



Chapter 10: Earth Hazards of the Western US

Natural hazards are events that result from natural processes and that have significant impacts on human beings. Extreme **weather** conditions or geologic activity can cause substantial short-term or long-term changes to our environment. These changes can influence crops, homes, infrastructure, and the **atmosphere**. The 4.6-billion-year-old Earth has experienced many of these natural changes, and it has always adjusted accordingly.

The Western United States is located at the junction of three tectonic **plates**: the Pacific, the Juan de Fuca, and the North American. The movement of these plates, even though it occurs on the scale of millimeters per year, makes the Western US a dynamic landscape. The dramatic result is a dizzying assortment of natural hazards such as **earthquakes**, **tsunamis**, landslides, and volcanoes. The Pacific plate is **subducting** under Alaska, creating the volcanoes of the Aleutian Islands. The Juan de Fuca plate is subducting under Washington, Oregon, and Northern California, creating the Cascade volcanoes, and the Pacific plate is grinding past the North American plate along the famous San Andreas Fault. At the same time, the Basin and Range province, which includes nearly the entire state of Nevada, is being stretched and **faulted** by plate movement. While the motion of all tectonic plates can cause earthquakes, the movement of a subducting plate can cause the world's largest earthquakes and tsunamis. Tectonic activity lifts the landscape high above sea level, and because uplifted land is subject to the force of gravity, **mass wasting** processes such as landslides are the inevitable result. These events can be triggered by rain, earthquakes, and coastal or river **erosion**. The Western US contains rugged landscapes and breathtaking vistas, but with that beauty comes a cost: there are more earthquakes, tsunamis, landslides, and volcanoes in the Western states than in all the other states combined. (While many of these same hazards affect the Hawaiian Islands, there are enough significant differences to warrant discussing Hawai'i separately.)

See Chapter 4: Topography to learn more about the landforms of the Western states.

Plate Tectonics

All tectonic plates move relative to other plates, and the Pacific plate is moving at a rate of roughly 50 millimeters/year (2 inches/year) relative to the North American plate. Most, but not all, of this motion occurs along the San Andreas Fault. The Sierra Nevada, whose **granite plutons** were created by

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

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

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

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.

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

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

CHAPTER AUTHORS

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Earth Hazards

Plate Tectonics

the subduction of an ancient plate known as the Farallon plate, are located on the North American plate, but they are being pulled along by the Pacific plate. The Juan de Fuca plate, which is all that remains of the Farallon, is moving towards North America at an average rate of 36 millimeters/year (1.4 inches/year), creating the Cascade Range's volcanoes. As the Pacific plate continues to move northwest, it is causing the Basin and Range to pull apart. As a result, Nevada is full of sinking valleys and tilted mountains, and is growing wider in the process (Figure 10.1). Although this diagram does not show Alaska, the Pacific plate is subducting underneath the North American plate, creating the volcanic Aleutian Island Arc.

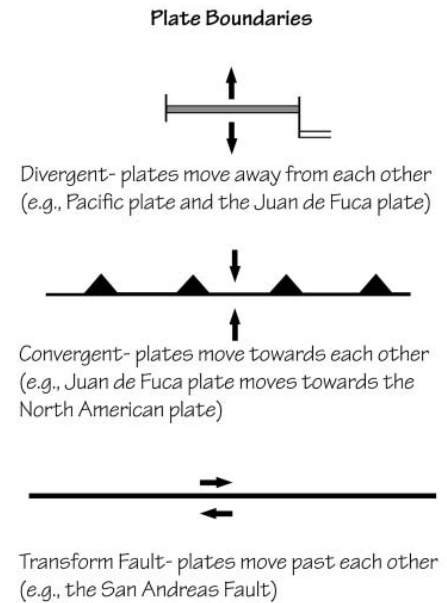
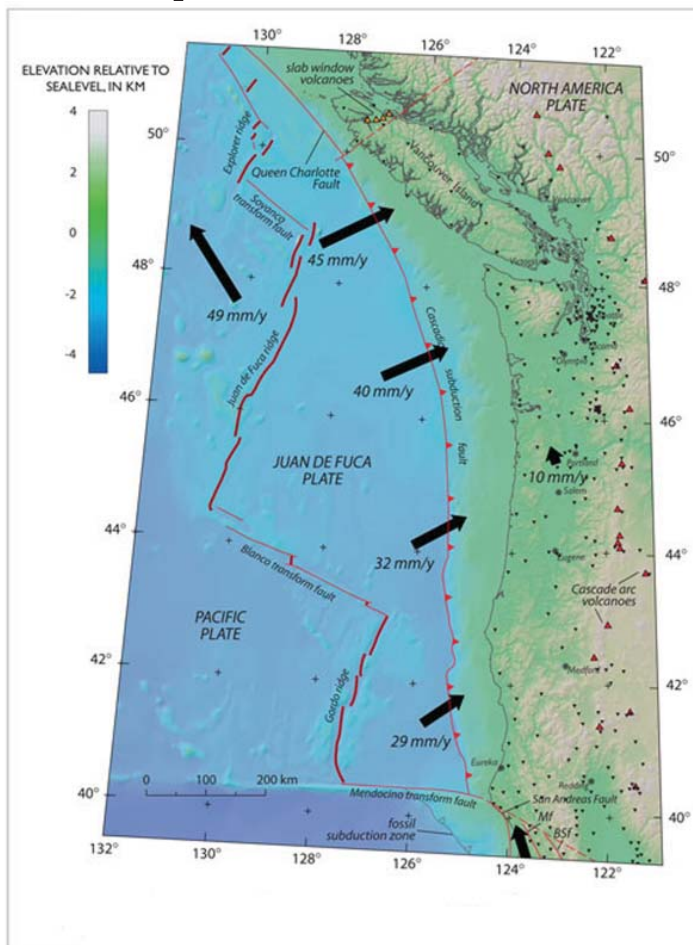


