



Chapter 9: Earth Hazards of the Southwestern 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 Southwest, like any other part of the US, has numerous hazards—based largely on its geography—that directly infringe upon people’s property and safety. Dangerously hot weather and drought are commonplace in the Southwest’s arid environment. Weather hazards such as tornados, thunderstorms, and winter storms frequently occur over the 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 and along large rivers. Geological hazards, including avalanches, **earthquakes**, **landslides**, and rockfalls, also occur throughout the Southwest, especially in areas with rugged, mountainous terrain.

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 9.1*). 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 range in size from the simple raveling of a stream embankment to the collapse of an entire mountainside that involves tens of thousands of cubic meters (yards) of material. 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 parts of the Southwest thanks to a combination of steep terrain, poorly consolidated sediments, and melting snowpack that leads to soil saturation (*Figure 9.2*). They often occur in high valleys with little vegetative cover. In years that are particularly wet or rainy,

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.

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

CHAPTER AUTHORS

Luke P. McCann
Andrielle N. Swaby

9



Earth Hazards

Landslides

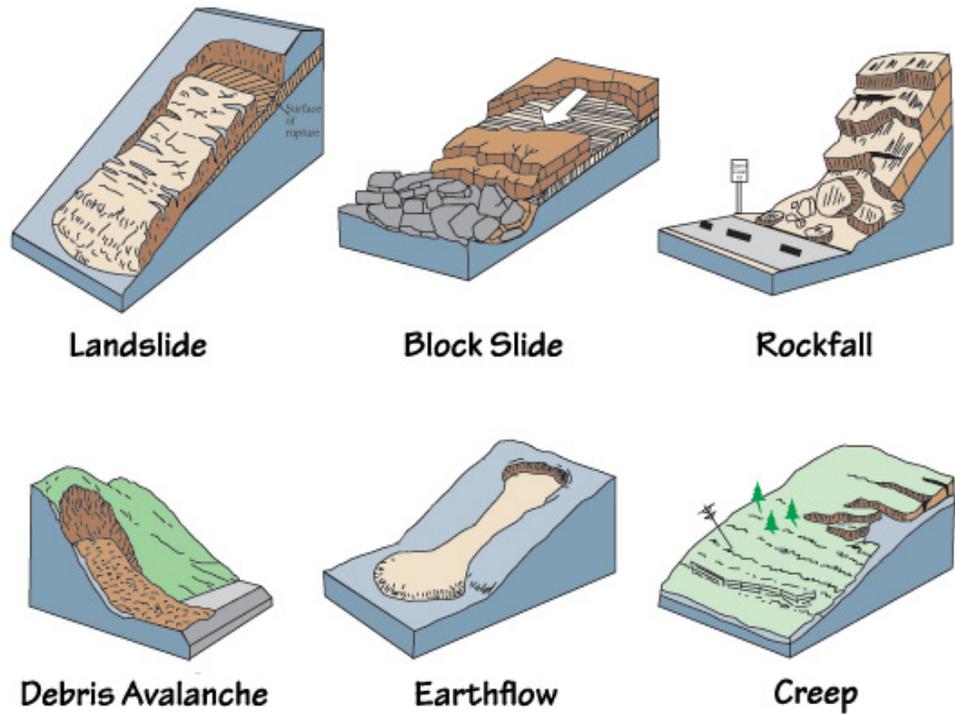


Figure 9.1: Common types of landslides.

LANDSLIDE INCIDENCE

- LOW (LESS THAN 1.5% OF AREA INVOLVED)
- MODERATE (1.5% - 15% OF AREA INVOLVED)
- HIGH (GREATER THAN 15% OF AREA INVOLVED)

LANDSLIDE SUSCEPTIBILITY/ INCIDENCE

- MODERATE SUSCEPTIBILITY/ LOW INCIDENCE
- HIGH SUSCEPTIBILITY/ LOW INCIDENCE
- HIGH SUSCEPTIBILITY/ MODERATE INCIDENCE

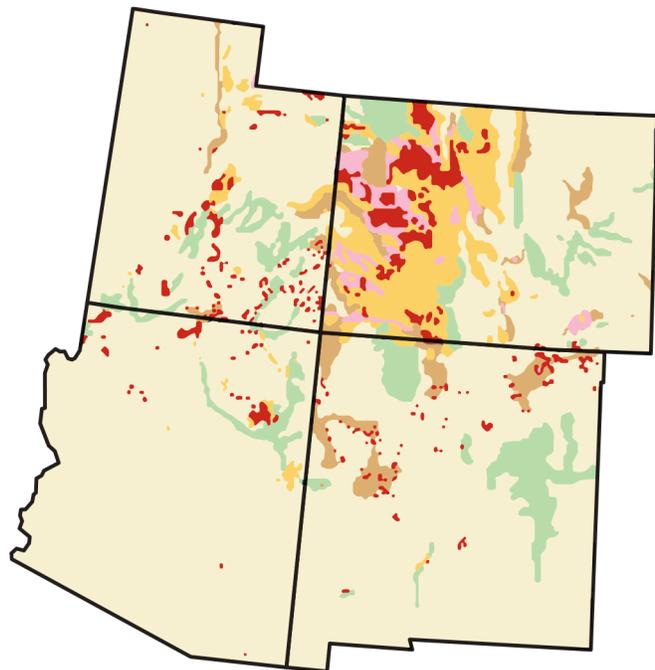


Figure 9.2: Landslide incidence and risk in the Southwestern US.



Landslides

liquefaction • a process by which water-saturated unconsolidated sediment temporarily loses strength and behaves as a fluid when vibrated.

landslide incidence increases as unstable soils on saturated slopes break free of the rock. Some very fast landslides can reach speeds exceeding 32 kilometers per hour (20 miles per hour). Although many slides in the Rockies are small, or take place in remote and inaccessible locations, people and property are impacted each year by these events. 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. Hundreds of avalanches occur every winter in the mountains of Colorado and Utah.

Utah has seen some of the largest landslides in US history. In April 1983, a massive landslide dammed the Spanish Fork River, destroying roads and flooding the town of Thistle with more than 80 million cubic meters of water that backed up behind the naturally formed dam (*Figure 9.3*). This dam eventually created a lake 60 meters (200 feet) deep and 5 kilometers (3 miles) long. Thistle was almost completely destroyed, and the nearby railroad and highways had to be rebuilt on higher ground. While these transportation routes were closed, communities in eastern and southeastern Utah were completely cut off from the rest of the state for up to eight months. Direct and indirect costs of the Thistle landslide have been estimated to be as high as \$950 million (adjusted for inflation); the state of Utah and the United States Geological Survey have categorized this landslide as the costliest in the nation. More recently, in April 2013, a massive landslide at Utah's Bingham Canyon Mine (also known as the Kennecott Copper Mine) displaced almost 70 million cubic meters (2.5 billion cubic feet) of dirt and rock from the side of the pit. This was the largest non-volcanic landslide in the history of North America; luckily, thanks to an early warning system, no injuries occurred. Two years later, the mine is still cleaning up debris from the slide. Massive landslides in Utah aren't just restricted to recent history, either. In 2014, scientists in Dixie National Park discovered the remnants of the largest known landslide anywhere on earth. This major prehistoric slide occurred 21 million years ago and stretched over 2700 meters (1700 miles)—an area the size of Rhode Island. Geologists studying the site have concluded that it originated when a volcanic field collapsed, and took place over an extremely short period of time, during which the friction of moving blocks pulverized and even melted the surrounding rocks.

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. Higher temperatures, thick melting snowpack, and an increase in spring rainstorms are thought to have generated the 2012 mudflow in Mesa County, Colorado, in which a slide five kilometers (three miles) long and 1.2 kilometers ($\frac{3}{4}$ of a mile) wide claimed the lives of three men as well as triggered a small earthquake (*Figure 9.4*). The Grand Mesa area, where the slide occurred, is prone to landslides due to a soft underlying layer of claystone that erodes easily from runoff and snowmelt.

9



Earth Hazards

Landslides

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

tree • any woody perennial plant with a central trunk.

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.

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



Figure 9.3: In spring 1983, a major landslide near Thistle, Utah created this dam and the resulting "Lake Thistle," inundating the town.

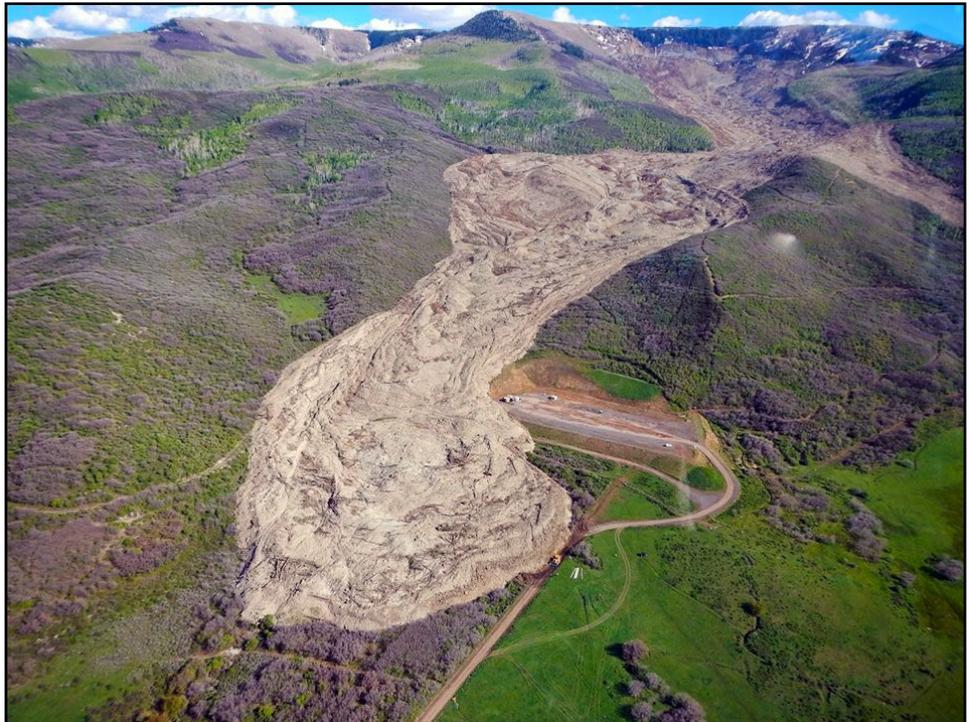


Figure 9.4: The catastrophic 2012 mudslide in Mesa County, Colorado, triggered by melting snow and unusually heavy rainfall, rushed down a mountain near the town of Collbran into the West Salt Creek Valley.



Landslides

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 Chalk Cliffs, Colorado, one or more small debris flows occur every year after periods of intense rainfall. Though less hazardous than debris flows that occur in populated areas, these deposits have blocked roads and diverted streams (*Figure 9.5*). Debris flows can also occur in otherwise stable landscapes after the occurrence of large wildfires, which can destabilize the ground due to the removal of vegetation and desiccation of the soil. Heavy rainfall following the fire can then cause the burned slopes to fail. The Sandia and Manzano Mountain areas in central New Mexico have been studied extensively regarding their susceptibility to post-wildfire debris flows.



Figure 9.5: Remnants of a 2002 debris flow near Buena Vista, Colorado, which blocked Chaffee County Road 306 in 11 places and trapped several motorists.

In the Rocky Mountains, where the bedrock contains many discontinuities (folded bedding planes, **faults**, **joints**, and **cleavage**) resulting from several episodes of mountain building (the **Antler**, **Laramide**, and **Sevier orogenies**), rock slides and rockfalls are common, especially along transportation routes running through the mountains. US Highway 6 in Colorado, State Route 9 (the Zion-Mount Carmel Highway) in Utah, and I-70 in west-central Colorado are often impacted by rockfalls, leading to frequent road closures (*Figure 9.6*). Stretches of highway can remain closed for periods of several months. Rockfalls can also have fatal consequences in populated areas where buildings have been constructed in high-hazard zones (*Figure 9.7*)

Not all mass wasting events are rapid—slow land movement, known as soil **creep**, is generally not hazardous, but can impact structures over a long period

cleavage • a physical property of minerals that occurs when it breaks in a characteristic way along a specific plane of weakness.

Antler Orogeny • a period of Mississippian mountain building that deformed rocks in a belt extending from the California–Nevada border northward into Idaho.

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

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

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

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

9



Earth Hazards

Landslides



Figure 9.6: Boulders weighing as much as 60 metric tons (66 tons) are blasted and removed from I-70 at Glenwood Canyon, Colorado, after a major rockfall closed the highway. The rocks punched holes in elevated sections of the roadway; luckily, no one was injured.

