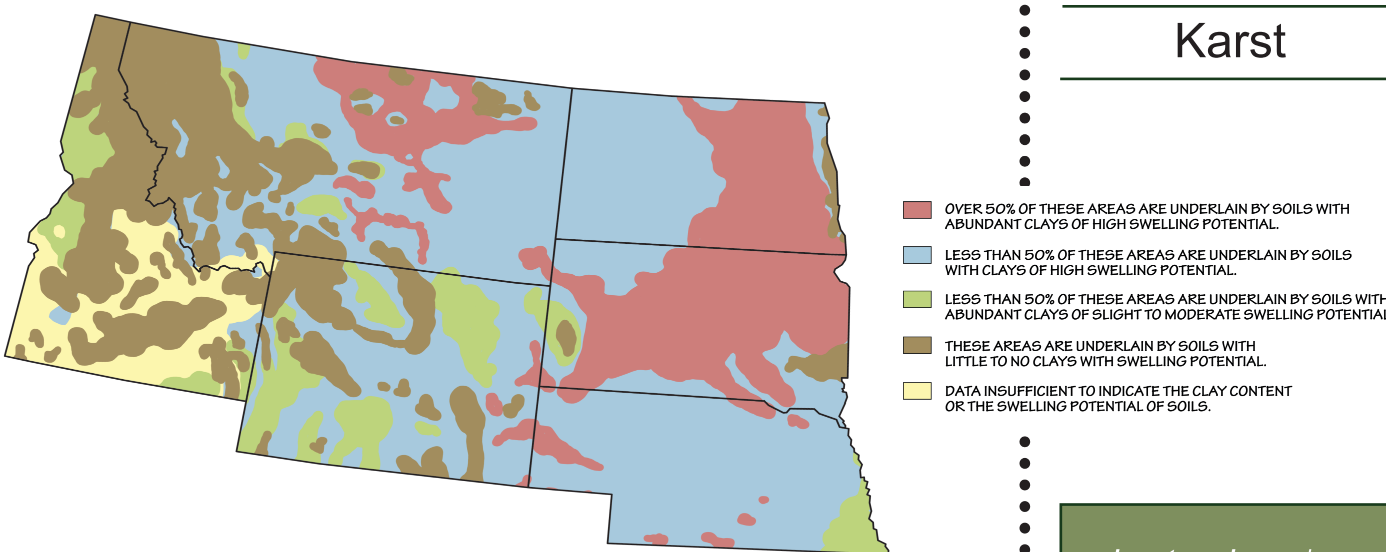

Figure 10.18: Approximate distribution of expansive soils in the Northwest Central US. This map is based on the distribution of types of bedrock, which are the origin of soils produced in place. (Where substantial fractions of the soil have been transported by wind, water, or ice, the map will not be as accurate.) (See TFG website for full-color version.)

water content of the soil constant. There are also chemical stabilizers, including **lime**, potassium, and ionic agents, that can reduce the potential for soil volume changes by increasing the clay's structural stability.

Damage to life and property from mass wasting events can be reduced by avoiding landslide hazard areas or by restricting access to known landslide zones. Hazard reduction is possible by avoiding construction on steep slopes or by stabilizing the slopes. There are two main ways to accomplish stabilization: 1) preventing water from entering the landslide zone through runoff, flooding, or irrigation and 2) stabilizing the slope by placing natural or manmade materials at the toe (bottom) of the landslide zone or by removing mass from the top of the slope.

Karst and Sinkholes

Karst topography forms in areas where the underlying bedrock is composed of material that can be slowly dissolved by water. Examples of this type of **sedimentary rock** include **carbonate rocks** such as **limestone**, **halite**, **gypsum**, **dolomite**, and anhydrite. Carbonate rocks may develop karst and other dissolution features due to the effects of circulating groundwater that has been made slightly acidic through the presence of dissolved carbon dioxide (which creates carbonic acid that reacts with the rock, dissolving it). Sinkholes and caverns can form, creating potential hazards (i.e., the land surface could

Karst

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

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

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

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

dolomite • *a carbonate mineral, consisting of calcium magnesium carbonate ($CaMg(CO_3)_2$).*

Karst

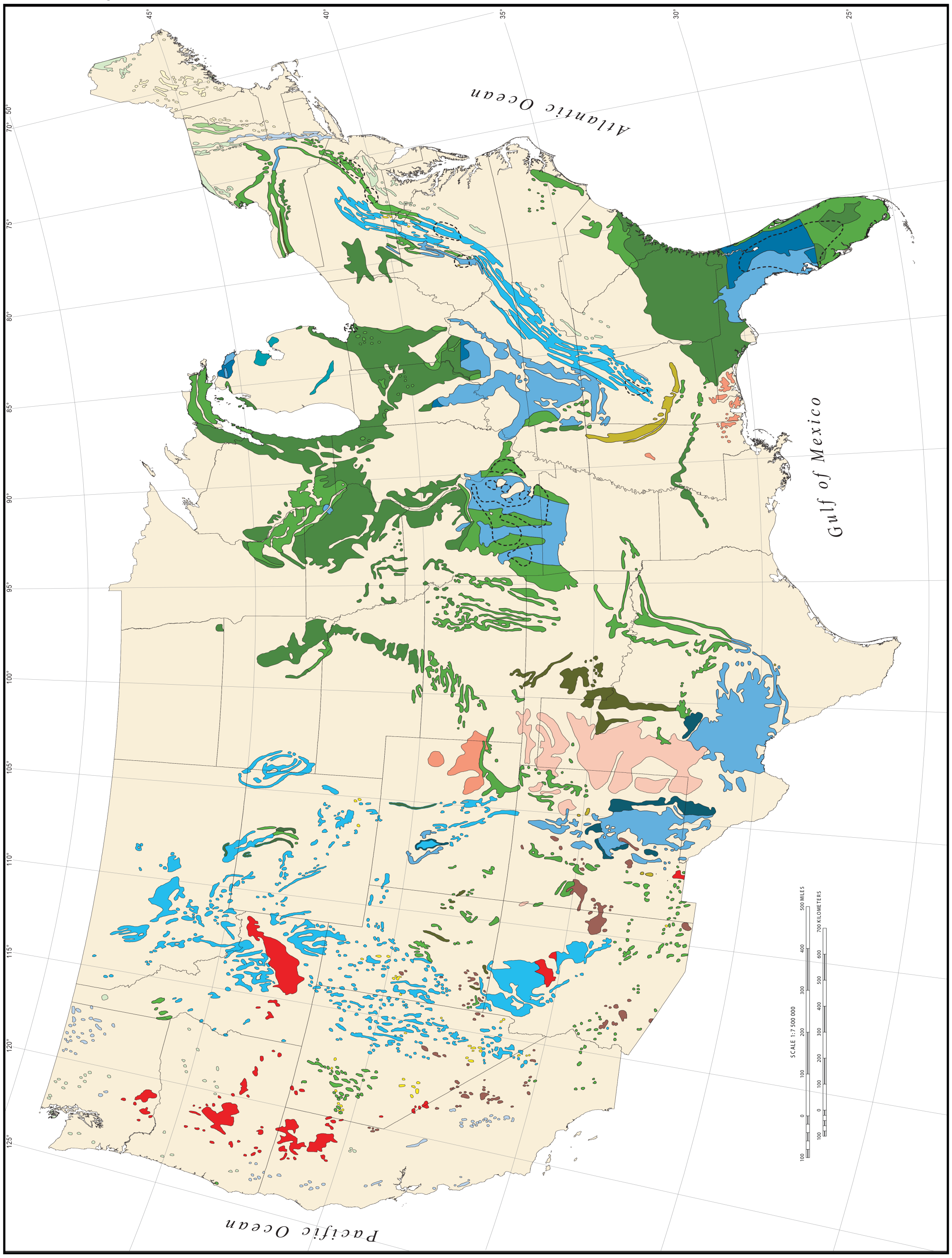

Figure 10.19: Areas of karst in the continental US associated with carbonate and evaporate rocks. (See TFG website for full-color version.)