Figure 10.1: The general tectonic setting of the West Coast. (See TFG website for full-color version.)

Convergent Boundaries

Where two plates collide, the denser plate (usually oceanic) subducts under the lighter one (either a younger oceanic plate or a continental plate) and



creates a subduction zone. Subduction zones produce the largest and deepest earthquakes in the world. The water in the subducting plate is carried deep into the **mantle** and causes the melting of the overlying mantle rock. The resulting **magma** is hot and buoyant, so it rises to the surface and creates volcanoes. In the Western US, the Aleutian Island Arc and the Cascade volcanoes provide surface evidence of **convergent boundaries**.

Divergent Boundaries

Divergent plate boundaries exist where tectonic plates are under tension—essentially being pulled apart. This tension leads to the upwelling of magma, which forces its way through the separating **crust** onto the surface. In oceanic settings, such as the Juan de Fuca Ridge, new oceanic crust is created, and shallow, minor earthquakes occur. In continental settings, such as the Basin and Range of Nevada, the result of the tension is faulting and shallow earthquakes. As the faults pull apart and thin the crust, the decrease in overlying pressure can result in the formation of **basaltic** magma, which, in turn, can lead to the formation of small volcanoes called **cinder** cones. The faulting also creates the down-dropped basins and tilted mountain ranges of the Basin and Range.

Transform Boundaries

Transform boundaries exist where adjacent tectonic plates are moving alongside each other, causing a transform fault to develop. Most transform fault boundaries can be found in the ocean, where they connect divergent boundaries. One exception is the San Andreas Fault, which is mainly located on land. It separates the small divergent boundaries in Mexico (between the mainland and the Baja Peninsula) from the Juan de Fuca Ridge, and runs through continental crust for the majority of its length. The San Andreas Fault produces earthquakes when the plates slip, but it can also create ridges parallel to the fault, as well as mountains and valleys when the fault changes direction.

Earthquakes

Earthquakes occur when a critical amount of stress is applied to the crust. According to the elastic rebound theory, rocks can bend elastically up to a point, until they finally break. The rocks then snap apart, releasing energy in the form of **seismic waves** (Figure 10.2). The plane defined by the rupture is known as a fault, and the rock layers become offset along it. An excellent example of this kind of offset can be found along the San Andreas Fault at Point Reyes National Seashore. The Earthquake Trail, which begins at the Bear Valley Visitor Center, follows the trace of the 1906 San Francisco earthquake to a picket fence along the fault (Figure 10.3). The fence was once connected, but today it is separated by a 6-meter (20-foot) gap. Looking at the photo, one can visualize how the foreground moved to the left, while the background moved to the right. Although the San Francisco earthquake was quite large, most of the damage to the city was actually caused by a fire, which is a common secondary hazard of earthquakes.