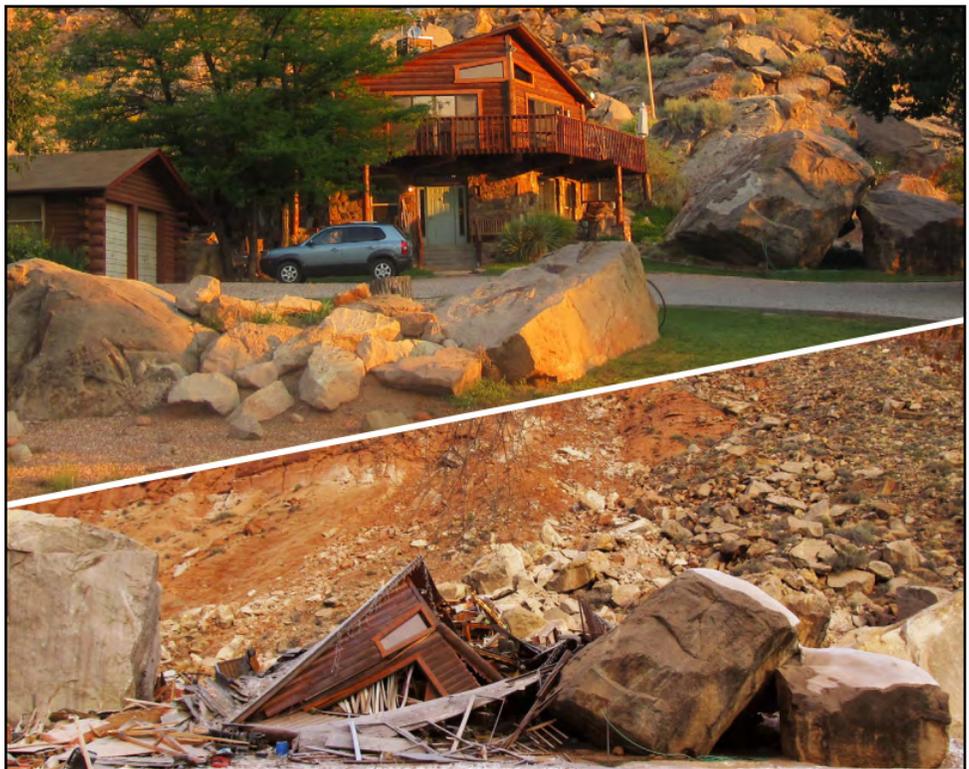


Figure 9.7: This house in Rockville, Utah, was demolished in a 2013 rockfall that destroyed the house, garage, and car and killed two residents. A motorist who witnessed the event estimated that it lasted only 10 seconds. Multiple nearby houses are also located in this high-hazard zone.



Landslides

of time. **Slumps** and creep are common problems in parts of the Southwest with a wetter **climate** and/or the presence of unstable slopes, especially in the Great Plains and on the Colorado Plateau. Many areas in the Southwest contain expansive soils generated from **clay-rich parent materials**, especially **volcanic ash** or debris. Certain clay **minerals** can absorb water and swell up to twice their original volume. The pressures exerted through expansion of the minerals in the soil can easily exceed 22 metric tons per square meter (5 tons per square foot)—a force capable of causing significant damage to highways and buildings. An estimated \$9 billion of damage to infrastructure built on expansive clays occurs each year in the United States, making swelling soils one of the costliest hazards. In addition, when the clay dries and contracts, the particles settle slightly in the downhill direction. This process can result in soil creep, a slow movement of land that causes fences and telephone poles to lean downhill, while trees adjust by bending uphill (*Figure 9.8*). Human development can exacerbate this process when homes are built along steep embankments, disturbing vegetation that would otherwise stabilize the slope or adding water to the land in the form of yard irrigation or septic systems.

See Chapter 7: Soils to learn more about the types and locations of expansive soils found in the Southwest.

Expansive soils can be found all over the US, and every state in the Southwest has bedrock units or soil layers that are possible sources (*Figure 9.9*). Clay minerals that expand and contract when hydrated and dehydrated due to their

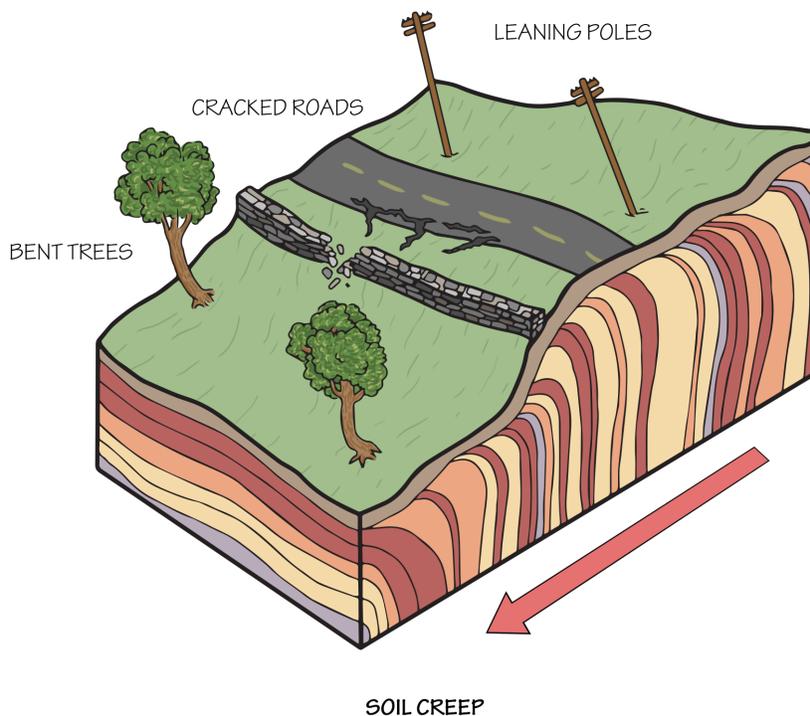


Figure 9.8: Some influences of soil creep on surface topography.

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.

parent material • the original geologic material from which soil formed.

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

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

9



Earth Hazards

Landslides

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

alluvial • a layer of river-deposited sediment.

- DATA INSUFFICIENT TO INDICATE THE CLAY CONTENT OR THE SWELLING POTENTIAL OF SOILS.
- OVER 50% OF THESE AREAS ARE UNDERLAIN BY SOILS WITH ABUNDANT CLAYS OF HIGH SWELLING POTENTIAL.
- LESS THAN 50% OF THESE AREAS ARE UNDERLAIN BY SOILS WITH CLAYS OF HIGH SWELLING POTENTIAL.
- LESS THAN 50% OF THESE AREAS ARE UNDERLAIN BY SOILS WITH ABUNDANT CLAYS OF SLIGHT TO MODERATE SWELLING POTENTIAL.
- THESE AREAS ARE UNDERLAIN BY SOILS WITH LITTLE TO NO CLAYS WITH SWELLING POTENTIAL.

terrace • a flat or gently sloped embankment or ridge occurring on a hillside, and often along the margin of (or slightly above) a body of water, representing a previous water level.

silt • fine granular sediment most commonly composed of weathered grains of quartz and feldspar, of grain diameter 1/250 to 1/16 millimeters.

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

layered molecular structure are generically referred to as smectite; soils that tend to form deep cracks during drought are often indicative of the presence of smectite. The Colorado Plateau and Great Plains regions have the highest risk of damage caused by swelling soil. Here, clays are typically composed of montmorillonite or **bentonite**, which have a very high shrink/swell potential. In the Basin and Range, the clay-rich beds of the Pantano Formation are prone to expansion, as are old **alluvial** fan surfaces along river **terraces**.

See Chapter 4: Topography for more on physiographic regions, including the Basin and Range.

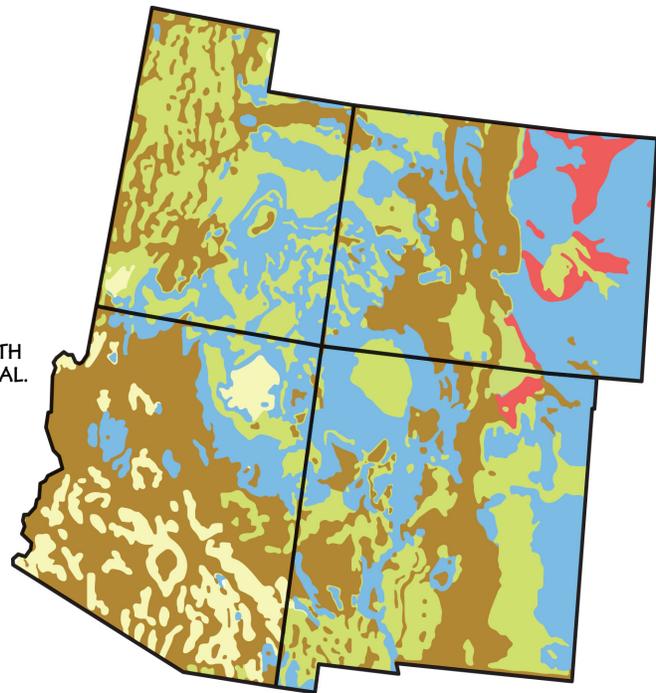


Figure 9.9: Approximate distribution of expansive soils in the Southwestern US. This map is based on the distribution of types of bedrock, which are the origin of soils produced in place. (Where substantial fractions of the soil have been transported by wind, water, or ice, the map will not be as accurate.) (See TFG website for a full-color version.)

Significant or repeated changes in moisture, which can occur from human use or in concert with other geologic hazards such as earthquakes, floods, or landslides, greatly increase the hazard potential of expansive soils. Because precipitation is infrequent in much of the Southwest, low-moisture soils also have a high potential for hydrocompaction, where dry **silt** and clay particles lose their cohesion upon wetting. This process causes the soil to collapse, settling lower. If hydrocompaction occurs over deeper layers that have been severely dried due to prolonged drought or receding groundwater levels, the settling **topsoil** may fall into and expose giant underground fissures, called desiccation cracks (Figure 9.10). These fissures can be up to a meter (3 feet) wide, 3 meters (9 feet) deep, and as much as 300 meters (1000 feet) long.



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.



Figure 9.10: This giant desiccation crack appeared in a road in Graham County, southeastern Arizona. Such cracks typically occur as a network of polygonal fissures.

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 (Figure 9.11). Slumping is common near roads and highways, thanks to the presence of steeper hills, roadcuts, and construction. On steep, high slopes, slumping often precedes earthflows and mudflows that develop farther downslope as water is added to the slump while it mixes the moving material.

The key to reducing expansive soil hazards is to keep the water content of the soil constant—in the dry Southwest, the best option is to utilize proper drainage methods, prevent the infiltration of surface water, and use moisture protection barriers around houses and other structures. There are also chemical stabilizers, including **lime**, potassium, and ionic agents, that can increase the clay's structural stability. Damage to life and property from larger 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.

9



Earth Hazards

Earthquakes

crust • the uppermost, rigid outer layer of the Earth.

seismic waves • the shock waves or vibrations radiating in all directions from the center of an earthquake or other tectonic event.

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

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

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 9.11: A hillside slump in Rocky Flats National Wildlife Refuge, Colorado. The slump occurred on a steep, manmade embankment after a severe storm saturated the soil.

Earthquakes

Earthquakes occur less frequently in the Southwestern US than they do in some other regions, but modest-sized earthquakes nonetheless represent potential hazards for the Southwestern states. 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 9.12). 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 Southwestern 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). Earthquakes have many different effects on the rocks in which they occur, including breaking and movement along faults, **uplift**, and displacement.

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

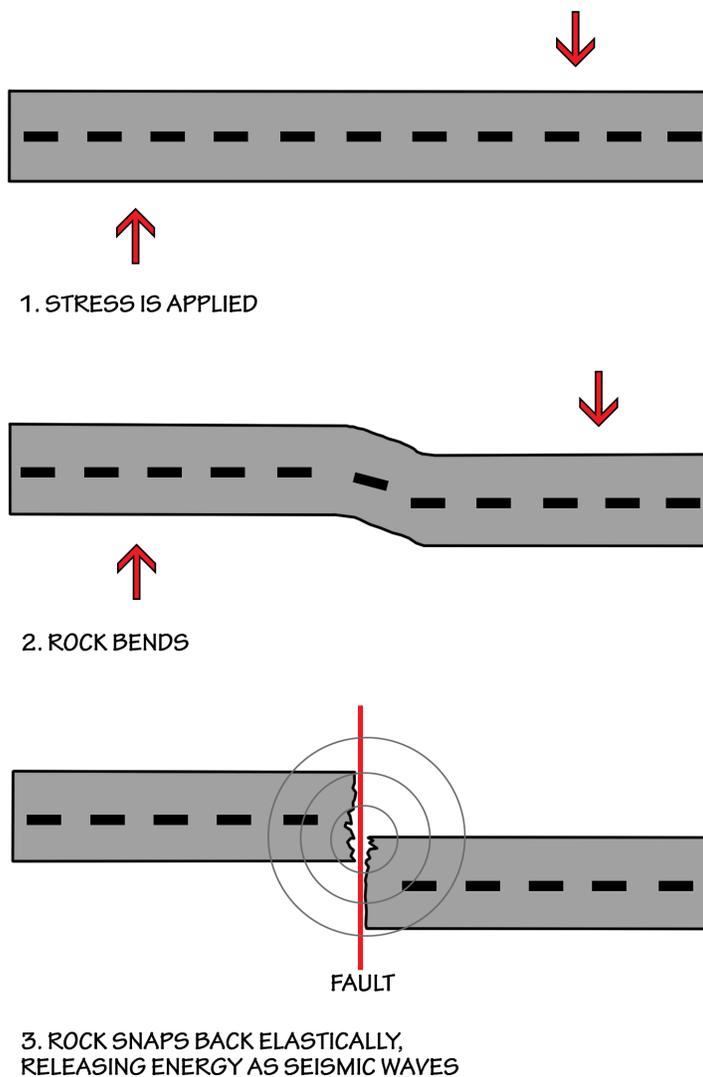


Figure 9.12: Elastic rebound.