FISSURES, TUBES, AND CAVES OVER 1,000 FT (300 M) LONG; 50 FT (15 M) TO OVER 250 FT (75 M) VERTICAL EXTENT

- In metamorphosed limestone, dolostone, and marble
- In moderately to steeply dipping beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock beneath an overburden of noncarbonate material 10 ft (3 m) to 200 ft (60 m) thick
- In moderately to steeply dipping beds of gypsum
- In gently dipping to flat-lying beds of gypsum

FISSURES, TUBES, AND CAVES GENERALLY LESS THAN 1,000 FT (300 M) LONG; 50 FT (15 M) OR LESS VERTICAL EXTENT

- In metamorphosed limestone, dolostone, and marble
- In crystalline, highly siliceous intensely folded cabonate rock
- In moderately to steeply dipping carbonate rock
- In gently dipping to flat-lying carbonate rock
- In gently dipping to flat-lying beds of carbonate rock beneath an overburden of noncarbonate material 10 ft (3 m) to 200 ft (60 m) thick
- In moderately to steeply dipping beds of gypsum
- In gently dipping to flat-lying beds of gypsum
- In gently dipping to flat-lying beds of gypsum beneath and overburden of nongypsiferous material 10 ft (3 m) to 200 ft (60 m) thick
- In carbonate zones in highly calcic granite (Alaska only)
- In moderately to steeply dipping beds of carbonate rock with a thin cover of glacial till and frost-derived residual soil (Alaska only)

FISSURES, TUBES, AND CAVES GENERALLY ABSENT; WHERE PRESENT IN SMALL ISOLATED AREAS, LESS THAN 50 FT (15 M) LONG; LESS THAN 10 FT (3 M) VERTICAL EXTENT

- In crystalline, highly siliceous intensely folded carbonate rock
- In moderately to steeply dipping beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock

FEATURES ANALOGOUS TO KARST

- Fissures and voids present to a depth of 250 ft (75 m) or more in areas of subsidence from piping in thick unconsolidated material
- Fissures and voids present to a depth of 50 ft (15 m) in a of subsidence from piping in thick, unconsolidated mate
- Fissures, tubes, and tunnels present to a depth of 250 ft (75 m) or more in lava
- Fissures, tubes, and tunnels present to a depth of 50 ft (15 m) in lava
- Areas in which extensive historical susidence has occurred

Karst

__subsidence__ • the sinking of an area of the land surface.

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

subside or collapse into the underground openings). This may principally occur in areas where cavities filled with water are emptied through groundwater withdrawal or other natural processes, resulting in the cavities being filled with air and reducing support for the overlying rock. Karst is not overly prevalent in the Northwest Central, but it is found in abundance throughout the Black Hills of South Dakota, and is scattered throughout several other states (*Figure 10.19*).

The Black Hills are surrounded and underlain by thick layers of **Mississippian** to **Jurassic** anhydrite and gypsum, which contain abundant karst features due to dissolution from groundwater and rain. Sinkholes are commonplace, ranging in size from small holes of a few meters (feet) across to large pits as wide as 140 meters (460 feet). The presence of other easily dissolved carbonate layers, laid down in **Paleozoic** and **Mesozoic inland seas**, has led to a variety of caves and small sinkholes found throughout the Northwest Central US. For example, the Little Belt Mountains in central Montana are underlain by a thick layer of limestone (the Madison Limestone) laid down in the Mississippian (*Figure 10.20*).

Figure 10.20: The Belt Meteor Crater southeast of Great Falls, Montana, is a sinkhole in the Madison Limestone measuring 10 meters (35 feet) deep and 30 meters (100 feet) across.

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

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

In Idaho, volcanic pseudokarst dominates the Snake River Plain. This type of topography is not technically karst—instead of forming through the dissolution on carbonate bedrock, these fissures, sinkholes, and caves were created by the **extrusion** of liquid lava. While sinkholes in volcanic pseudokarst are rare, they tend to be related to the collapse of old **lava tubes**.

Because karst terrain is very **porous** and fractures easily, groundwater pollution can be a serious problem. Contaminants that might otherwise be filtered through the sedimentary rock are quickly transported into **aquifers** by runoff. The hazards of pollution are increased by rampant industrial, agricultural, and residential development over karst features.

Radon

Radon is a naturally occurring **radioactive**, colorless, odorless gas. It is the leading cause of lung cancer in American non-smokers, and the second leading cause of lung cancer overall. It can collect in homes, buildings, and even in the water supply. Radon gas is formed naturally when uranium-238 undergoes radioactive decay, producing energy and several radioactive products such as radon-222 and thorium-232. (The thorium later decays to emit energy and radon-220.) Radon is more commonly found where uranium is relatively abundant in bedrock at the surface, often in **granite**, shale, and limestone. The EPA produced a map of the US showing geographic variation in radon concentrations, divided into three levels of risk: low, medium, and high (*Figure 10.21*).

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

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

aquifer • *a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.*

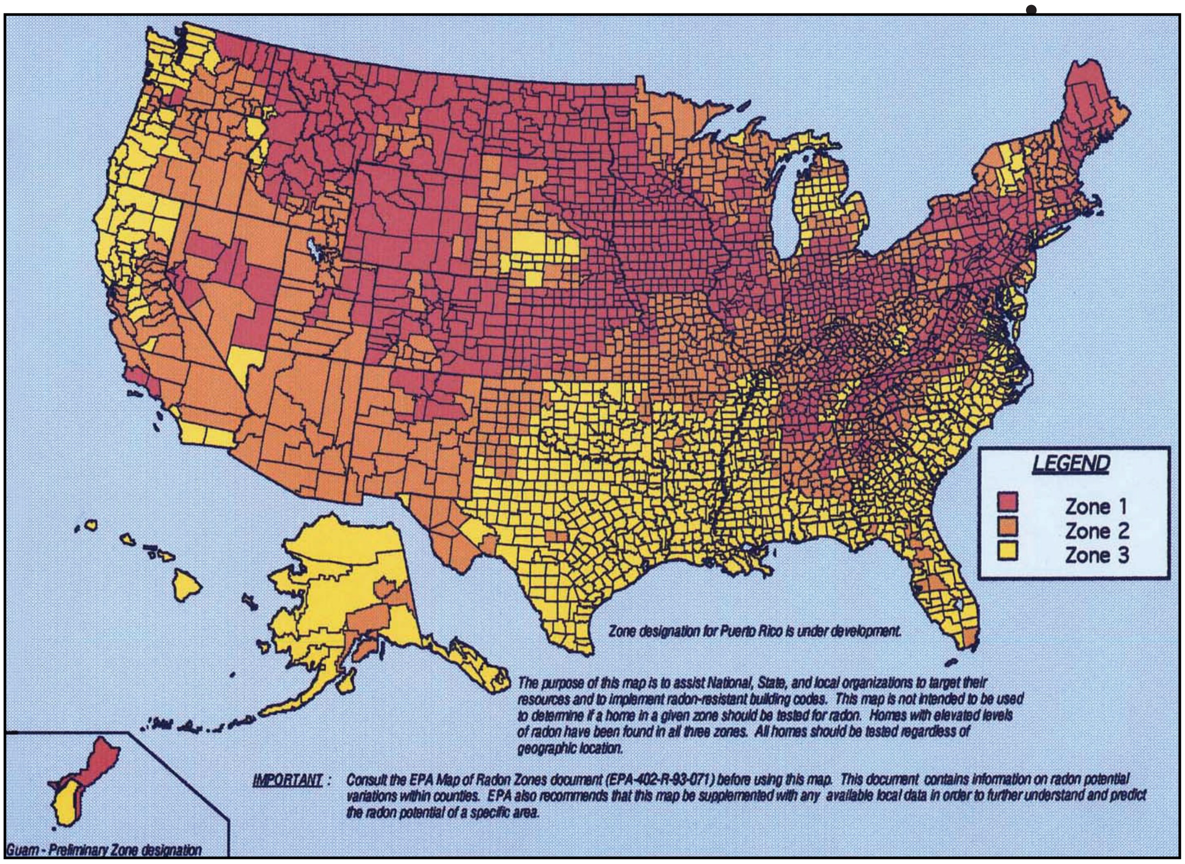

Figure 10.21: Radon zone map of the US. (Note: Zone 1 contains the highest radon levels.) (See TFG website for full-color version.)