Earthquakes

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

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

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

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

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

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



Earthquakes

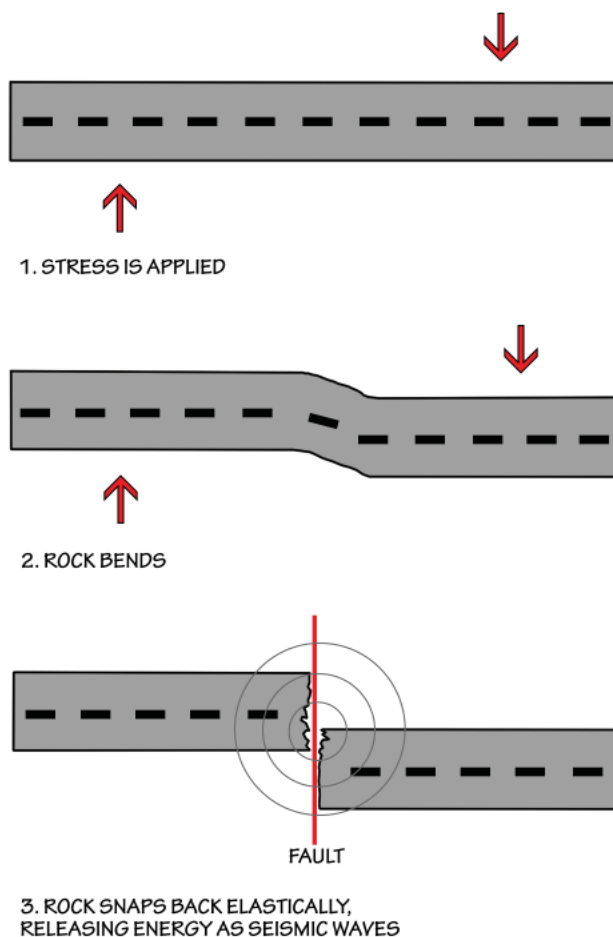


Figure 10.2: Elastic rebound.

There are two ways to measure 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, which measures the amplitude of a seismic wave at a defined distance from the earthquake. The Richter scale is somewhat limited, however, because it cannot accurately measure or compare large earthquakes. In 1979 Thomas C. Hanks and Hiroo Kanamori developed the Moment Magnitude scale, abbreviated M_w . Both the Richter scale and the Moment Magnitude scale use the numbers 1–10 to measure the amount of energy released. Although it is possible to have a magnitude smaller than 1, and there is technically no upper limit, this is the range commonly used when reporting earthquakes to the public. The United States Geological Survey (USGS) describes earthquakes as *minor* ($M3.0$ – 3.9), *light* ($M4.0$ – 4.9), *moderate* ($M5.0$ – 5.9), *strong* ($M6.0$ – 6.9), *major* ($M7.0$ – 7.9) and *great* ($M8.0$ or higher). These scales are logarithmic, meaning that a $M9.0$ earthquake would have 10 times the amplitude, and release 32 times the energy of a $M8.0$ earthquake. Accordingly, an $M9.0$ quake would have 100 times the amplitude and 1024 times the energy of a $M7.0$ earthquake. The largest earthquake in US history was the 1964 Alaskan Earthquake, which had an M_w of 9.2.



Earthquakes



Figure 10.3: The picket fence provides clear visual proof of the potential significance of this type of offset.

Notable Earthquakes of the Western States		
Date	Location	M_w
3-28-1964	Prince William Sound, AK	M9.2
1-26-1700	Cascadia subduction zone, OR, WA, CA	M9.0
2-4-1965	Rat Islands, AK	M8.7
3-9-1957	Andreanof Islands, AK	M8.6
11-10-1938	Shumagin Islands, AK	M8.2
4-1-1946	Unimak Island, AK	M8.1
9-11-1899	Yakutat Bay, AK	M8.0
11-3-2002	Denali Fault, AK	M7.9
1-9-1857	Fort Tejon, CA	M7.9
4-18-1906	San Francisco, CA	M7.8
2-24-1892	Imperial Valley, CA	M7.2
6-28-1992	Landers, CA	M7.3
1-17-1994	Northridge, CA	M6.7

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Earth Hazards

Earthquakes

The magnitude of an earthquake does not tell us how much damage is done by the waves in a particular area. 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.*” The MMI scale is a subjective gauge compared to the Moment Magnitude scale. The USGS has attempted to improve the accuracy of MMI shake maps by soliciting data from the public. *Figure 10.4* shows the intensities felt by the 1964 Great Alaskan Earthquake (when data were collected through mail questionnaires). Today, after experiencing an earthquake, anyone may go to the USGS earthquake website and describe the effects at the “Did You Feel It?” page.