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 earthquake 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

9



Earth Hazards

Earthquakes

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

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

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

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.

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 and 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 Southwest occurred in 1934 in Kosmo, Utah (M6.6). Notable earthquakes that have occurred just outside the Southwestern states, such as the 1887 Sonoran earthquake (M7.4) and the 1940 Imperial Valley earthquake (M7.1), have also caused extensive shaking and property damage, especially in Arizona.

Notable Earthquakes of the Southwestern States

Date	Location	M_w
03-12-1934	Kosmo, UT	6.6
11-08-1882	Denver, CO	6.6
11-15-1906	Socorro, NM	6.5
07-21-1959	AZ-UT border	5.6
09-02-1992	Springdale, UT	5.6
08-09-1967	Denver, CO	5.3
08-22-2011	Trinidad, CO	5.3
06-29-2014	NM-AZ border	5.2
01-23-1966	Dulce, NM	5.1

The magnitude of an earthquake 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 9.13* shows the intensities felt in surrounding areas after the 1934 earthquake near Kosmo, Utah, which is the largest earthquake known to have occurred in the state.

Large earthquakes are relatively uncommon in the Southwestern US, due to the area's distance from current **plate** boundaries—the Southwest is located in the center of a tectonic plate rather than at an **active plate margin**. All earthquakes that occur in the Southwestern US are therefore referred to as “intraplate” earthquakes, and they are largely related to faults that localize earthquakes in particular areas, along linear **seismic belts** or **zones**. Many of the largest earthquakes in the Southwest, especially those in the Rocky Mountains, stem from activity along the *Intermountain Seismic Belt* (*Figure 9.14*). This linear zone of earthquake activity extends 1290 kilometers (800 miles) from northwestern Montana southward along the Idaho-Wyoming border, through



Earthquakes

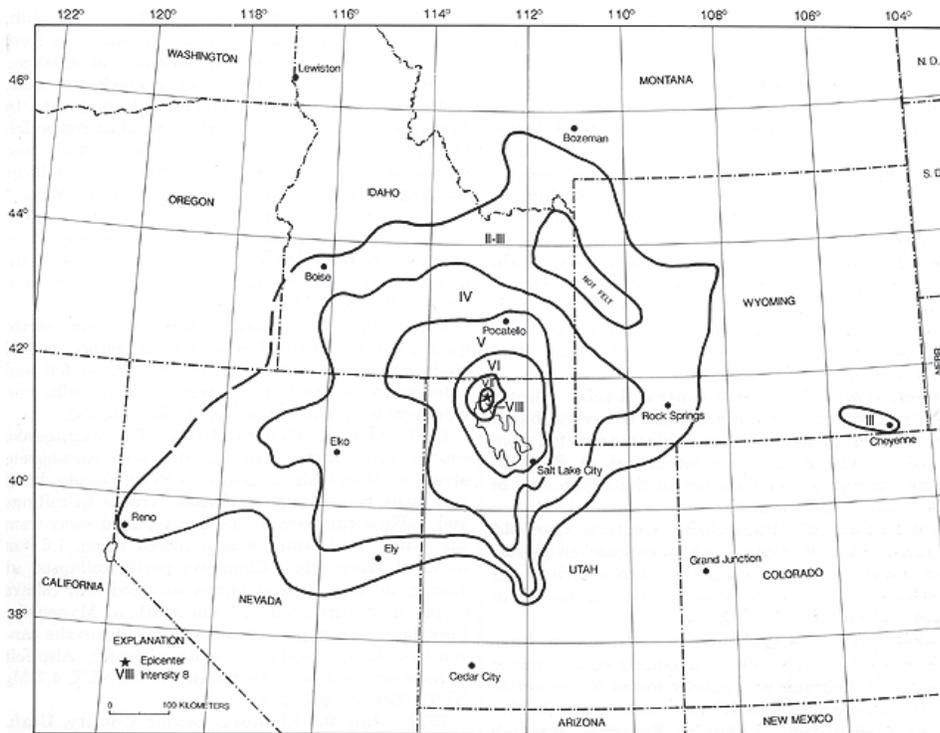


Figure 9.13: Intensity map of the 1934 Kosmo earthquake.

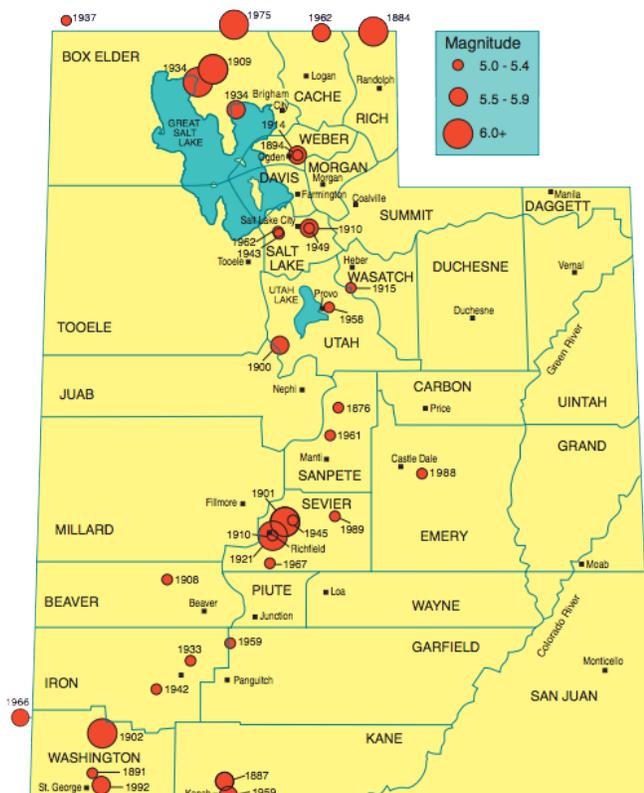


Figure 9.14: Since 1850, there have been 35 earthquakes in Utah with a magnitude of 5 or higher. All have occurred in or near the Intermountain Seismic Belt. (See TFG website for a full-color version.)

9



Earth Hazards

Earthquakes

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.

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

Utah, and into southern Nevada. Many active fault lines occur along this belt; the largest and most active is the Wasatch Fault, which marks the eastern edge of Basin and Range extension (*Figure 9.15*). Geologic studies indicate that the Wasatch Fault has experienced 19 or more surface-faulting earthquakes in the last 600 years. Some of these prehistoric earthquakes displaced the land surface by as much as 3 meters (10 feet) in a 30- to 65-kilometer (20- to 40-mile) radius, while others formed **fault scarps** over 6 meters (20 feet) high. Because the Wasatch Front is such a desirable place to live—about 80% of Utah’s population resides along this mountain range, known for its spectacular views—the area is designated as having the greatest earthquake risk in the interior western US. Scientists estimate that the Wasatch Range has a 1-in-7 chance of being hit by a M7.0 earthquake sometime in the next 50 years.

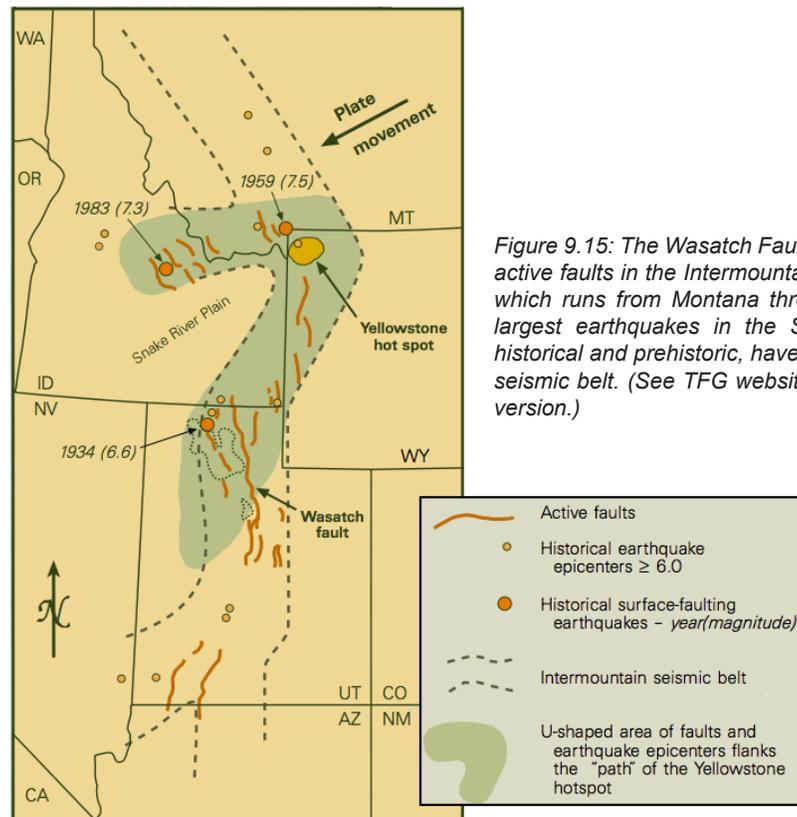


Figure 9.15: The Wasatch Fault is one of many active faults in the Intermountain Seismic Belt, which runs from Montana through Utah. The largest earthquakes in the Southwest, both historical and prehistoric, have occurred in this seismic belt. (See TFG website for a full-color version.)

The *Northern Arizona Seismic Belt* is an offshoot of the Intermountain Seismic Belt that extends south into Arizona along the Colorado Plateau. Faults in this zone are **Quaternary** in age, and are thought in part to have formed due to stress between the Basin and Range and edge of the Colorado Plateau. Swarms of tiny earthquakes occur along these fault lines in Arizona every year, most too small to be felt. Major quakes can and do occur, though, and geologists are keeping a close eye on the Anderson Mesa Fault near Flagstaff, which could conceivably produce an earthquake between M5.0 and M6.5.

Earthquakes can also occur through human causes, or “induced seismicity.” These events are specifically linked to the high-pressure injection of wastewater



from **oil** and gas extraction operations into the ground. The pressure of the water increases the likelihood that a rupture might occur along an otherwise locked fault. In early 2016, the US Geological Survey released a list of states considered to be at the highest risk for manmade earthquakes. Colorado and New Mexico rank fourth and fifth respectively due to the presence of the Raton Basin, an important source of coalbed methane and **natural gas**.

See Chapter 6: Energy to learn more about the process of extracting coalbed methane.

Networks of seismograph stations have improved geologists' ability to detect and accurately locate earthquake hazards (Figure 9.16), and specific fault zones are being studied throughout the Southwest. This information on earthquake risk can lead to better designs for high-risk infrastructure like dams, high-rise buildings, and **power** plants—and it can also be used to inform the public of potential hazards to lives and property. The hazards associated with earthquakes are mainly related to collapsing buildings and other structures, as well as fire related to broken gas lines and other utilities (and broken water lines that prevent fire-fighting).