Radon

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

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

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

Radon concentrations are generally high throughout the Northwest Central US (*Figure 10.22*). Uranium is relatively concentrated in the granites and metamorphic rocks of the Rocky Mountains, Black Hills, and Basin and Range, as well as in the sediments eroded from these areas. Uranium is also concentrated in some **Paleogene sandstones** and **coal** deposits. Taken together, these areas account for a broad part of the Northwest Central. There are, however, areas that are moderate or low in radon—the Sandhills of northwest Nebraska have the lowest radon concentrations in the Northwest Central. This area is composed of windblown sediment that was separated from the clay and heavier minerals that contain relatively high amounts of uranium. In the Columbia Plateau, radon associated with basalt bedrock is also lower in concentration than that found in the mountains farther north.

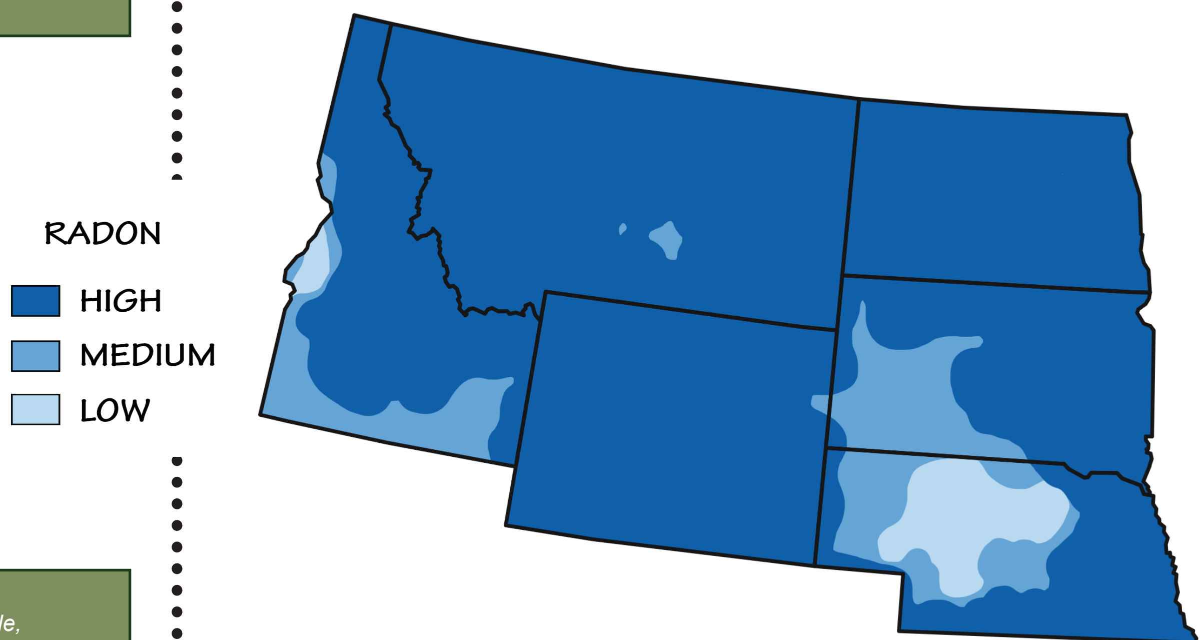

Figure 10.22: Radon risk levels at the surface in the Northwest Central US.

Radon is chemically inert, meaning that it does not react or combine with elements in the ground, and it can move up through rocks and soil into the atmosphere. It is dangerous primarily when it accumulates indoors, creating a health hazard similar to that of secondhand smoke. Radon gas finds its way through cracks in basement foundations, sump pump wells, dirt floor crawlspaces, and basement floor drains. It can also be found in well and municipal water. Since radon is more easily released from warm water than from cold water, one of the greatest forms of exposure likely occurs while showering in water with high radon levels.

Radon cannot be detected by sight or smell, so there is no way that the body can sense its presence. Fortunately, with proper monitoring and mitigation (reduction) techniques, radon gas can be easily reduced to low levels. One technique that is often used in homes involves sealing cracks in the basement floor, covering drains, and installing ventilation systems. A well-ventilated space will prevent the radon from accumulating and will reduce the risk of exposure. Most states have licensed radon mitigation specialists who are trained in the proper testing and mitigation of radon levels in buildings. The EPA has also published a homebuyer's guide designed to help citizens make informed decisions about radon gas. For radon in water, filtration systems can be installed to mitigate exposure in the home.

Floods

Floods are controlled by the rate of precipitation, run-off, stream flow, and shape of the land surface. They may occur when water overflows the banks of a standing water body (such as a lake) or flowing water (such as a stream), or when rainwater accumulates in an area that normally contains neither standing nor flowing water. Areas near rivers, tributaries, creeks, and streams are likely to experience flooding during periods of heavy rainfall.

Flooding can occur at any time of the year and is caused when more water enters a stream/river channel than the channel can contain. This situation can develop when water is unable to soak into the ground and instead runs off into a river channel. Runoff can occur if the ground is already saturated (full of water) or if the ground is too dry, hard, or frozen. The slope of a river (i.e., the topography of the land) can also contribute to flooding. If rivers have a steep slope, water can quickly move through the channel and continue downstream. If rivers have a shallow slope, water moves slowly through the river channel and remains in the area instead of moving downstream. Flash floods—rapid flooding of low-lying areas—are often associated with heavy rain, which can quickly waterlog soil and lead to mudslides on steep terrain, resulting in damage to roads and property. In areas of lower elevation, flash floods can be produced when slow-moving or multiple thunderstorms occur over the same area. When storms move more quickly through an area, flash flooding is less likely.

Floodplains are areas adjacent to rivers and streams that occasionally flood but are normally dry, sometimes for many years. When storms produce more runoff than a stream can carry in its channel, waters rise and inundate adjacent lowlands, leaving behind layers of settled sediment. Significant damage and sometimes loss of human life can occur when buildings and other human infrastructure are built on floodplains, under the assumption that future floods may never occur or will only occur in the distant future. Major floods in the Northwest Central generally occur along the Missouri River or its tributaries (*Figure 10.23*), and these events are more frequent in spring and fall after periods of heavy or sustained rains when stream levels rise rapidly.

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

Floods

Figure 10.23: The Missouri River and its tributaries. (See TFG website for full-color version.)

Flooding in the Northwest Central generally occurs through flash floods, periods of long-term rainfall, spring snowmelt, or some combination of these factors. While flash floods tend to impact a smaller area than do long-term rainfall and snowmelt, they can be especially dangerous because they arise so suddenly. Famous flash floods include the Republican River Flood of 1935 in Nebraska, when 46–61 centimeters (18–24 inches) of rain fell on May 30th that year; the Cheyenne Flood of 1985, when 18 centimeters (7 inches) of rain fell in three hours on August 1st in Cheyenne, Wyoming; and the Black Hills Flood of 1972 on Rapid Creek in Rapid City, North Dakota, when 38 centimeters (15 inches) of rain—approximately one million metric tons overall—fell over six hours from June 9–10, 1972. The Black Hills Flood is considered to be one of the most significant floods in US history: a surge caused a breach in the Canyon Lake Dam, releasing water into Rapid City and killing 238 people, destroying 1335 homes, and causing over $900 million (adjusted) in damage (*Figure 10.24*).