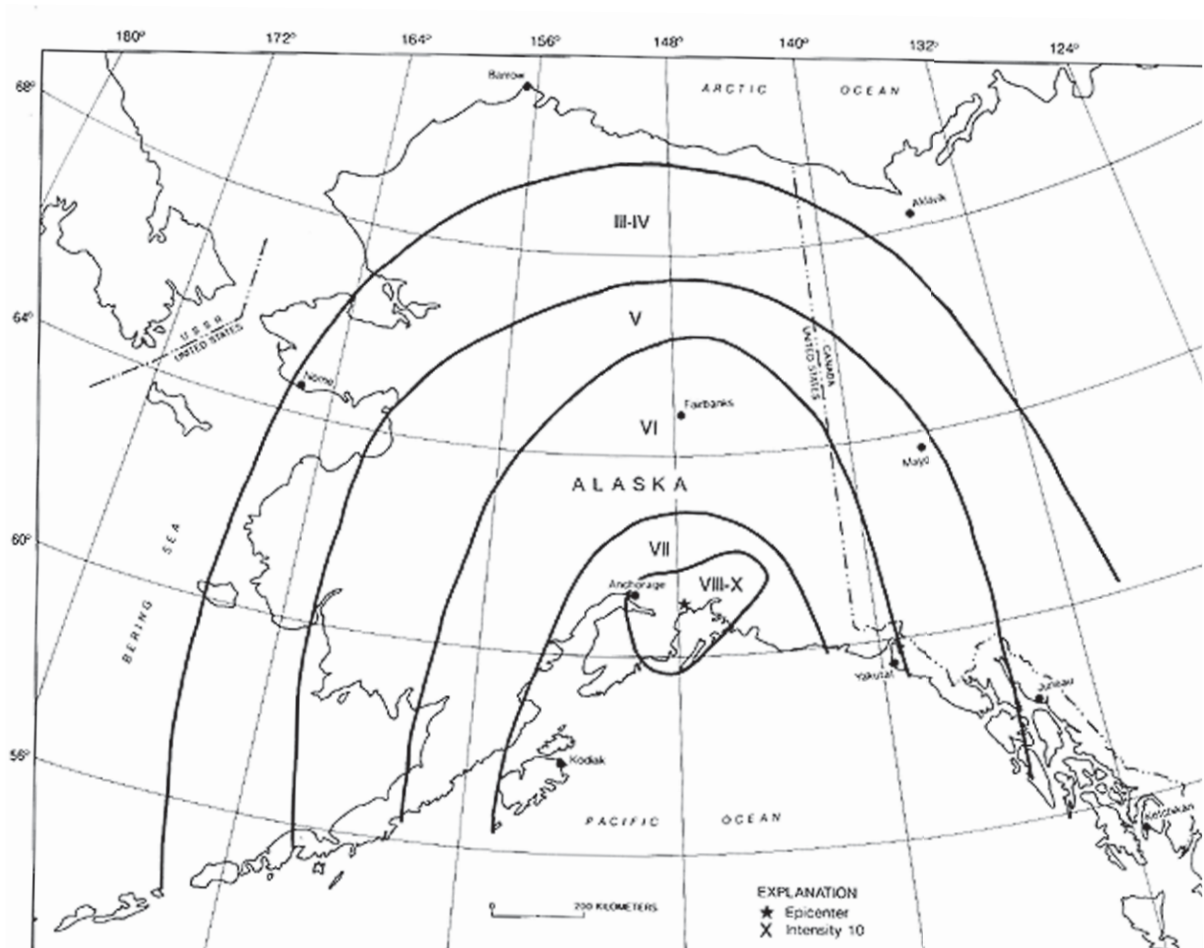


Figure 10.4: Intensity map of the 1964 Great Alaskan Earthquake.



Alaska has more earthquakes than all of the other states combined. California is second, with only about half as many as Alaska. The following table lists the number of earthquakes of M3.5 or greater from 1974 to 2003, according to the USGS Earthquake Hazards Program.

Alaska	12,053
California	4895
Hawai'i	1533
Nevada	778
Washington	424
Idaho	404
Wyoming	217
Montana	186
Utah	139
Oregon	73

Cascadia

Although Washington and Oregon have not experienced many major earthquakes in the recent past, they are located above the Cascadia subduction zone (Figure 10.5). Since the Cascadia subduction zone is as large as the subduction zone that created the 2004 Sumatra Earthquake and subsequent