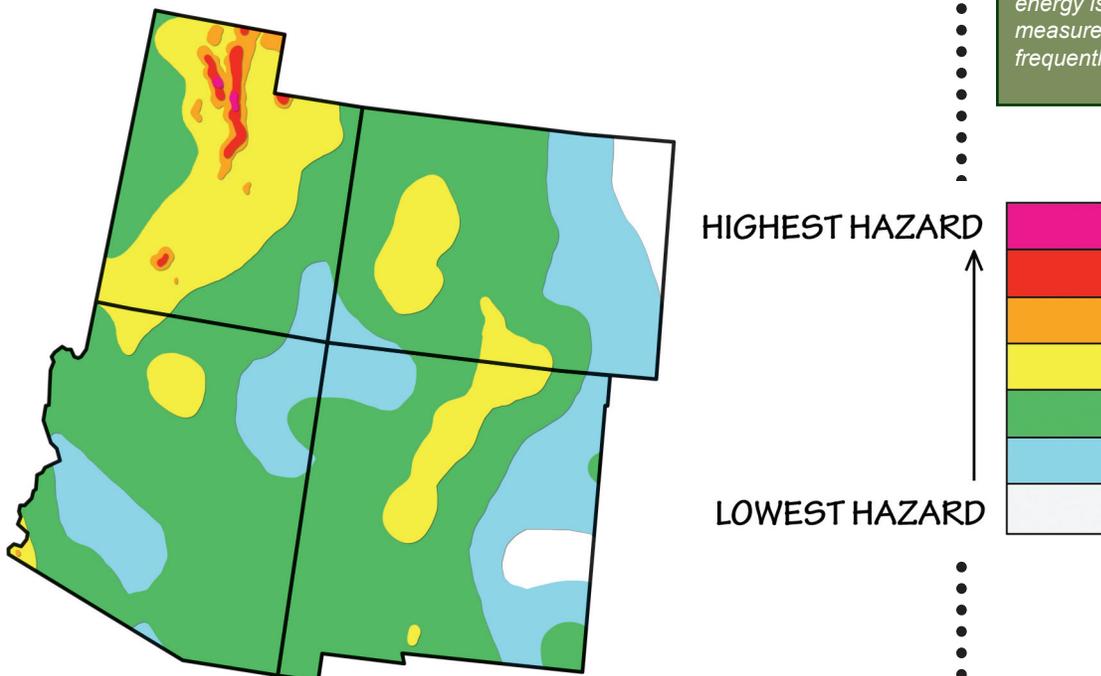


Figure 9.16: Seismic hazard map of the Southwestern US, based on 2014 data. (See TFG website for a full-color version.)

Earthquakes

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

natural gas • a hydrocarbon gas mixture composed primarily of methane (CH₄), but also small quantities of hydrocarbons such as ethane and propane.

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



Karst

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.

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

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 ($\text{CaMg}(\text{CO}_3)_2$).

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.

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 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. Many parts of the Southwest are underlain by karst and soluble carbonate bedrock (see *Figure 9.19*), especially Arizona's Colorado Plateau and New Mexico's Basin and Range. Because karst terrain is very **porous** and **fractures** easily, groundwater pollution can also be a serious problem. Contaminants that might otherwise be filtered through underlying 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.

The Colorado Plateau of northern Arizona contains extensive surface limestone and subsurface gypsum/**salt** deposits. As these beds dissolve beneath the surface through the movement of groundwater, sinkholes form through the collapse of overlying layers. Karst features such as open caverns also commonly form at the surface. The mountains of southeastern Arizona also contain limestone layers that have dissolved to form caverns such as Colossal Cave near Tucson—these features are less extensive than those on the Plateau and collapse at the surface is uncommon. In New Mexico, karst is concentrated in the northern Sacramento Mountains and the Guadalupe Mountains, where a large number of impressive caverns (including Carlsbad Cavern) have formed in **Permian reef** limestone (*Figure 9.17*). Although karst collapse is less prevalent in New Mexico than in many other parts of the United States, it is still an environmental issue of concern. In Colorado, the highest karst and sinkhole hazards are located in the Roaring Fork and Eagle river valleys, where hundreds to thousands of meters (yards) of subsidence has already occurred via subsurface dissolution and deformation of **evaporite** rocks. Colorado's sinkholes also form in arid and easily eroded soils, creating a landform known as "pseudokarst."

See Chapter 4: Topography to learn about the unique way in which sulfuric acid has generated karst in New Mexico.

Sinkholes are funnel-shaped depressions in the land surface formed by the dissolution of near-surface rocks or by the collapse of underground channels and caverns (*Figures 9.18 and 9.20*). Sinkholes can form by several different mechanisms, but all require dissolution of rock beneath the surface (*Figure 9.21*). Manmade sinkholes can also occur through the collapse of mine shafts



Figure 9.17: Carlsbad Cavern in New Mexico is an extensive cave system formed in the Permian limestone of the Capitan Formation. Uniquely, this and many other karst caves of New Mexico were formed through dissolution by sulfuric acid rather than the more common carbonic acid.



Figure 9.18: Hole-in-the-ground sinkhole, Millard County, Utah.

Karst

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

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

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

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

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

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

9



Earth Hazards

Karst

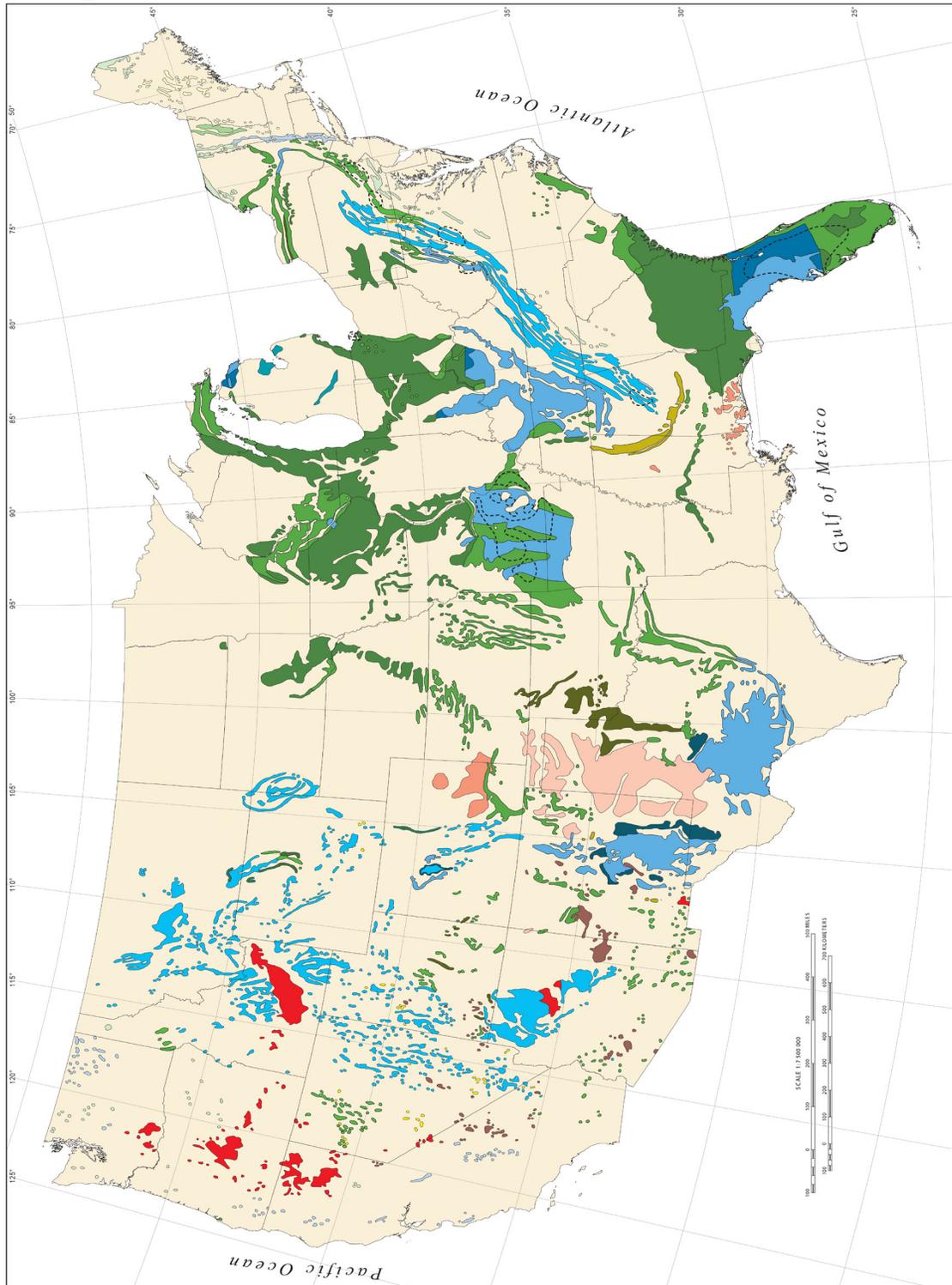


Figure 9.19: Areas of karst in the continental US, associated with carbonate and evaporate rocks. See Key on facing page. (See TFG website for full-color version.)



Karst



9



Earth Hazards

Karst



Figure 9.20: Aerial view of large aligned sinkholes in the Permian Kaibab Formation, southeast of Winslow, Arizona.

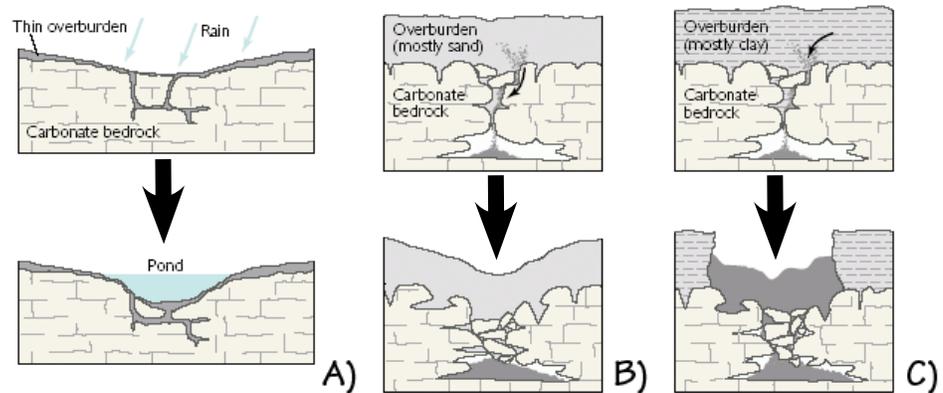


Figure 9.21: Three mechanisms of sinkhole formation.

- A) *Dissolution: Rain and surface water percolate through carbonate bedrock, dissolving a hole from the top down.*
- B) *Cover-subsidence: Carbonate bedrock dissolves beneath a permeable overlying layer such as sand. As the sand falls into the hole below, slow downward erosion leads to a depression.*
- C) *Cover-collapse: Carbonate bedrock dissolves beneath an overlying layer made largely of clay. The clay collapses from beneath into the cavity below, abruptly forming a dramatic sinkhole when the surface is breached. This type of sinkhole causes the most catastrophic damage, as it is not easily detected before it forms.*



and tunnels, or the removal of groundwater and oil (*Figure 9.22*). Sinkhole formation commonly damages roads, buildings, and utilities, and it is a problem in all four Southwestern states.

Sinkholes may be very small or large enough to swallow even **hectares** (acres) of land, along with any structures that had been built upon the surface. The early stages of sinkhole development may be indicated by signs of mass wasting such as “pistol-grip”-shaped trees, cracked building foundations, and leaning fence posts. Structural damage from sinkholes can be mitigated, but usually only at significant cost. It is therefore often far more prudent to avoid building in such locations altogether. Evaluating sinkhole risk commonly involves foundation testing by drilling or remote sensing (e.g., measuring electrical resistivity) prior to construction.



Figure 9.22: This sinkhole near Carlsbad, New Mexico formed after improper solution mining practices created a large cavity beneath the desert. Three days after its collapse, the sinkhole was 200 meters (670 feet) long and 140 meters (450 feet) wide, and there are major concerns that it could expand into the town of Carlsbad.

Asbestos

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

asbestos • a fibrous silicate mineral that is resistant to heat, flames, and chemical action.

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

Asbestos

The name **asbestos** is used to describe a variety of fibrous minerals, including chrysotile and crocidolite, which occur naturally as bundles of fibers that can be separated into durable filaments. The fibers are non-conductive and naturally resistant to chemicals and **heat**. During the early twentieth century, asbestos was commonly mined for its numerous industrial applications such as weather

9



Earth Hazards

Asbestos

insulation and fireproofing for buildings. However, when asbestos-laden dust is inhaled, the microscopic mineral fibers are capable of piercing and damaging the cells in which they come into contact. This can cause lung irritation and lead to serious health problems, including cancer.

While many people worry about the asbestos insulation hazards found in older buildings, few consider the hazards associated with the minerals' natural occurrence. Natural asbestos sources can be found throughout the Southwest, and it has been mined in both Utah and Arizona (*Figure 9.23*), though these mines are no longer in operation thanks to recent limitations placed on the minerals' use. Remediation attempts on abandoned mines include blocking off access to contaminated areas and burying contaminated soil that has been found near surface water sources.