Floods

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

Figure 10.24: A pile of cars swept away by the 1972 Black Hills Flood. This event destroyed over 5000 vehicles.

There are numerous recorded instances of flooding on the Missouri River due to long-term rainfall, contributing to subsequent flooding downstream in St. Louis and into the Mississippi. The Great Flood of 1993, when floodwaters traveled down the Missouri River from South Dakota and Nebraska into Iowa, Kansas, and Missouri, flooded over 4 million hectares (11 million acres) and caused at least 50 deaths and over $24 billion (adjusted) in damage. The 2011 Missouri River Flood, caused by high winter snowfall in Montana and Wyoming followed by large spring rainfall on the plains of Montana, inundated roads and buildings (*Figure 10.25*) and threatened towns and cities along the river from Montana to Missouri. The Great Flood of 1881 in South Dakota and Nebraska (notably including Omaha) was caused by ice jams along the Missouri River, and the April 1997 Red River Flood of Grand Forks, North Dakota was due to abundant snowfall combined with heavy rain during the previous fall (*Figure 10.26*).

Devils Lake in North Dakota is known for dramatic annual changes in water level depending on local precipitation, and has gained a net increase of about 40 meters (130 feet) in water depth since 1940. The lake has quadrupled in size over the last two decades, growing from 18,000 **hectares** (44,000 acres) in 1994 to about 82,000 hectares (202,000 acres) today (*Figure 10.27*). Devils Lake is a closed drainage basin with no natural outlets, and water can therefore leave its confines only through evaporation, ground infiltration, or overflow. During one period of especially rapid increase, rainfall between 1993 and 1999 caused the lake's water level to rise about 20 meters (66 feet), flooding 28,000 hectares (70,000 acres) of farmland, displacing 300 homes, and costing about

Figure 10.25: The Fort Calhoun Nuclear Reactor and surrounding areas of Nebraska were inundated by floodwater during the 2011 Missouri River Flood.

Figure 10.26: Wreckage in Grand Forks, North Dakota, after the 1997 Red River Flood.

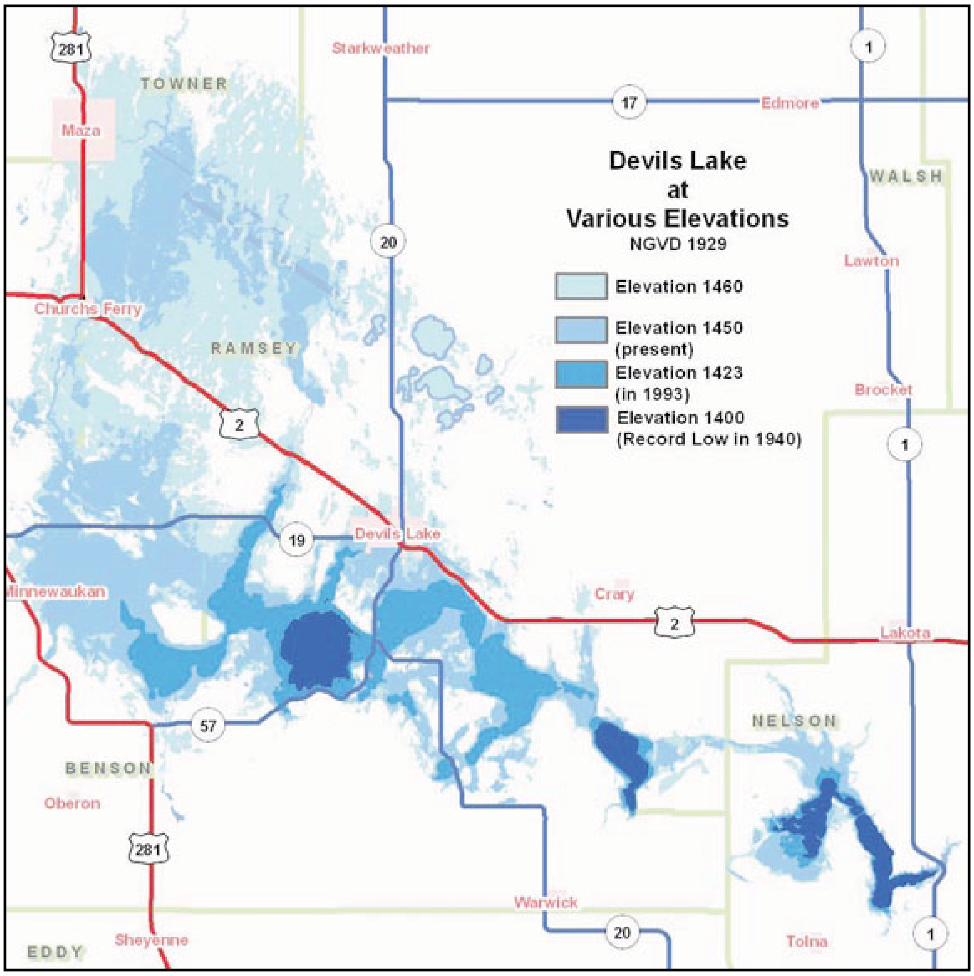

Figure 10.27: The extent of Devils Lake at different water level elevations. (See TFG website for full-color version.)

$450 million to mitigate the flooding. There has been substantial controversy about the ecological impacts of proposed mechanisms to create an outlet that would offset further lake rise, partially focused on where to divert the water and the consequences of potentially moving invasive species into other basins. Flooding from the lake today continues to affect agriculture and infrastructure in the surrounding area.

While floods are always considered a hazard to life and property, they present a compound threat when they trigger mudslides or contribute to the conditions that cause expansive soils and karst topography. While there is no way to completely avoid the destructive impacts of flooding, good community planning and informed decision-making can greatly reduce the safety concerns and economic impacts of these events. The Federal Emergency Management Agency (FEMA) provides guidelines for communities that are planning mitigation strategies designed to minimize the impacts of natural hazards such as flooding.

10 Earth Hazards

Weather

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

tornado • *a vertical funnel-shaped storm with a visible horizontal rotation.*

cold front • *the boundary between the warm air and the cold air moving into a region.*

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

derecho • *a set of powerful straight-line winds that exceed 94 kph (58 mph) and can often approach 160 kph (100 mph).*

wind shear • *when wind speed and/or direction changes with increasing height in the atmosphere.*

Weather Hazards

Weather is the measure of short-term atmospheric conditions such as temperature, **wind** speed, and humidity. The Northwest Central is an active location for atmospheric events such as thunderstorms and **tornados**. It also experiences a variety of other weather hazards, including high temperatures and drought.

Storms, Tornados, and Derechos

Several types of severe storms present challenges to people living in the Northwest Central. Summer brings severe thunderstorms associated with **cold fronts**. Fall and spring can bring ice storms, while winter brings snow and, in some cases, blizzard conditions. In October 2013, for example, a major blizzard affected the Northwest Central and much of the Midwest, dumping up to 1.5 meters (5 feet) of snow across the Great Plains. The snow affected 5000 ranches in South Dakota, scattering and killing herds of cattle and sheep, as well as disabling **power** for more than 20,000 homes and trapping people inside their cars. The storm system's winds blew up to 112 kilometers per hour (kph) (70 miles per hour [mph]), generating 22 separate tornados as well as severe thunderstorms and ice storms.