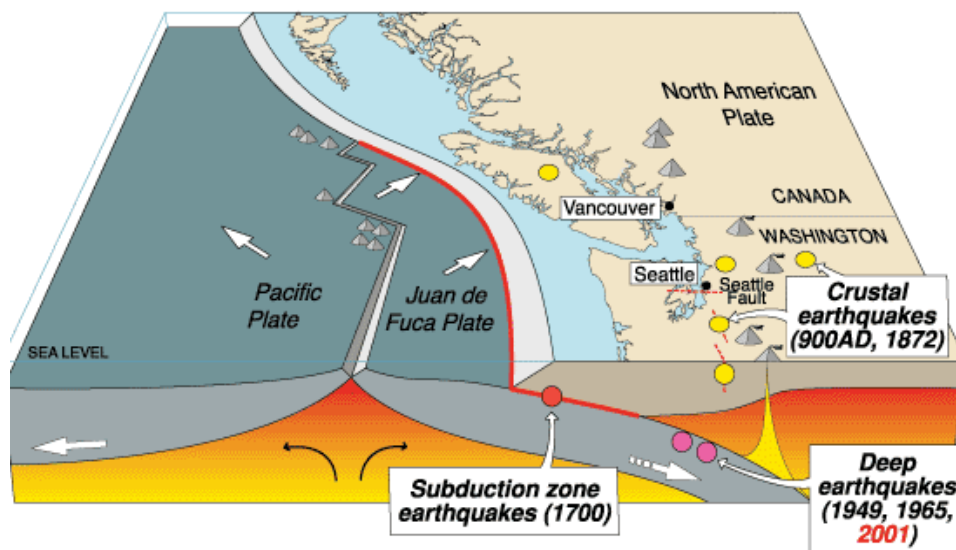


Figure 10.5: The Cascadia subduction zone and its related seismic occurrences.



Tsunamis

landslide • the rapid slipping of a mass of earth or rock from a higher elevation to a lower level under the influence of gravity and water lubrication.

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

tsunami, it could potentially generate an M8.0 or higher earthquake. It did just that in the year 1700, when the tip of the overriding plate (North America), which had been buckling upward under the stress of the ongoing collision, flattened out when the plates suddenly slipped past one another. The resulting earthquake caused the submergence of coastal land and the drowning of cedar forests along 965 kilometers (600 miles) of California, Oregon, Washington, and southern British Columbia. Places formerly above sea level dropped down, pushing enormous waves all the way across the ocean, and creating a tsunami that struck Japan. Written records of the damage to Japan's coastal villages allow us to pinpoint the day and time this earthquake occurred—the evening of January 26, 1700.

If the Cascadia subduction zone were to partially rupture today, it could create an M8.2 earthquake, and if it were to rupture along its entire length, it could generate an M9.0 earthquake. Geologists have recently forecast a 37% chance of an M8.2 or higher event within 50 years, and a 10–15% chance of an event of M9.0 or higher. Unlike Alaska, which had a population of only 763,000 in 2013, Washington and Oregon have a combined population of over 10 million people, most of whom live near the coast. Needless to say, Cascadia inhabitants would benefit greatly by preparing for a large earthquake and tsunami.

San Andreas

The San Andreas Fault, a 1304-kilometer (810-mile) long plate boundary (*Figure 10.6*), is not a single fault but a fault zone because it does not move all at once. Instead, great lengths of the fault rupture while other sections remain locked. Some sections do neither, but instead creep along without generating significant earthquakes.

Southern California is particularly susceptible to a devastating earthquake, in part because it has been so long since a major or great quake has occurred. Over 150 years ago, the M7.9 Fort Tejon earthquake caused 360 kilometers (225 miles) of the San Andreas Fault to rupture. The southernmost section of the San Andreas has not ruptured in the last 300 years. In response to this growing hazard, geologists have created a “Great ShakeOut” earthquake scenario. This scenario models the effects of a M7.8 earthquake on a 300-kilometer (180-mile) rupture from Bombay Beach at the Salton Sea to Lake Hughes north of Los Angeles. Both the Fort Tejon segment and the southernmost segment of the San Andreas fault zone are considered at risk for a major earthquake at any time, and either one could generate an earthquake that would wreak havoc on the lives of the 23 million inhabitants of Southern California. Earthquake preparedness drills based on this scenario have been taking place in southern California since 2008, and they attract millions of participants every year.

Tsunamis

A tsunami is a series of ocean waves that are generated by the sudden displacement of water. Although earthquakes are the most common cause, tsunamis may also be generated by **landslides**, **volcanic** explosions, meteor



Figure 10.6: San Andreas Fault and associated seismic zones.
(See TFG website for full-color version.)

Tsunamis

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

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

calving • when ice breaks off from the end of a glacier.

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

impacts, **nuclear** explosions, and **glacier calving**. Unlike a **wind**-generated sea wave, a tsunami wave has an extremely long wavelength. A very large wind-generated wave might have a wavelength of 200 meters (650 feet), but a typical tsunami has a wavelength of 200 kilometers (120 miles). Incredibly, tsunamis can travel at 800 kilometers per hour or kph (500 miles per hour or mph) in the open ocean.

Although tsunamis have extremely long wavelengths, while at sea they have only minimal height. In fact, ships in the open ocean may never notice the passing of a tsunami wave. As the wave approaches shore, however, the wavelength decreases and the wave height (amplitude) increases (*Figure 10.7*) as the water “piles up” upon reaching shallower depths. Even a tsunami with a moderate wave height can do great damage, however, because the great wavelength means it may take a single wave 20 to 30 minutes to sweep up the shore. Such waves resemble a wall of water more than a simple breaking wave (*Figure 10.8*).