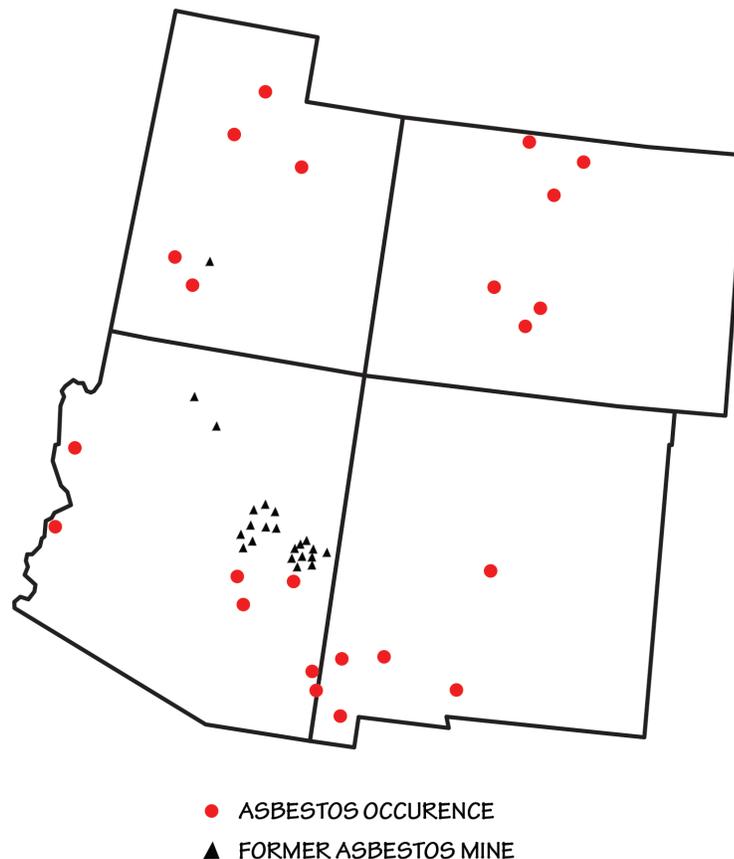


Figure 9.23: Presence of significant asbestos sources and former mines in the Southwestern states.

Natural events such as landslides can release previously trapped asbestos minerals, which can then be transported across great distances by the wind or even carried by surface water running over an asbestos site. Asbestos crystals can then make their way into streams and lakes, spreading contamination over large areas. People within the vicinity of exposed sources are at risk from windblown particles and mud particles collected on their shoes, clothing, and vehicles. The particles can then be carried into homes.



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 has produced a map of the US showing geographic variation in radon concentrations, divided into three levels of risk: high, medium, and low (*Figure 9.24*).

Although radon is more or less universally present, high levels of radon are associated with areas containing uranium-rich bedrock. Most rocks have a small amount of uranium, but certain rocks tend to have higher concentrations of the radioactive element, such as light-colored volcanic rocks, granites, dark shales, sedimentary rocks with **phosphates**, and **metamorphic rocks**. Radon concentrations are generally high in the Southwest's mountainous areas, as uranium is relatively concentrated in the granites, black shales, and metamorphic rocks of the Rocky Mountains (*Figure 9.25*). The sediments eroded from those areas also carry a high radon hazard potential, leading to moderate radon presence throughout the Southwest.

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.

Radon

radioactivity • the emission of radiation by an unstable atom.

thorium • a radioactive rare earth element.

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

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

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

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

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.



Earth Hazards

Radon

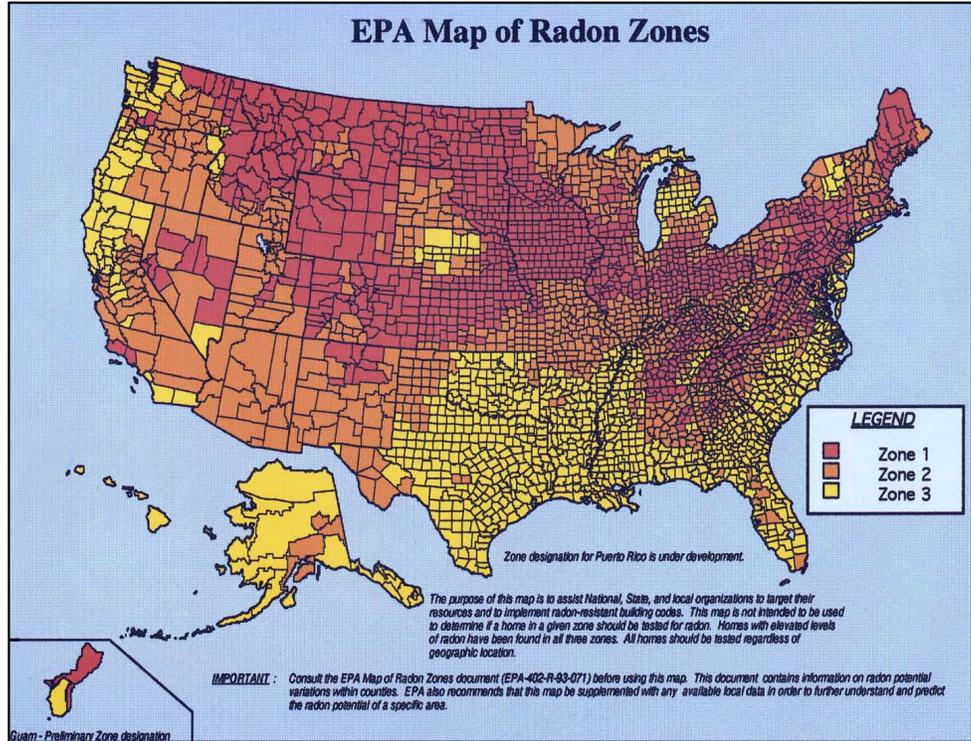


Figure 9.24: Radon zone map of the US. (Note: Zone 1 contains the highest radon levels.)
(See TFG website for full-color version.)

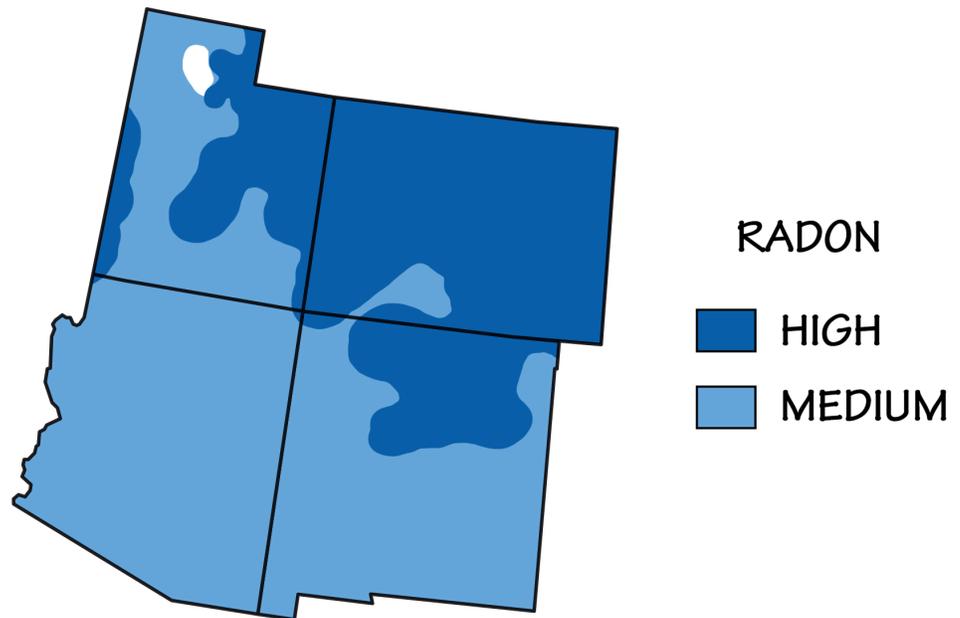


Figure 9.25: Radon risk levels at the surface in the Southwestern US.
(See TFG website for a full-color version.)



Floods

Although the Southwest has an overall arid climate, there are several large rivers that flow through the area, including the Colorado River and Rio Grande. Many of the Southwest's largest floods have occurred along the Colorado River and its tributaries (Figure 9.26). Along **floodplains**, the soil is fertile thanks to nutrients deposited by the rivers, and nearby water allows for easy irrigation. These factors encourage development on flood-prone areas throughout the Southwest. In the Great Plains, a large proportion of farmland—a significant industry in the Southwest—is located on floodplains along rivers that flow through the region. Before humans settled along rivers, floods were often beneficial events: a flood would wash away nutrient-depleted soil and then deposit fresh minerals and other nutrients to help support future plants. People now face the dilemma of whether or not to build in areas that are potentially subject to flooding. Water control structures such as dams are engineered to protect infrastructure and lives, but nature is not always so easily controlled.

Floods

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



Figure 9.26: The Colorado River and its tributaries in the Southwestern states. (See TFG website for full-color version.)

9



Earth Hazards

Floods

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

Floods are controlled by the rate of precipitation, run-off, stream flow, and shape of the land surface. They may occur as 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 has neither standing nor flowing water. Areas near rivers, tributaries, creeks, and streams are likely to experience flooding during periods of heavy rainfall.

See Chapter 8: Climate to learn more about precipitation in the Southwestern states.

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. Large floods typically result from unusually rapid regional melting of snow in the spring or from major weather **systems** that bring heavy rainfall over a large region. 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. Although flash floods may be of only a short duration, they can cause major damage—they have been known to wash coffins out of graveyards, destroy structures, and demolish manmade dams.

In the Southwest, arid air travelling from the western mountains draws in moisture from the south where there are no mountains to block the moisture, a phenomenon known as a monsoon climate. Warm, moist air has a concentration of energy that may be released in sudden, violent thunderstorms, generating downpours that lead to flash floods. Monsoon floods occur in every Southwestern state, and can reach heights of 9 meters (30 feet) or more, moving rocks and trees, sweeping away vehicles, and destroying buildings (*Figure 9.27*). Flash floods in the Southwest also tend to be especially deadly and destructive due to the area's many canyons, which funnel water to great speeds and depths. In September 2015, extreme rainfall generated by Pacific Hurricane Linda flooded Keyhole Canyon in Zion National Park, Utah. In only 15 minutes, the Virgin River's flow increased from 1.5 cubic meters (55 cubic feet) per second to 74.5 cubic meters (2630 cubic feet) per second. Seven hikers were swept away and killed. Near Hildale, Utah, rainfall from the same event caused major flash floods that swept away vehicles, killing 13 people, as well as destroying water lines, bridges, and power infrastructure for the town (*Figure 9.28*).

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



Floods



Figure 9.27: In August 2006, runoff from heavy rains sent a wall of water into the town of Hatch, New Mexico. No one was injured, but damages exceeded \$4 million. The summer of 2006 was a record monsoon season in New Mexico, with a total of 91 flash flood events.



Figure 9.28: The remains of a vehicle swept away by the Hildale flash flood in September 2015. Ten of the vehicle's eleven occupants were killed.

9



Earth Hazards

Floods

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. Floods can occur at any time, but major floods are more frequent in spring and fall after periods of heavy or sustained rains when stream levels rise rapidly. For example, rapid runoff from distant storms in the Rocky Mountains has had devastating effects, both in the mountains and where streams spread over broad areas of more open land. These floods have damaged structures, property, and put lives in peril. For example, in September 2013, torrential rains over Colorado's Front Range resulted in catastrophic flooding along the South Platte River and related tributaries. Up to 510 millimeters (20 inches) of rain fell over a three-day period; water levels of the river reached as high as 2.7 meters (8.8 feet) above flood level and affected 17 counties (*Figure 9.29*).

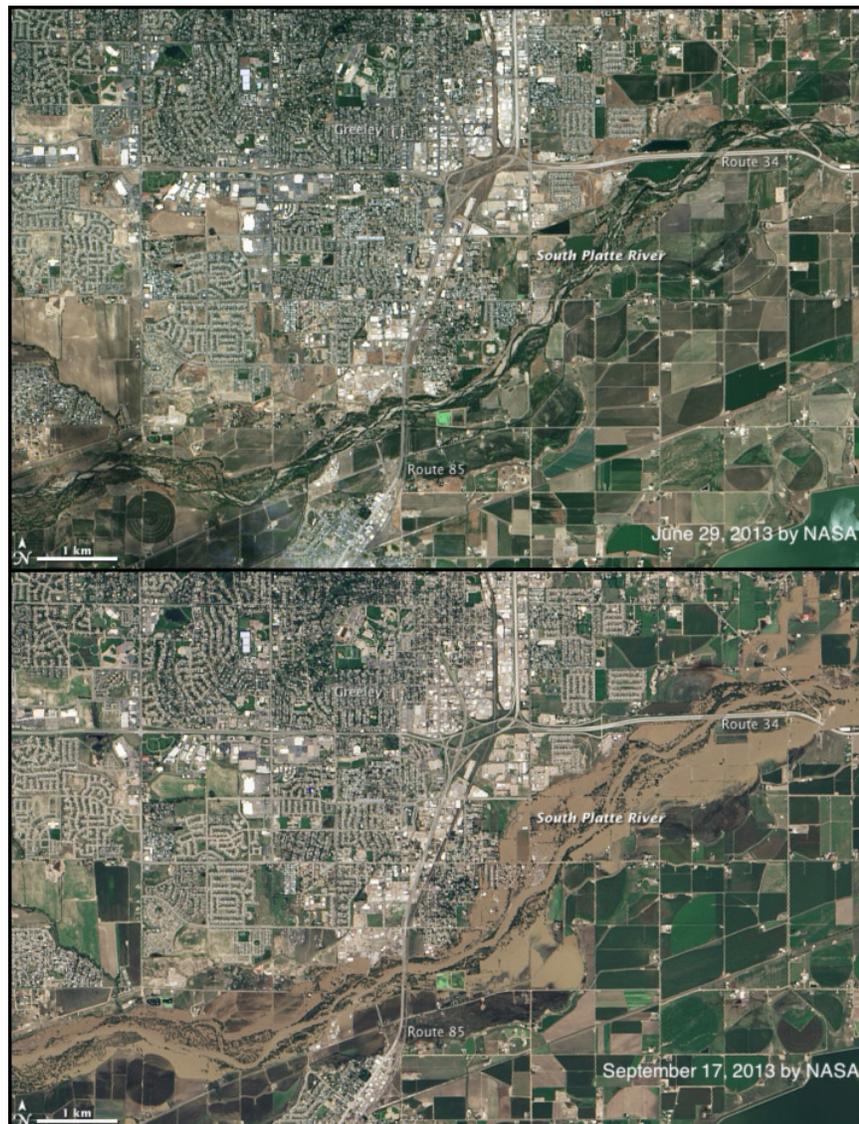


Figure 9.29: Before (top) and after (bottom) images of the South Platte River flood near Greeley, Colorado, in September 2013.