Rainstorms arise where colder air from higher latitudes abruptly meets warmer air. Severe thunderstorms are a common occurrence for people living in the Northwest Central because the conditions over the Great Plains are perfect for the development of severe weather. The flat, open fields are warmed by the summer sun, which sits high in the sky during this time of year. This results in large temperature differences when cold air masses move across the country. At the boundary between warmer and cooler air, buoyant warm air rises, and then cools because air pressure decreases with increasing height in the atmosphere. As the air cools, it becomes saturated with water vapor, condensation occurs, and clouds begin to form. Because liquid water droplets in the clouds must be very small to remain suspended in the air, a significant amount of condensation causes small water droplets to come together, eventually becoming too large to remain suspended. Sufficient moisture and energy can lead to dramatic rainstorms. Because warm air has a lower pressure relative to cold air, and the movement of air from areas of high pressure to areas of low pressure generates wind, the significant difference in air pressure associated with these boundaries and rainstorms also generates strong winds. Flat regions, such as the Great Plains, allow winds to move unimpeded by topography, and are often subject to severe thunderstorms.

While severe thunderstorms are common in some parts of the Northwest Central, two less common storm hazards have the potential to cause serious property damage and endanger lives: **derechos** and tornados. Both of these storm events are associated with **wind shear**, which occurs when the wind's speed or direction changes with increasing height in the atmosphere. Wind shear can happen when a cold front moves rapidly into an area with very warm air. There, the condensing water droplets mix with the cooler, drier air in the upper atmosphere to cause a downdraft. When these downdrafts are very powerful, they can cause a derecho, or a set of powerful straight-line winds that exceed 94 kph (58 mph) and can often approach 160 kph (100 mph). These powerful windstorms can travel over 400 kilometers (250 miles) and cause substantial wind damage, knocking down trees and causing widespread power outages. The lightning associated with these intense storms can cause both forest fires and house fires. Approximately one derecho every two years or so will occur in easternmost South Dakota and Nebraska, and they appear with decreasing frequency as one travels westward (*Figure 10.28*).

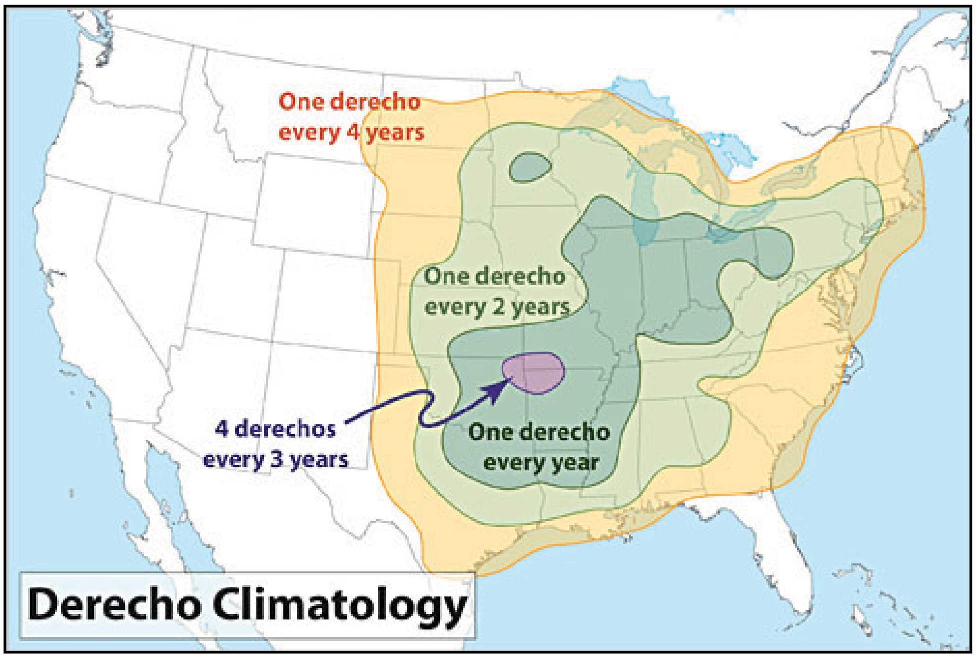

Figure 10.28: Derecho frequency in the continental US. (See TFG website for full-color version.)

The differences between tornados and derechos are indicated in their names: *derecho* is the Spanish word for "straight ahead," while the word tornado has its roots in the Spanish word *tonar*, which means "to turn." Both types of storm events can be associated with the same major cold front boundary because they require similar conditions to get started. However, tornado formation is more complicated. At the frontal boundary, warm, moist air rapidly rises as cooler, dry air descends; in the meantime, the pressure differences between the warm and cold air masses cause strong winds. Clouds with a visible horizontal rotation can appear, appearing to roll like waves crashing on the shore of a beach. This horizontal motion can tilt, lifting the rotating cloud vertically, and the rolling cloud will form a tornado. Most tornados will last a few seconds to several minutes. During that time, many tornado-prone areas will use tornado sirens to alert residents of the danger. A smaller tornado might generate flying debris that can cause injury or damage to buildings, while larger tornados can cause buildings and houses to be completely broken apart. Tornados are classified by their ranking on the Enhanced Fujita scale, or EF scale. These classifications are estimates of wind speeds based on the type of damage that is observed following the storm.

Measuring Tornado Intensity

Tornado intensity is measured on the Fujita scale, or simply F-scale, based on the amount of damage that a tornado can cause. The scale ranges from F0 to F5. The scale was modified recently to more accurately reflect specific wind speeds; this newer scale is known as the "Enhanced Fujita scale" and ranges from EF0 to EF5.

EF Scale	Estimated Wind Speed (kph)	Estimated Wind Speed (mph)
EF0	104–137	65–85
EF1	138–177	86–110
EF2	178–217	111–135
EF3	218–266	136–165
EF4	267–322	166–200
EF5	> 322	> 200

"Tornado Alley" is the nickname for an area, extending from Texas to Minnesota, that experiences a high number of exceptionally strong tornados due to its flatter topography and high incidence of severe thunderstorms. Both Nebraska and South Dakota reside within Tornado Alley, leading to more tornados in this part of the Northwest Central (*Figure 10.29*). From 1991 to 2010, for example, an annual average of 57 and 36 tornados occurred in Nebraska and South Dakota, respectively (*Figure 10.30*). To the west and north of Tornado Alley, fewer tornado strikes occur, with an annual average of 32, 12, 10, and 5 striking North Dakota, Wyoming, Montana, and Idaho, respectively. The boundaries of Tornado Alley vary in application, depending on whether the frequency, intensity, or number of events per location are used to determine the area's borders.

Although specific tornado paths are not predictable, the conditions that produce them are used to alert people so that they can seek shelter. The National Weather Service issues a *watch*, if the conditions are right for a type of storm event, or a *warning*, if the conditions are occurring or imminent for the storm event. The National Weather Service is part of the National Oceanographic and Atmospheric Administration, which maintains a US map of all current watches

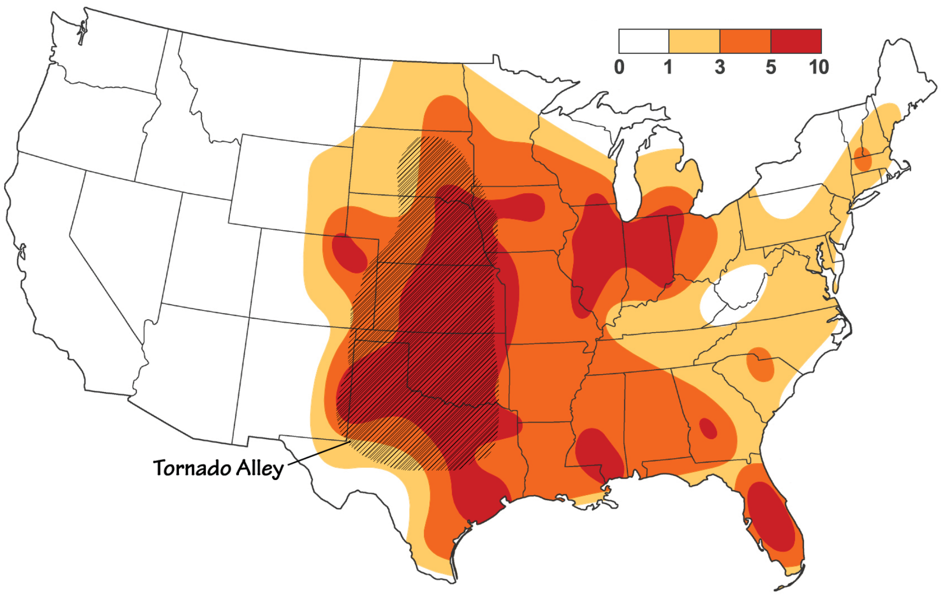

Figure 10.29: Annual tornado reports per 29,500 square kilometers (10,000 square miles) in the continental US, between 1950 and 1995. (See TFG website for full-color version.)