Tsunamis

tree • any woody perennial plant with a central trunk.

extinction • the end of species or other taxonomic groups, marked by death of the last living individual.

dinosaur • a member of a group of terrestrial reptiles with a common ancestor and thus certain anatomical similarities, including long ankle bones and erect limbs.

The tallest wave ever recorded occurred in Lituya Bay, located along the Alaskan Panhandle. On the night of July 9, 1958, a M8.5 earthquake initiated a landslide. Thirty million cubic meters (forty million cubic yards) of rock plunged into the bay, creating a local tsunami that destroyed all **trees** and vegetation up to a height of 524 meters (1720 feet) above the bay. Unusually high tsunamis

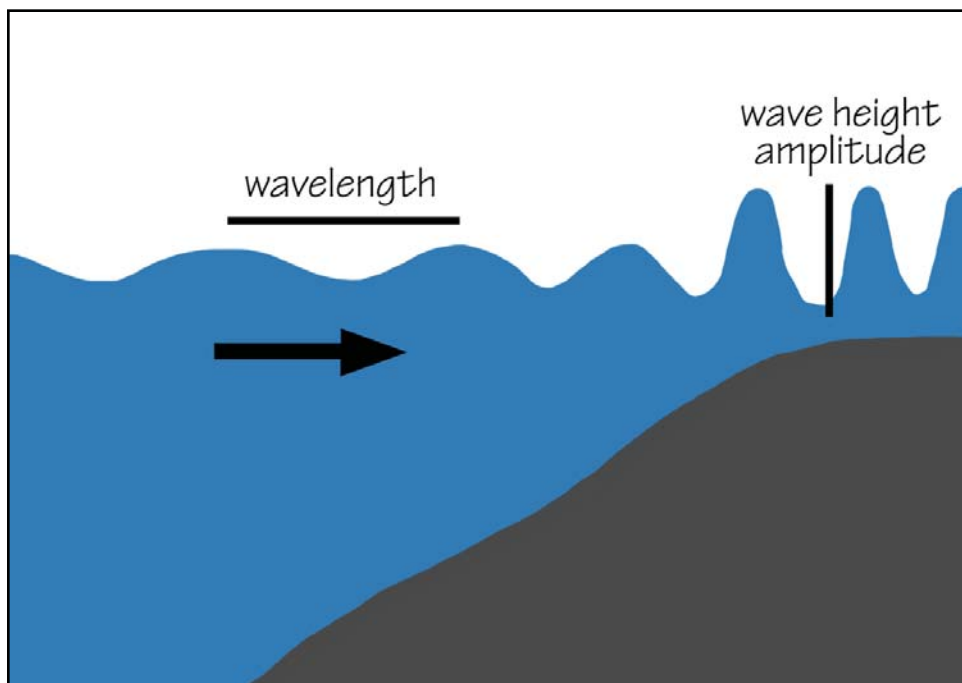


Figure 10.7: Changes to a tsunami wave as it approaches the shore.

are referred to as *megatsunamis*. This category includes landslide-generated tsunamis as well as tsunamis generated by a meteor impact, such as the meteor that struck 66 million years ago, causing the **extinction** of the **dinosaurs**. The height of the wave caused by that impact is estimated to have been as much as 5 kilometers (3 miles) high!

Often the trough of a wave will arrive before the crest, making it appear as if the sea is retreating. This strange sight might give residents time to escape before the crest arrives, if they recognize that the drawdown is a warning sign and not just the tide going out very quickly. The shape of a bay or harbor can accentuate the effects of a tsunami, funneling the wave's energy inland—such was the case in Crescent City, California, after the Great Alaskan Earthquake of 1964. The earthquake created a tsunami that arrived at Crescent City four hours later. Although the first three waves did only minor damage, the fourth wave, approximately 6 meters (20 feet) tall, inundated the town, killing 12 residents and injuring over 100, and destroying hundreds of buildings. Forty-seven years later, Crescent City was once again struck by a tsunami, this time from the 2011 M9.0 Tohoku-Oki Japan earthquake. Fortunately, there was only