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. Flood control is part of the mission statements of many government agencies, including the National Resource Conservation Service (NRCS), US Corps of Engineers (USCE), and US Geological Survey (USGS). These agencies and others maintain gauges on most large rivers and streams in the Southwest from which flow data are gathered. Using historical records and flow data collected over a long period of time, hydrogeologists can apply statistics to calculate the frequency and **recurrence intervals** of flows of different magnitude. These data have been used by the USGS to produce special topographic maps showing flood-prone areas. 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.

Weather Hazards

Weather is the measure of short-term atmospheric conditions such as temperature, wind speed, and humidity. The Southwest 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 and Tornados

Several types of severe storms present challenges to people living in the Southwest. 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 March 2016, for example, a major blizzard dumped 60 centimeters (2 feet) of snow on the Denver metropolitan area and Colorado's Front Range, knocking out power, shutting down the Denver International Airport, and closing schools. A second event in April 2016—dubbed Winter Storm Vexo—inundated the Southwest with more heavy snowfall, from 1.3 meters (51 inches) in Pinecliffe, Colorado to 28 centimeters (11 inches) near Questa, New Mexico and 18 centimeters (7 inches) in Bellemont, Arizona.

Rainstorms occur where colder air from higher latitudes abruptly meets warmer air. Severe thunderstorms are a common occurrence for people living in the eastern Southwest because the conditions over the Great Plains are perfect for the development of severe weather. The region's 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

Weather

recurrence interval • the time elapsed between major events, such as floods.

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.

9



Earth Hazards

Weather

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

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. Hail is also a possible occurrence during storms as a result of moisture high in the atmosphere that condenses and forms rain droplets. If the wind is strong enough to keep the droplets suspended, and cold enough to freeze them, they may become hailstones. If the wind continues to persist and keeps the hail suspended in the clouds long enough, they can even grow as large as golf balls. Once they reach a mass that is too great for the wind to keep them suspended, they fall to the Earth, where they can do considerable harm upon impact. Anyone caught in a significant hailstorm can expect some bruises or stinging sensations. If the hail is large enough, property can be damaged; car windshields, sunroofs, and canopies are especially susceptible.

With freak and intense thunderstorms comes the added risk of lightning strikes. Friction in the atmosphere from a chaotic storm can produce a buildup of static electricity and an unbalanced electrical charge. When the imbalance is great enough, the accumulated energy will discharge itself in the form of a lightning bolt. This discharge can be heard as the sound of thunder. The intense beam of energy can scorch or kill any life that is unlucky enough to be at the point of contact. If a lightning strike occurs in an arid, vegetated area, the resulting fires may develop into full-blown forest fires.

Some severe thunderstorms, called supercells, have the potential to develop into tornados that can cause serious property damage and endanger lives. 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. 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 form, 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.

The word tornado has its roots in the Spanish word *tonar*, which means to turn.

"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. The Great Plains of Colorado and New Mexico are part of Tornado Alley, leading to more tornados



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 is labeled 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

in this part of the Southwest (*Figure 9.30*). From 1991 to 2010, for example, an annual average of 53 and 11 tornadoes occurred in Colorado and New Mexico, respectively (*Figure 9.31*). To the west, fewer tornado strikes occur, with an annual average of five and three striking Arizona and Utah, 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 its borders.

Dust Storms

In arid climates, even under non-drought conditions, dust storms are a hazard. Dust storms occur when winds hold dust aloft, sometimes briefly over a local area, and sometimes over broad regions for days. They can be hazardous to health and, because they drastically reduce visibility, dangerous to motor vehicle and airline traffic.

Among the most spectacular dust storms are those known as haboobs (or monsoonal dust storms), which occur when strong thunderstorm downdrafts blow loose sediments up from the desert, sending dust up to over 1000 meters (3300 feet) into the sky. Large haboobs can be as much as 100 kilometers (62 miles) across, and travel at speeds of 50 to 100 kilometers per hour (about 30 to 60 miles per hour) for over an hour. These storms occur in the summer, across southernmost New Mexico and Arizona (*Figure 9.32*), as well as in California and Texas.

9



Earth Hazards

Weather

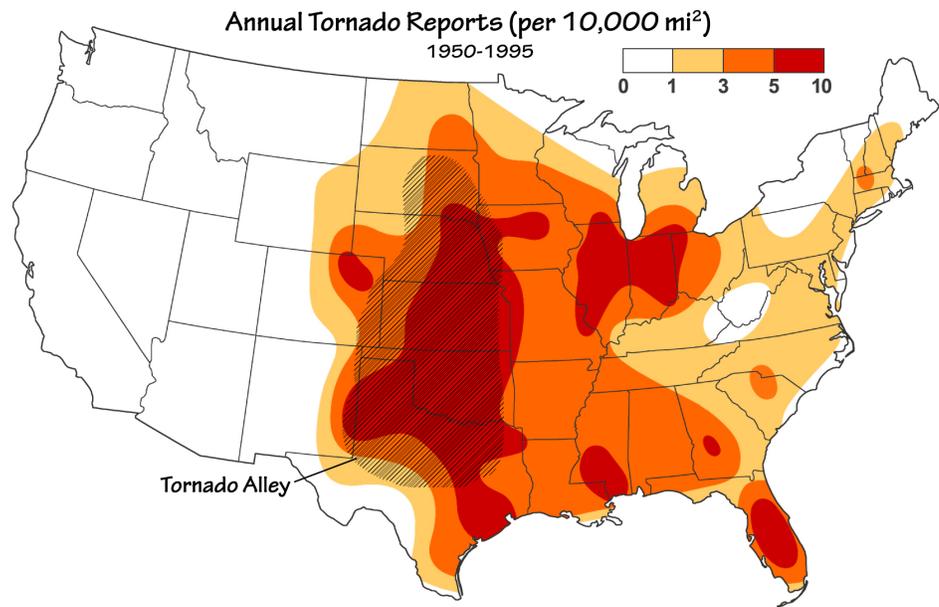


Figure 9.30: Annual tornado reports per 29,500 square kilometers (10,000 square miles) in the continental US, between 1950 and 1995. (See TFG website for full-color version.)



Figure 9.31: A tornado touches down over the hills near Roswell, New Mexico.



Drought

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



Figure 9.32: A haboob blows into the village of Ahwatukee, part of Phoenix, Arizona, in August 2003.

In addition to the inhalation of silt and clay dust, other health hazards associated with dust storms include fungi, bacteria, pollutants, and heavy metals. These materials can irritate the lungs and trigger asthma attacks, allergic reactions, and other illnesses. One fungus, *Coccidioides*, causes "valley fever," which causes cold- and flu-like symptoms and sometimes rashes. Though most recover without treatment, it can have serious consequences and even lead to death for some people with weak immune systems.

Extreme Temperature and Drought

Extreme temperatures can create dangerous conditions for people and may lead to property damage. Summer temperatures in the arid Southwest can reach dangerously high levels, and temperatures around or above 38°C (100°F) are not uncommon. High heat can lead to a series of health complications if not properly dealt with—heat exhaustion, heat stroke, and dehydration can all result from exposure to extreme temperatures. Since the human body can only survive a few days (typically three) in the desert without water, a stranded and unlucky hiker or camper can easily die of dehydration if a suitable water supply cannot be reached in time. **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

9



Earth Hazards

Drought

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

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. In the summer of 2015, a record-setting heat wave occurred across the desert Southwest, scorching Arizona and leaving Phoenix with a new daily record of 46°C (115°F). Temperatures hovered above 38°C (100°F) even later than 10 pm. The heat wave contributed to severe drought, amplified heat-based health emergencies, and caused a heavy spike in electricity usage (related to increased air conditioning use) that generated a record-breaking demand on the power grid. Other times when heat waves have affected the Southwestern states include the heat wave of June-July 2013, which scorched the Southwest and Great Plains, baking Utah and setting records for extreme heat across New Mexico (*Figure 9.33*); and the heat wave of June-July 2012, which broke previous record highs across Colorado.

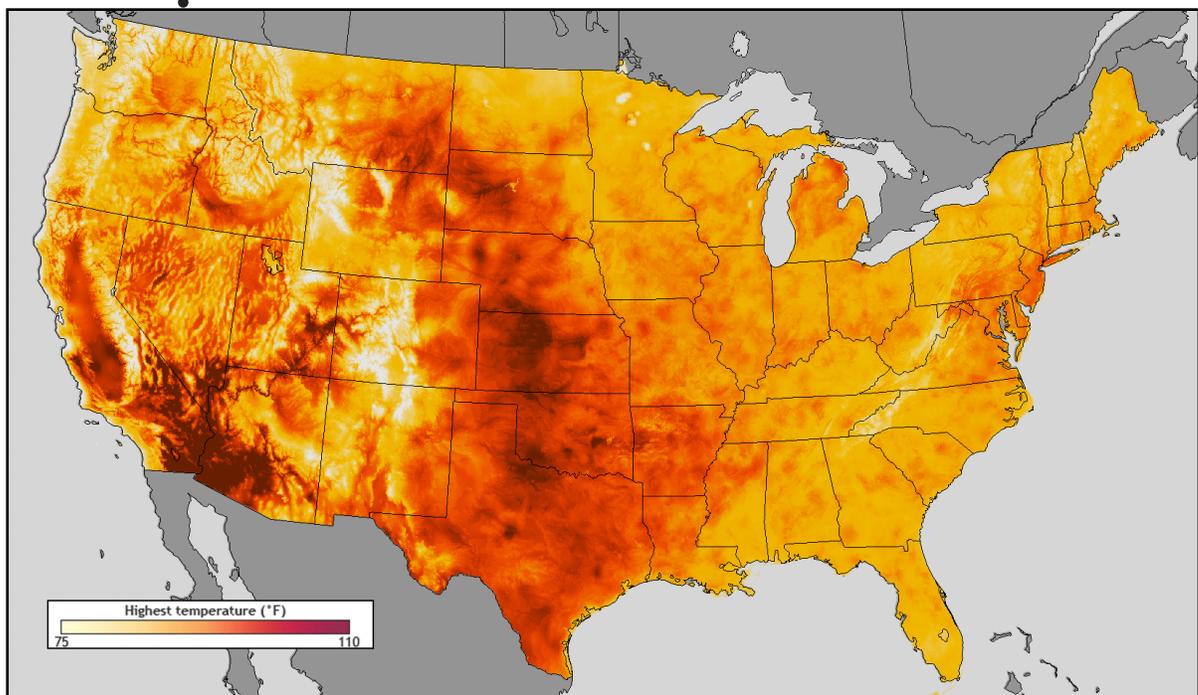


Figure 9.33: Air temperatures across the continental US during July 2013. (See TFG website for full-color version.)



Drought

While high temperatures can be directly dangerous, a larger scale hazard arises when these temperatures are coupled with lack of precipitation in an extended drought period. The Southwest has experienced both short-term and even decade-long periods of drought. Unlike other hazards, drought sets in slowly and takes time to be recognized. Agricultural areas can be seriously affected by a lack of rainfall and insufficient water supplies. Even higher-altitude forests show signs of stress since the combination of heat and long-term lack of precipitation deprives the land of one of its key resources. Lack of precipitation does not simply mean a lack of rain—it also means less seasonal snowfall in the mountains. Relatively little mountain snow in the winter translates into a lack of water for crop irrigation and household use in desert portions of the Southwest. Change in the flow rate of the Colorado River, which originates in the Rocky Mountains, serves as an excellent diagnostic for the effects of drought. This river is crucial for the irrigation of crops, and it feeds manmade reservoirs such as Lake Powell that supply drinking water to much of the region.

See Chapter 8: Climate to learn how global warming has influenced changes in the Colorado River's flow rate.