Figure 10.30: Two tornados touch down simultaneously in a South Dakota field between the towns of Enning and White Owl.

heat wave • *a period of excessively hot weather that may also accompany high humidity.*

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

heat island effect • a phenomenon in which cities experience higher temperatures than do surrounding rural communities.

global warming • *the current increase in the average temperature worldwide, caused by the buildup of greenhouse gases in the atmosphere.*

topsoil • *the surface or upper layer of soil, as distinct from the subsoil, and usually containing organic matter.*

and warnings. Since the atmospheric conditions can change very quickly, an important factor in preventing loss of human life is getting the public to act upon the severe weather alerts. One recent attempt to improve public response to warnings is through a tornado alert index that helps people evaluate the risk of a local tornado. The Tor:Con index used by the Weather Channel provides a number from 1 to 10 that represents the probability of a tornado occurring. Meteorologists evaluate the atmospheric conditions associated with a storm and assign a score. For example, a 4 on the Tor:Con index would indicate a 40%, or moderate, chance of a tornado forming in a particular area.

Extreme Temperature and Drought

Extreme temperatures can create dangerous conditions for people and may lead to property damage. **Heat waves** are periods of excessively hot weather that may also accompany high humidity. Temperatures of just 3°C (6°F) to 6°C (11°F) above normal are enough to reclassify a warm period as a heat wave. Under these conditions, the mechanism of sweating does little to cool people down because the humidity prevents sweat from evaporating and cooling off the skin. Heat waves have different impacts on rural and urban settings. In rural settings, agriculture and livestock can be greatly affected. **Heat** stress recommendations are issued to help farmers protect their animals, particularly pigs and poultry, which, unlike cattle, do not have sweat glands.

The impacts of heat waves on urban settings include a combination of the natural conditions of excessive heat and the social conditions of living in a densely populated space. Cities contain a considerable amount of pavement, which absorbs and gives off more heat than vegetation-covered land does. Air conditioning units that cool down the inside of buildings produce heat that is released outside. Pollution from cars and industry also serve to elevate the outdoor temperatures in cities. This phenomenon, in which cities experience higher temperatures than surrounding rural communities do, is known as the **heat island effect**. Other social conditions can increase the hazards associated with heat waves in urban areas. People who are in poor health, live in apartment buildings with no air conditioning, or are unable to leave their houses are at greatest risk of death during heat waves.

During the first half of 2012, North America experienced a heat wave that set thousands of temperature records, particularly in the Midwest and Northwest Central and parts of central Canada (*Figure 10.31*). Within the Northwest Central, the Great Plains region experienced some of the most anomalous temperatures in the country. The event was attributed to persistent low-level winds blowing warm air from the Gulf of Mexico toward Canada. Like other climate events, the heat wave could not be directly attributed to **global warming**, but climate change is thought to have increased the event's severity by 5 to 10%. The heat wave was also associated with the start of a serious drought in the central United States.

While high temperatures can be directly dangerous, a larger scale hazard arises when these temperatures are coupled with a lack of precipitation in an extended drought period. Most famously, high temperature and drought in the 1930s, combined with deep plowing that removed moisture-trapping grasses,

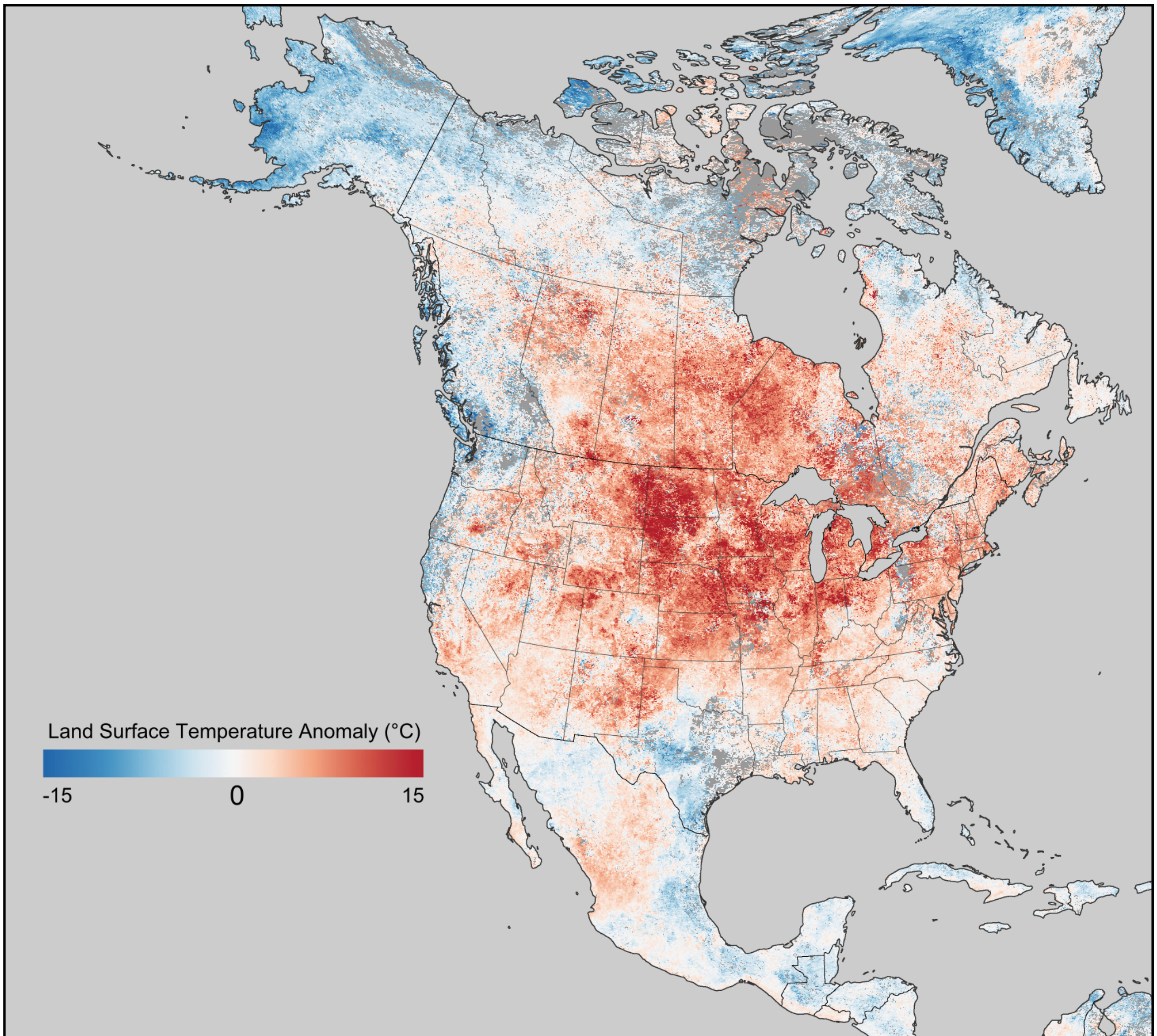

Figure 10.31: Land surface temperature anomalies in March 2011. Red areas represent above average temperatures and blue areas represent below average temperatures. (See TFG website for full-color version.)

led to the Dust Bowl—dust storms that carried vast clouds of black dust across the Midwest and central US, greatly damaging both the ecology and agriculture across that portion of the country (*Figure 10.32*). Although the Dust Bowl was most intense in the panhandles of Texas and Oklahoma, the event impacted agriculture throughout the Great Plains, including Nebraska and South Dakota. Dust storms destroyed **topsoil**, buried equipment and houses, and contributed to the incidence of lung disease.