Tsunamis

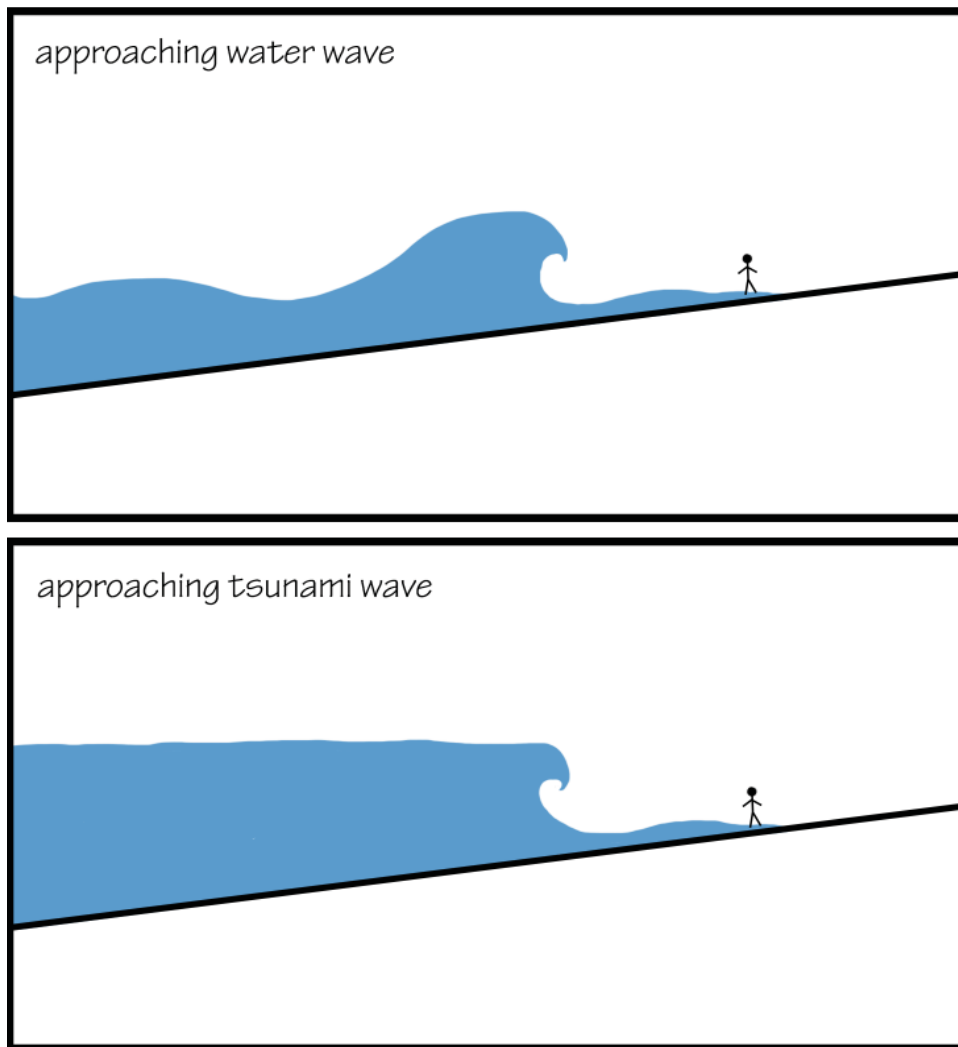


Figure 10.8: The difference between normal water waves and tsunami waves as they approach the shore.

one death because at-risk areas of the city were evacuated before the arrival of the first wave.

The West Coast of North America is prone to tsunamis because of the seismically active “Ring of Fire” around the Pacific Ocean. The National Oceanic and Atmospheric Association’s (NOAA’s) Pacific Tsunami Warning Center has created a tsunami warning system based upon earthquake data and real-time tsunami detectors in the deep ocean. If a tsunami is generated at a distance, residents of coastal communities can be warned so that they can follow established tsunami evacuation routes to high ground (*Figure 10.9*). If, however, a tsunami is generated just offshore, there is not enough time for a warning, as was the case for coastal Japan with the 2011 M9.0 earthquake and associated tsunami.



Landslides

megathrust • powerful earthquakes occurring at subduction zones, where one plate is forced beneath another.

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

creep • the tendency of a material to move slowly or deform under the influence of pressure or stress.

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

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

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.



Figure 10.9: A typical tsunami evacuation route sign.

The Japan 2011 and Alaskan 1964 earthquakes are good examples of **megathrust** earthquakes that are likely to create tsunamis. As one tectonic plate tries to subduct below another, the two plates can become stuck together. The pressure from the subducting plate builds up and deforms the overlying plate by causing it to buckle (Figure 10.10). When the subducting plate finally moves, the overlying plate snaps back, **uplifting** the ocean and creating a tsunami. Not only could this happen along the Aleutian Island Arc's trench, it could happen again along the Cascadia subduction zone. The location of the trench, just offshore of northern California, Oregon, and Washington, is likely to give coastal residents little time for evacuation.