Many significant droughts have occurred in the Southwestern states—one notable instance of catastrophic drought in the Southwest was the Dust Bowl of the 1930s. Severe drought led to a drying of much of the topsoil, which was crucial to the agriculture of the area. High winds stripped the land of this topsoil, making crop growth impossible. This, in turn, led to the collapse of the farming industry, which was one of the main factors contributing to the Great Depression. More recently, severe drought conditions in 2002 forced Denver, Colorado to impose mandatory limits regarding water use; in addition, from 2011–2014, New Mexico was struck by its worst drought since the Dust Bowl. As of May 2016, much of the Southwest, especially Arizona, is experiencing conditions of moderate drought or abnormal dryness. Compiled tree-ring records over the past several thousand years shows that there have been past “megadroughts” that have been worse, and lasted longer, than recent ones. Models suggest that the likelihood of such droughts is expected to increase due to the effects and continuing patterns of climate change. Recent research using both models and data suggests that the climate of the Southwestern US has become and will remain drier, as subtropical dry zones move north.

Careful planning for seasonal drought, as well as extended drought, is the most effective way to reduce the chance of storage depletion in the Southwest. Conservation must be implemented as a series of progressive steps to be taken as water becomes scarcer. Out of necessity, the Southwest actually implements some of the most effective water management strategies in the United States. Still, no amount of planning can eliminate the long-term threat of drought, especially in an area dominated by deserts and under threat of the influence of changing climate.



Climate Change

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

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 Southwest 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. Today these most often start due to human activities, such as a poorly extinguished campfire, but they can also occur by natural ignition from lightning. Hundreds of square kilometers (miles) of forest have been lost to wildfires despite our best efforts to prevent, control, and extinguish them. Rural towns and summer homes, along with the people who inhabit them, can be suddenly caught in the blaze. Not only do these fires spread quickly, but human attempts to extinguish the blaze are hindered by the lack of available water to fight the fire. The Wallow Fire, which raged from May to July 2011, was the largest fire in Arizona's history; it consumed 2180 square kilometers (840 square miles) of land, destroyed 17 structures, and caused the evacuation of over 6000 people. In 2012, one of the Southwest's worst wildfire years, 1041 fires burned across Colorado, destroying 90,875 hectares (224,559 acres) of land, while over 1000 fires in Utah scorched more than 171,000 hectares (422,000 acres). And fires don't have to be large to be destructive—the most destructive fire in Colorado history, 2013's Black Forest Fire, burned only 5780 hectares (14,280 acres) but destroyed 511 homes and led to two fatalities (*Figure 9.34*).



Figure 9.34: The remains of a home destroyed by Colorado's Black Forest Fire on June 12, 2013.



Climate Change

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

Water supply is also a critical issue for the Southwestern states. Here, most water is obtained from precipitation, snowmelt, and runoff, which will dramatically decrease in quantity as temperature and aridity rise. In addition, parts of Colorado and New Mexico obtain agricultural and drinking water from the Ogallala 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 the Great Plains. 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 9.35*). However, the aquifer only replenishes at a rate no greater than 150 millimeters (6 inches) per year. Some estimates indicate that at its current rate of use, the entire Ogallala aquifer could be depleted by as early as 2028, threatening human lives, our food supply, and the entire Great Plains ecosystem.

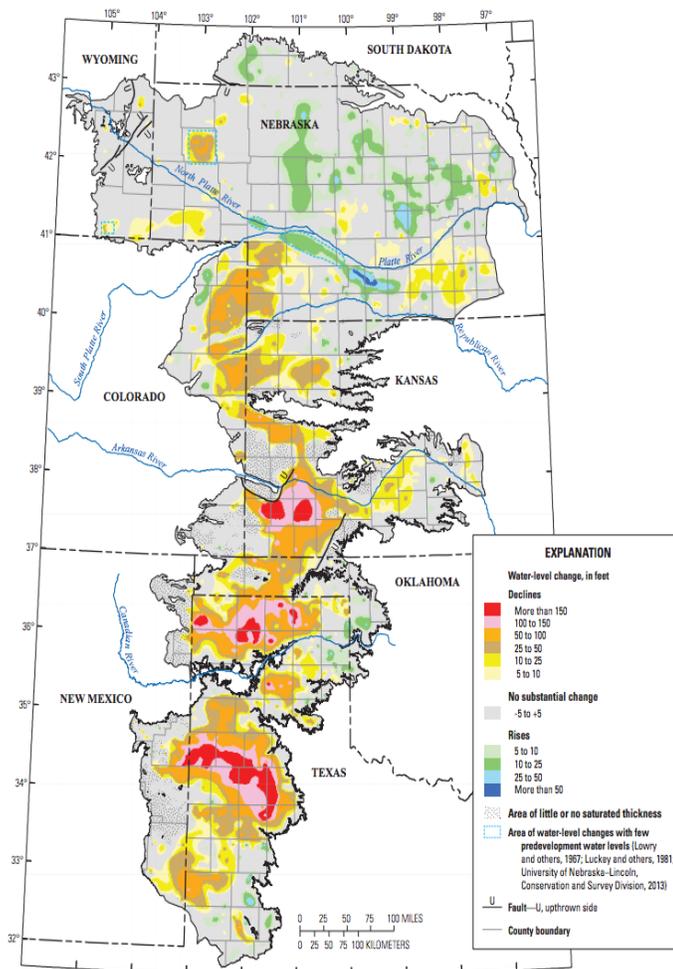


Figure 9.35: Water level change in the Ogallala aquifer between 1950 and 2013. (See TFG website for full-color version.)

9



Earth Hazards

Climate Change

water table • the upper surface of groundwater.

hurricane • a rapidly rotating storm system with heavy winds, a low-pressure center, and a spiral arrangement of thunderstorms.

In rural desert and semi-desert areas that are not served by well-planned regional or municipal systems, most people are dependent upon streams and wells. Streams often run dry, especially in the summer. The **water table** (the level of underground water) then migrates deeper, forcing people to extend wells deeper into the ground. Unfortunately, this is only a temporary solution.

In most of these areas, water is being withdrawn much more quickly than it is naturally replenished. Another hazard arising from excessive pumping of groundwater in the Southwest is land subsidence and subsidence-related earth fissures. In sum, lack of water reserves can lead to a cycle of economic disasters as well as the displacement of populations and businesses. The preservation and storing of water in large aquifers (water banking) for future use is an important technique to help adapt to drought.

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, organisms that damage ecosystems, such as the bark beetle, are better able to survive warmer winters, thrive, and multiply. In recent decades, bark beetles are estimated to have affected more than twice the forest area burnt by wildfires in New Mexico and Arizona.

Another concern regarding hazards exacerbated by climate change in the Southwest is whether or not there has been or will be an increase in the number or severity of storms, such as **hurricanes** and tornados. According to NASA, the present data is inconclusive in terms of whether hurricanes are already more severe, but there is a greater than 66% chance that global warming will cause more intense hurricanes 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 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 9.36*).

See Chapter 8: Climate for more on the effects of climate change in the Southwest.



SCIENCE CONNECTIONS → EXTREME WEATHER & CLIMATE CHANGE

→ Strongest Scientific Evidence Shows Human-Caused Climate Change Is Increasing Heat Waves and Coastal Flooding



Figure 9.36: The strength of evidence supporting an increase in different types of extreme weather events caused by climate change.

Climate Change



Resources

Resources

General Resources on Earth Hazards

- Gunn, A. M., 2001, *The Impact of Geology on the United States: a Reference Guide to Benefits and Hazards*, Greenwood Press, Westport, CT, 296 pp.
- Maccougall, J. D., 2011, *Why Geology Matters: Decoding the Past, Anticipating the Future*, University of California Press, Berkeley, 285 pp.
- NASA Earth Observatory Natural Hazards map. [Monthly images of Earth hazards occurring globally.] <http://earthobservatory.nasa.gov/NaturalHazards/>.

General Resources on Earth Hazards in the Southwest

- Environmental Geology and Geologic Hazards in Arizona, The Arizona Geological Survey, <http://www.azgs.az.gov/hazards.shtml>.
- Geologic Hazards, Colorado Geological Survey, <http://coloradogeologicalsurvey.org/geologic-hazards/>.
- Geologic Hazards, New Mexico Bureau of Geology and Mineral Resources, <http://geoinfo.nmt.edu/geoscience/hazards/home.html>.
- Harris, R. C., and P. A. Pearthree, 2002, *A Homebuyer's Guide to Geologic Hazards in Arizona*, Down-To-Earth 13, Arizona Geological Survey, Tucson, AZ, 36 pp., http://www.azgs.az.gov/HomeOwners-OCR/home_buyers_guide_2002_full.pdf.
- Hazards, Ready Colorado, Colorado Homeland Security Emergency Management, <https://www.readycolorado.com/about-ready-colorado>.
- Highland, B., 2013, *Colorado Natural Hazard Events: an Overview of When and Where Nature Impacted People in Colorado*, Highland & Associates, Morrison, CO, 68 pp.
- King, B., 2008, Drought, *Utah Natural Hazards Handbook*, Utah Division of Water Resources, pp. 95–108, <http://www.utah.gov/beready/documents/HazardsHandbookDraft8.pdf>.
- Natural Hazards Center, University of Colorado at Boulder, <https://hazards.colorado.edu/>.
- Natural Hazards in Arizona*, Arizona Geological Survey. [Interactive map] <http://data.azgs.az.gov/hazard-viewer/>.
- Utah Natural Hazards Handbook*, Utah Division of Homeland Security, 2008, 128 pp., <http://www.utah.gov/beready/documents/HazardsHandbookDraft8.pdf>.

This “General Resources on Earth hazards” section may contain additional information on each of the specific topics in the lists below.

Resources on Climate- and Weather-related Earth Hazards

Floods

- Cook, T., 2013, Releasing a flood of controversy on the Colorado River, *Earth Magazine*, <http://www.earthmagazine.org/article/releasing-flood-controversy-colorado-river>.
- Desert Safety Tips and Desert Survival*. [This has a section on flash floods.] http://www.desertusa.com/thingstodo/du_safetytips.html.
- Preparing for the Flash Flood Season, What is the Wash?*, Las Vegas Wash Coordination Committee, https://www.lvwash.org/html/what_visit_flood.html.
- Rosen, J., 2014, Colorado River researchers find signs of ancient, devastating floods, *Los Angeles Times*, June 19, 2014, <http://www.latimes.com/science/sciencenow/la-sci-sn-colorado-floods-20140618-story.html>.



Droughts and High Temperatures

- Climate Change and Drought in the American Southwest*, Climate Institute, <http://climate.org/effects-of-21st-century-climate-change-on-drought-risk-in-the-american-southwest/>.
- Drought Monitoring, Climate Assessment for the Southwest*, The University of Arizona, <http://www.climas.arizona.edu/sw-climate/drought-monitoring>.
- Fischetti, M., 2015, U.S. droughts will be the worst in 1,000 years: the Southwest and central Great Plains will dry out even more than previously thought, *Scientific American*, <http://www.scientificamerican.com/article/u-s-droughts-will-be-the-worst-in-1-000-years1/>.
- Harris, R. C., Giant desiccation cracks in Arizona, Arizona Geological Survey, *Arizona Geology*, 34(2): 1–3, http://www.azgs.az.gov/Hazards_ocr/Swelling_Shinking%20soils/Desiccation%20Cracks%20in%20AZ-2004.pdf.

Dust, Dust Storms, and Haboobs

- Dust Storm and Haboob Safety Tips*, National Weather Service, http://www.nws.noaa.gov/airquality/dust_storm.shtml.
- Environmental Mediation of Valley Fever*, Department of Geography, US Geological Survey, and University of Arizona, <http://www.casa.arizona.edu/~peter/valleyfever/web/index.html>.
- Hinkley, T. K., *Mineral Dusts in the Southwestern U.S.*, US Geological Survey, <http://geochange.er.usgs.gov/sw/impacts/geology/dust/>.
- Thomas, M., The mysterious fungus infecting the American Southwest, *The Atlantic*, August 8, 2014, <http://www.theatlantic.com/health/archive/2014/08/the-mysterious-fungus-infecting-the-american-southwest/375191/>.

Tornados

- Edwards, R., *Tornado Safety*, Storm Prediction Center, National Weather Service, <http://www.spc.noaa.gov/faq/tornado/safety.html>.
- Historical Records and Trends [in Tornados in the US]*, National Centers for Environmental Information, National Oceanic and Atmospheric Administration, <https://www.ncdc.noaa.gov/climate-information/extreme-events/us-tornado-climatology/trends>.
- The Most "Important" US Tornadoes by State*, Tornado Project Online, <http://www.tornadoprotect.com/alltorns/worstts.htm>.
- Tornado History Project. [Searchable database of reported US tornadoes since 1950.] <http://www.tornadohistoryproject.com/>.
- Vaughan, K. and B. Hubbard, Colorado ranks near top nationally in tornado activity, *Rocky Mountain PBS News*, June 13, 2013, <http://inewsnetwork.org/2013/06/19/colorado-ranks-near-top-nationally-in-tornado-activity/>.