Weather

polar vortex • *a regularly occurring area of low pressure that circulates in the highest levels of the upper atmosphere.*

jet stream • *a fast-flowing, narrow air current found in the atmosphere.*

Figure 10.32: A car and other farm equipment lies buried following a dust storm near Dallas, South Dakota in 1936.

Recently, a different extreme temperature phenomenon has made the news: the **polar vortex**. As the name implies, a polar vortex is a regularly occurring area of low pressure that circulates in the highest levels of the upper atmosphere. Typically, the polar vortex hovers above Canada. However, a pocket of the counterclockwise rotating, low-pressure center can break off and shift southward at a lower altitude, covering the northern United States with frigid air. The **jet stream** then shifts to a more southward flow than usual, and its chill can even reach the southern states. A polar vortex can lock the jet stream in this new pattern for several days to more than a week. In early January 2014, the polar vortex dipped low over the upper United States, bringing with it some of the coldest temperatures seen in over 20 years. Temperatures in North Dakota plummeted to −30°C (−23°F), with wind chills of up to −51°C (−60°F). The lowest temperature in the US— −34°C (−30°F)—was recorded near Poplar, Montana. Although the cold temperatures of a polar vortex can be uncomfortable and make traveling dangerous in the winter, the Northwest Central has not yet experienced any major economic or health-related impacts from this type of extreme weather event.

See Chapter 9: Climate to learn more about the jet stream.

Climate Change

It is important to understand that most of the extreme climate change in Earth's history occurred before humans existed. That being said, the rapid release of carbon dioxide into the atmosphere from human activity is currently causing a global warming event. The seemingly slight increase in the average annual temperatures in the Northwest Central over the past 25 years has been accompanied by more frequent heat waves, shorter winters, and an increased likelihood of drought and wildfires.

Although wildfires can occur during any season, summer fires are the most common, since increased dryness contributes to fire risk. In June 2012, the Fontenelle wildfire in Wyoming's Bridger-Teton National Forest consumed 25,990 hectares (57,324 acres) of forest after sparks from a downed power line ignited dry, dead timber. In August 2013, a lightning strike ignited the Bear Creek wildfire in Idaho, which burned more than 40,440 hectares (100,000 acres), threatened two popular ski resorts, and required the efforts of more than 1200 firefighters to combat the blaze. The 2012 fire season was among the worst on record in Wyoming, with more than 1300 fires burning about 240,000 hectares (600,000 acres) across the state, thanks to extremely dry conditions and swaths of dead trees killed by pine beetles. Unfortunately, the Rocky Mountains' rugged terrain can make fires even more difficult to extinguish.

Water supply is also a critical issue for the Northwest Central States. Here, most water is obtained from precipitation, snowmelt, and runoff, which will dramatically decrease in quantity as temperature and aridity rise. In addition, Nebraska obtains much of its agricultural and drinking water from the Ogalalla aquifer, an underground layer of water-bearing **permeable** rock. Part of the High Plains aquifer system, this underground reservoir supplies vast quantities of groundwater to Nebraska as well as Texas, Oklahoma, and Kansas. As drought intensifies and temperature rises, the amount of water drawn from the aquifer (especially for agricultural irrigation) has increased, while the rate at which the aquifer recharges has decreased. The aquifer's average water level has dropped by about 4 meters (13 feet) since 1950, and in some areas of heavy use, the decrease is as high as 76 meters (250 feet) (*Figure 10.33*). However, the aquifer only replenishes at a rate no greater than 150 millimeters (6 inches) per year. While the portion of the aquifer beneath Nebraska has yet to be adversely affected, some estimates indicate that at its current rate of use, the entire Ogalalla aquifer could be depleted by as early as 2028, threatening human lives, our food supply, and the entire Great Plains ecosystem.

Increasing temperatures also allow certain pests, such as ticks and mosquitoes, to live longer, thereby increasing the risk of contracting the diseases they carry. In addition, invasive organisms that damage ecosystems, such as the mountain pine beetle, have a better chance of multiplying and outcompeting native organisms because increased temperatures stress local ecosystems and create an environment more favorable to invasive species.

permeability • *a capacity for fluids and gas to move through fractures within a rock, or the spaces between its grains.*

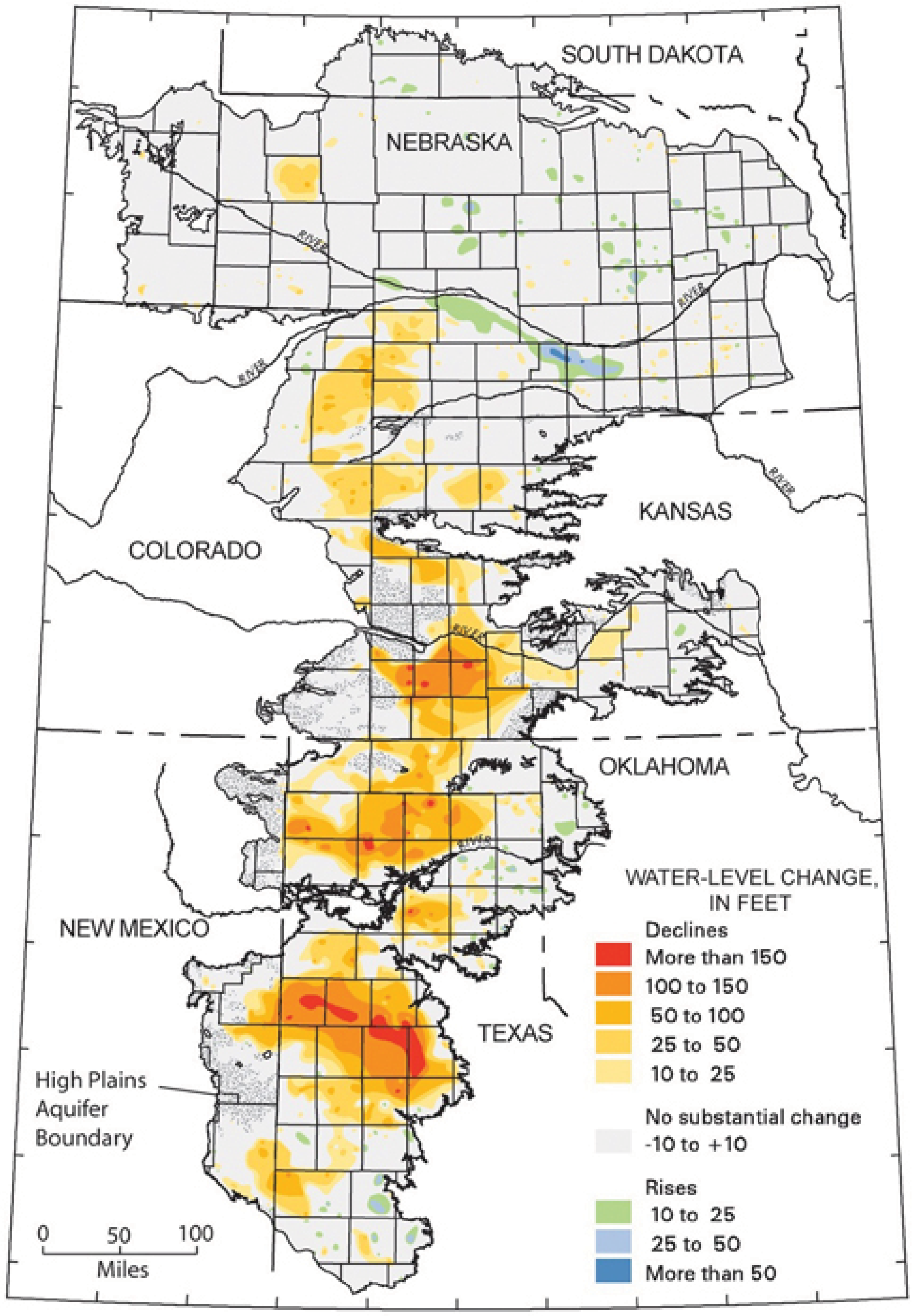

Figure 10.33: Water level change in the Ogalalla aquifer between 1950 and 2005. (See TFG website for full-color version.)