Resources on Landscape-related Earth Hazards

Expansive Soils

- Harris, R. C., and P. A. Pearthree, 2002, Problem soils, in: *A Homebuyer's Guide to Geologic Hazards in Arizona*, Down-To-Earth 13, Arizona Geological Survey, Tucson, AZ, pp.11–15, http://www.azgs.az.gov/HomeOwners-OCR/HG4_problemsoils.pdf.
- King, H., *Expansive Soil and Expansive Clay: the Hidden Force Behind Basement and Foundation Problems*, Geologic Hazards, Geology.com, <http://geology.com/articles/expansive-soil.shtml>.
- Noe, D. C., C. L. Jochim, and W. P. Rogers, 1997, *A Guide to Swelling Soils For Colorado Homebuyers and Homeowners*, 2nd edition, Colorado Geological Survey Special Publication 43, 52 pp., http://vonscolorado.com/wp-content/uploads/2014/04/A_Guide_to_Swelling_Soils_Pub43.pdf.

Landslides

- Burt, C. B., 2014, *Worst Landslides in U.S. History*, Weather Underground, March 25, 2014, <https://www.wunderground.com/blog/weatherhistorian/worst-landslides-in-us-history>.
- Gootee, B. F., 2006, *The Marcus Landslide: an Ancient Landslide in the McDowell Mountains*, The Arizona Geological Survey, http://www.azgs.az.gov/MarcusLandslide_2008.shtml.
- Highland, L., Landslide types and processes, 2004, *US Geological Survey Fact Sheet 2004-3072*, 4 pp., <http://pubs.usgs.gov/fs/2004/3072/pdf/fs2004-3072.pdf>.
- Highland, L. M., & Bobrowsky, P., 2008, The landslide handbook—A guide to understanding landslides, *US Geological Survey Circular 1325*, 129 pp.



Resources

Landslide Hazards Program, US Geological Survey, <http://landslides.usgs.gov/>.
Landslides in the United States Since 2007 (map), National Geographic, <http://news.nationalgeographic.com/news/2014/04/140422-surveying-american-landslides-interactive/>.
 Wald, L., *Reconstruction of an Avalanche: The West Salt Creek Rock Avalanche, Colorado, May 25, 2014*, Landslide Hazards Program, USGS, <http://landslides.usgs.gov/research/featured/2015-westsaltcreek/>.

Karst, Sinkholes, and Fissures

Arizona's Earth Fissure Center, The Arizona Geological Survey, <http://www.azgs.az.gov/EFC.shtml>.
 Hill, C. A., 2003, Caves and karst in New Mexico, New Mexico Bureau of Geology and Mineral Resources, *New Mexico Earth Matters*, 3(1): 1–4, https://geoinfo.nmt.edu/publications/periodicals/earthmatters/3/n1/em_v3_n1.pdf.
 Lindberg, P. A., 2009, *Devil's Kitchen Sinkhole—Sedona, AZ: a Potential Geohazard*, The Arizona Geological Survey, http://www.azgs.az.gov/arizona_geology/winter09/article_devilskitchen.html.

Resources on Tectonics-related Earth Hazards

Earthquakes

A Brief History of Earthquake Activity in Arizona, AZ Central, <http://www.azcentral.com/story/news/arizona/2014/06/30/arizona-earthquake-timeline/11787839/>.
Earthquakes [in Colorado], Colorado Geological Survey, <http://coloradogeologicalsurvey.org/geologic-hazards/earthquakes/>.
 Fellows, L. D., 2000, Earthquake hazard in Arizona, Arizona Geological Survey, *Arizona Geology*, 30(1): 1–4, http://www.azgs.az.gov/Hazards_ocr/earthquakes/Earthquake%20Hazard%20in%20AZ-2000.pdf.
 Haneberg, B., 2016, *Do We Have Earthquakes in New Mexico?*, New Mexico Bureau of Geology and Mineral Resources, <http://tremor.nmt.edu/faq/here.html>.
 Incorporated Research Institutions for Seismology (IRIS) Education and Public Outreach, <http://www.iris.edu/hq/programs.epo>.
Induced Earthquakes, Earthquake Hazards Program, US Geological Survey, <http://earthquake.usgs.gov/research/induced/>.
IRIS Seismic Monitor, Incorporated Research Institutions for Seismology (IRIS), <http://www.iris.edu/seismon/>.
Putting Down Roots in Earthquake Country: Your Handbook for Earthquakes in Utah, 2008, Utah Seismic Safety Commission, 33 pp., http://www.utah.gov/beready/documents/roots_earthquake_low.pdf.
 Stover, C. W., and J. L. Coffman, 1993, Seismicity of the United States, 1568–1989 (revised), *US Geological Survey Professional Paper 1527*, 418 pp., <http://pubs.usgs.gov/pp/1527/report.pdf>.
 Eldredge, S. N., 1996, The Wasatch Fault, *Utah Geological Survey Public Information Series 40*, 17 pp., <http://files.geology.utah.gov/online/pdf/pi-40.pdf>.
Today in Earthquake History, Earthquake Hazards Program, US Geological Survey. [Content abridged from Stover & Coffman, 1993.] <http://earthquake.usgs.gov/learn/today>.
U of U Seismic Stations, Earthquake Center, University of Utah, <http://quake.utah.edu/earthquake-center/quake-map>.
US Earthquake Information by State/Territory, USGS Earthquake Hazards Program, <http://earthquake.usgs.gov/earthquakes/states/>.
US Earthquake Monitor, US Geological Survey, <http://earthquake.usgs.gov/earthquakes/map/>.
Utah Faults, Utah Geological Survey, <http://geology.utah.gov/hazards/earthquakes-faults/utah-faults/>.

Volcanoes

Duffield, W., 1997, *Volcanoes of Northern Arizona: Sleeping Giants of the Grand Canyon Region*, Grand Canyon Association, Grand Canyon, AZ, 68 pp.
Frequently Asked Questions about New Mexico Volcanoes, New Mexico Bureau of Geology and Mineral Resources, <https://geoinfo.nmt.edu/faq/volcanoes/>.
 Hagadorn, J., 2015, *Colorado's Volcanoes, Just the Facts*, Front Porch Stapleton [News], <https://frontporchstapleton.com/article/colorados-volcanoes/>.
 Pfeiffer, T., *Volcanoes of Canada and USA (Mainland)*, Volcano Discovery. [Volcanos active within the past 10,000 years.] <https://www.volcanodiscovery.com/north-america.html>.



The Volcanoes of New Mexico, Online Exhibits, New Mexico Museum of Natural History and Science,

<http://www.nmnaturalhistory.org/online-exhibits-geoscience/volcanoes-new-mexico>.

U.S. Volcanoes and Current Activity Alerts, Volcano Hazards Program, US Geological Survey,

<http://volcanoes.usgs.gov/index.html>.

Resources on Materials-related Earth Hazards

Radon

Radon, Colorado Department of Public Health and Environment, <https://www.colorado.gov/pacific/cdphe/categories/services-and-information/environment/radon>.

Radon Fact Sheet, Air Check Inc., 2009, http://www.radon.com/radon/radon_facts.html.

Radon: Health Risks, Environmental Protection Agency, 2013,

<http://www.epa.gov/radon/healthrisks.html>.

Radon Information, Environmental Protection Agency, <http://www.epa.gov/radon/index.html>.

Radon levels for [any US state], http://**-radon.info/ [in which ** = two-letter state code, such as AZ, CO, NM, or UT].

Radon (Rn), United States Environmental Protection Agency (EPA). [Includes state radon maps with county-level data.] <http://www.epa.gov/radon/whereyoulive.html>.

Asbestos

Harris, R. C., 2004, Asbestos in Arizona, Arizona Geological Survey, *Arizona Geology*, 34(1): 1–4, <http://www.azgs.gov/Mineral%20Scans/Asbestos%20in%20AZ%2004.pdf>.

Van Gosen, B. S., 2008, Reported historic asbestos mines, historic asbestos Prospects, and natural asbestos occurrences in the southwestern United States (Arizona, Nevada, and Utah), *US Geological Survey Open-File Report 2008-1095*, 1 plate, <http://pubs.usgs.gov/of/2008/1095>.

Earth Hazards Teaching Resources

Investigating Speed and Acceleration Using Tornado Tubes, Hamline University Graduate School of Education MnSTEP Teaching Activity Collection, <http://serc.carleton.edu/sp/mnstep/activities/27202.html>.

Karst Formation, City of Austin Youth Education resources, http://austintexas.gov/sites/default/files/files/Watershed/youth_education/karst_lesson_high_school.pdf.

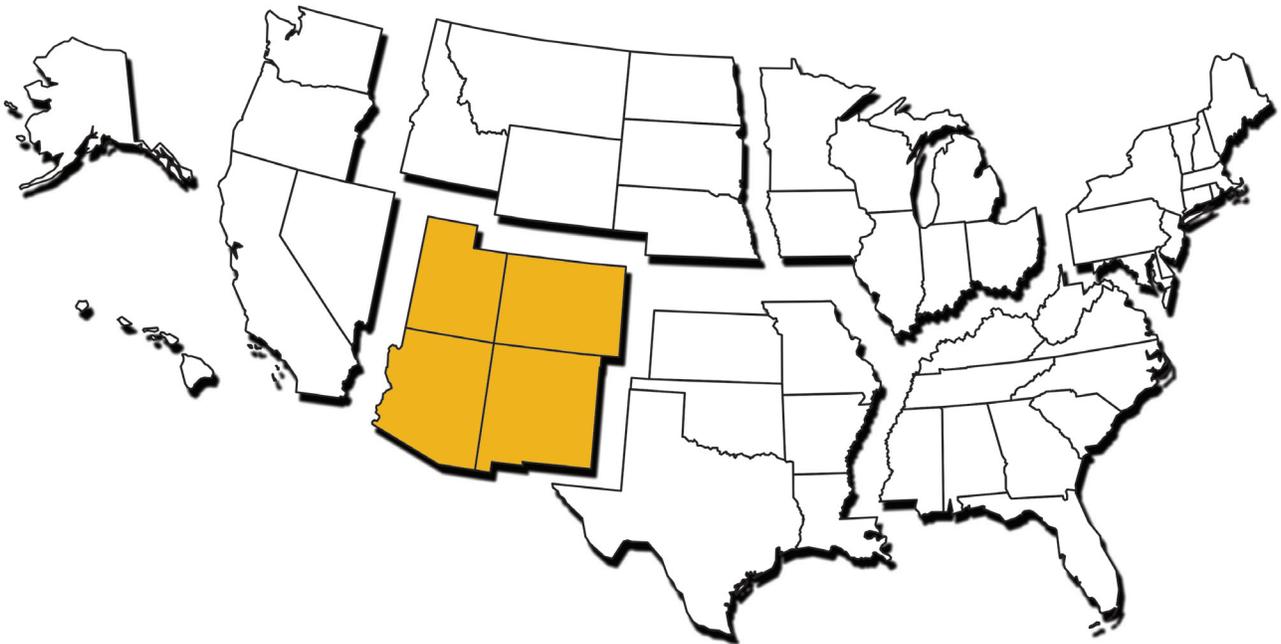
Radke, J., *Impact of Natural Disasters on the Earth*, Hamline University Graduate School of Education MnSTEP Teaching Activity Collection, <http://serc.carleton.edu/sp/mnstep/activities/19789.html>.

Radon Activities from the Alabama Radon Program, Alabama and Auburn Universities Extension, <http://www.aces.edu/fcs/hndh/radon/alradon.php>.

Teaching Quantitative Concepts in Floods and Flooding, SERC Resources for Undergraduate Students and Faculty, <http://serc.carleton.edu/quantskills/methods/quantlit/floods.html>.

The
Teacher-Friendly
Guide™

to the Earth Science of the
Southwestern US



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

Paleontological Research Institution
2016

ISBN 978-0-87710-514-5
Library of Congress no. 2016952807
PRI Special Publication no. 50

© 2016 Paleontological Research Institution
1259 Trumansburg Road
Ithaca, New York 14850 USA
priweb.org

First printing September 2016

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



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

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

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

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

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

Cite this book as:

Swaby, A. N., M. D. Lucas, & R. M. Ross (eds.), 2016, *The Teacher-Friendly Guide to the Earth Science of the Southwestern US*. Paleontological Research Institution (Special Publication 50), Ithaca, New York, 458 pp.

Cite one chapter as (example):

Allmon, W. D., and R. A. Kissel, 2016, Fossils of the Southwestern US. Pages 89–157, in: A. N. Swaby, M. D. Lucas, & R. M. Ross (eds.). *The Teacher-Friendly Guide to the Earth Science of the Southwestern US*. Paleontological Research Institution (Special Publication 50), Ithaca, New York.

On the back cover: Blended geologic and digital elevation map of the Southwestern 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>.