Another concern regarding hazards exacerbated by climate change in the Northwest Central is whether or not there has been or will be an increase in the number or severity of storms, including thunderstorms and tornados. According to NASA, the present data is inconclusive in terms of whether major storms are already more severe, but there is a greater than 66% chance that global warming will cause more intense storms in the 21st century. Since climate is a measure of weather averaged over decades, it might take many years to determine that a change has occurred with respect to these types of storms. Scientists are certain, however, that the conditions necessary to form such storms are becoming more favorable due to global warming. The Union of Concerned Scientists has created an infographic that demonstrates the relative strength of the evidence that various hazards are increasing as a result of climate change (*Figure 10.34*).

See Chapter 9: Climate for more on the effects of climate change in the Northwest Central.

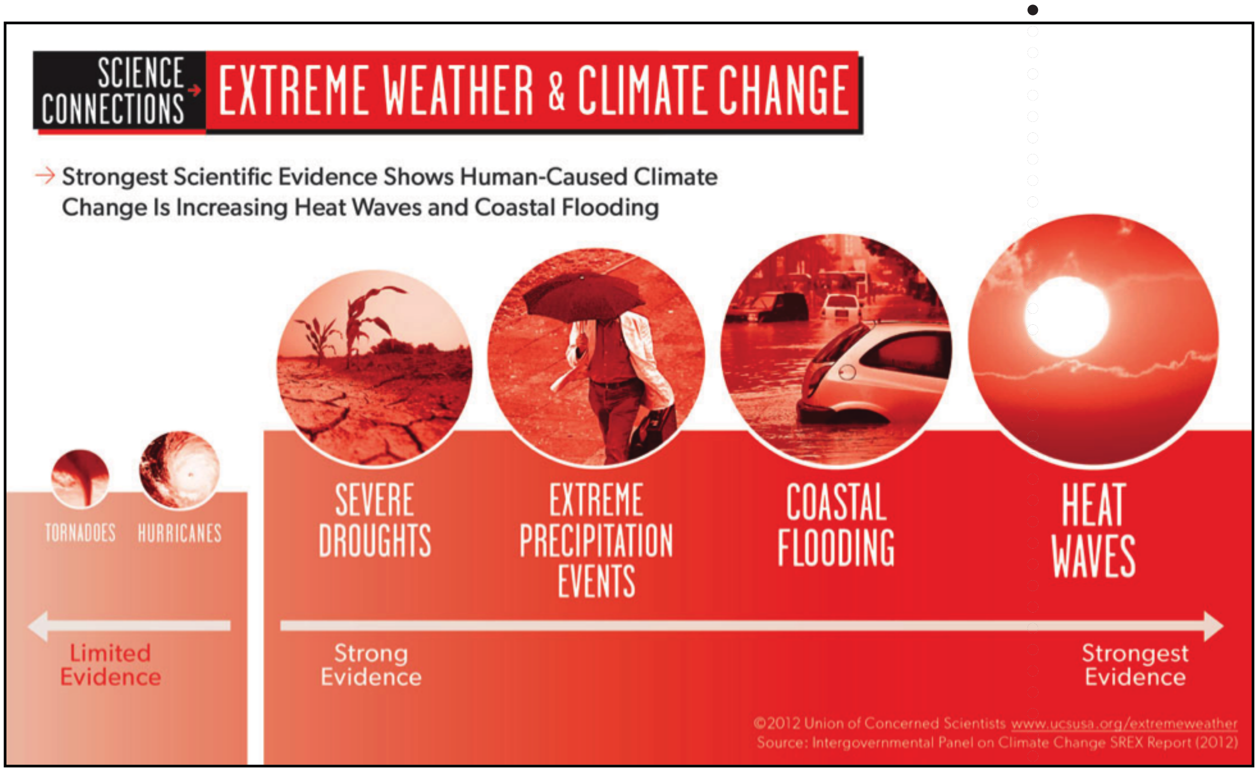

Figure 10.34: The strength of evidence supporting an increase in different types of extreme weather events caused by climate change.

10

Earth Hazards

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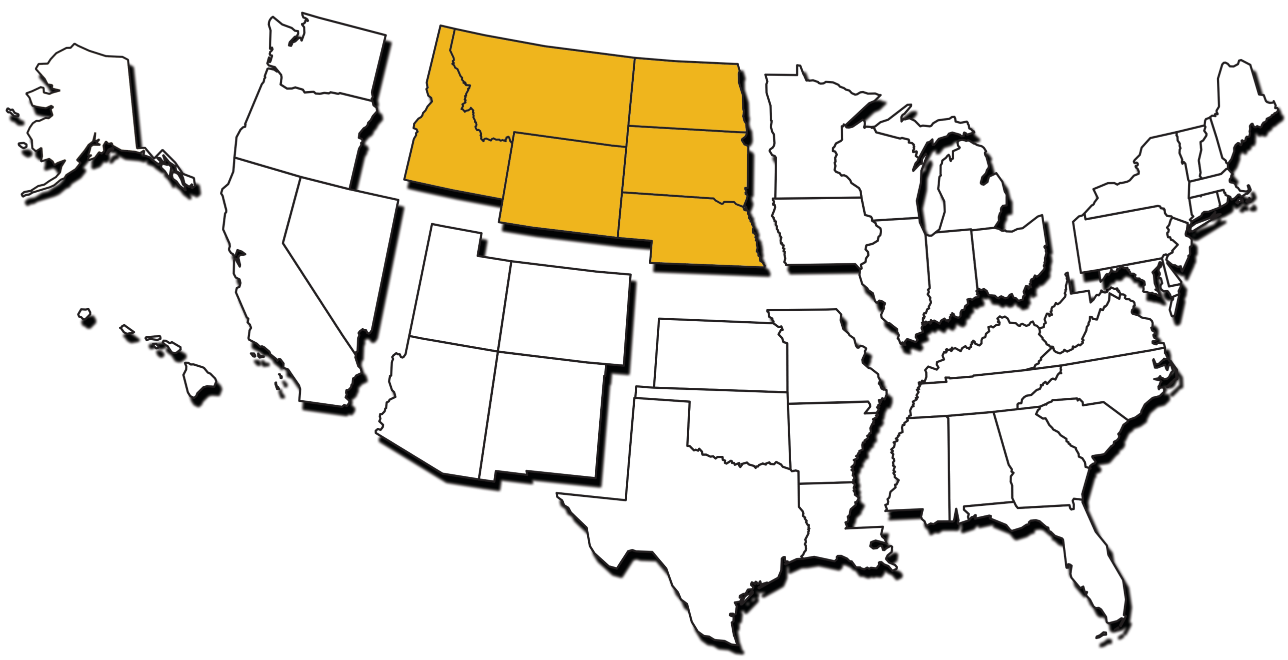
The Teacher-Friendly Guide™

to the Earth Science of the Northwest Central US



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

Paleontological Research Institution
2015

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

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

First printing September 2015

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

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

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

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

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

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

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