Landslides

The generic term “landslide” refers to a wide range of mass wasting events during which rock material moves downhill. The rugged **topography** of the Western US makes landslides a common problem. Landslides are usually triggered by high rainfall, but they can also be triggered by earthquakes, erosion, deforestation, groundwater pumping, and volcanic eruptions. Not all mass wasting events are rapid—slow land movement, known as **soil creep** (Figure 10.11), usually does not cause loss of life, but it can still destroy roads and buildings. Mud and **debris flows** are very fast landslides that are likely to kill anyone unfortunate enough to be caught in their path, as they can reach speeds that exceed 32 kph (20 mph).



Landslides

The slowest kind of landslide is known as **creep**. When **clay** in the **soil** on a hillside absorbs water, it will expand, causing the soil to swell. As the clay dries and contracts, the particles settle slightly in the downhill direction. The process causes fences and telephone poles to lean downhill, while trees adjust by bending uphill (Figure 10.11).

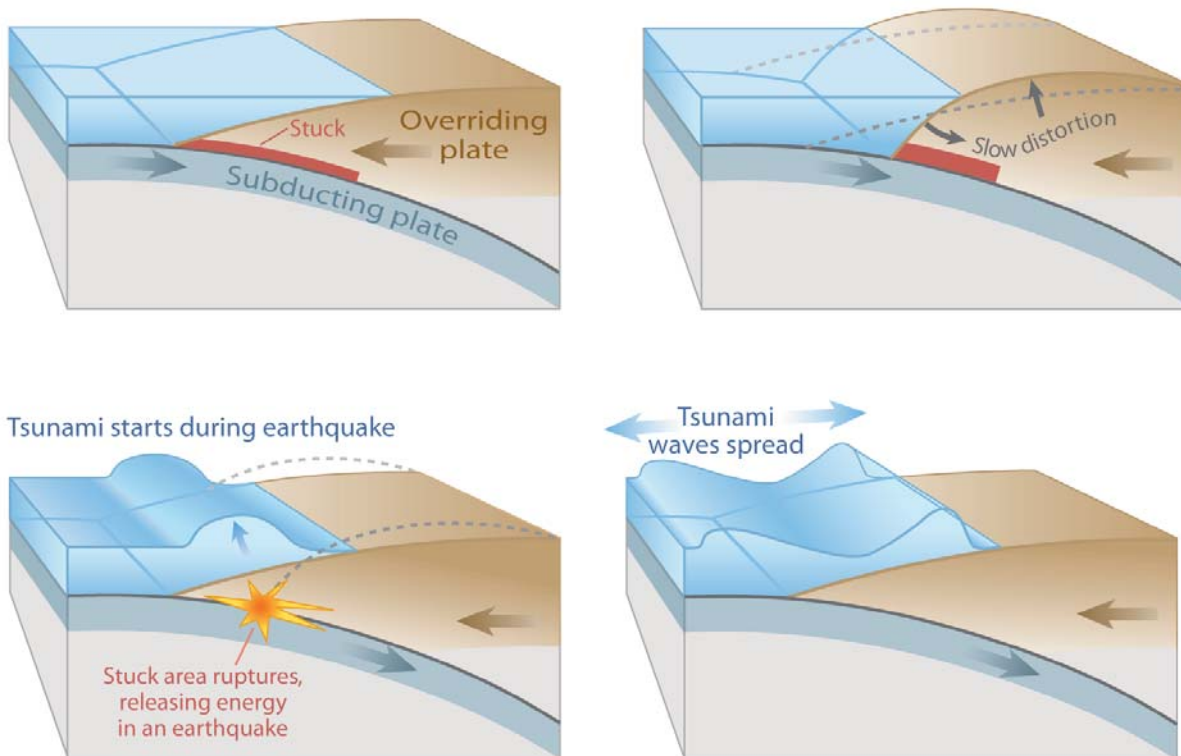


Figure 10.10: The steps involved in a megathrust earthquake and tsunami.

The Arctic tundra of Alaska is experiencing an unusual form of creep called **solifluction**. During the summer, rain passes through the thawed upper layer of the soil but cannot penetrate the **permafrost** below. Instead, the water builds up against the **impermeable** permafrost. As a result, the water and soil move slowly downhill like thick porridge.

The Pacific Northwest is particularly prone to landslides because of its high levels of rainfall. The most damaging landslide in recent history was the March 22, 2014 Hazel mudslide in Oso, Washington. The Hazel landslide has been active for over 60 years, causing numerous smaller slides—the March 22 slide came from a high **terrace** made of a poorly **cemented** layer of glacial **sand** and **gravel**. After a period of extremely high rainfall, a section of the terrace collapsed into a fast-moving mudflow that engulfed 49 homes and took 41 lives. Incredibly, most of the homes were located across a river from the terrace, on a bluff nine meters (30 feet) above the river.

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

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

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



Landslides

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

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).

lahar • a pyroclastic debris flow or mudflow that typically flows down river valleys after a volcanic eruption.

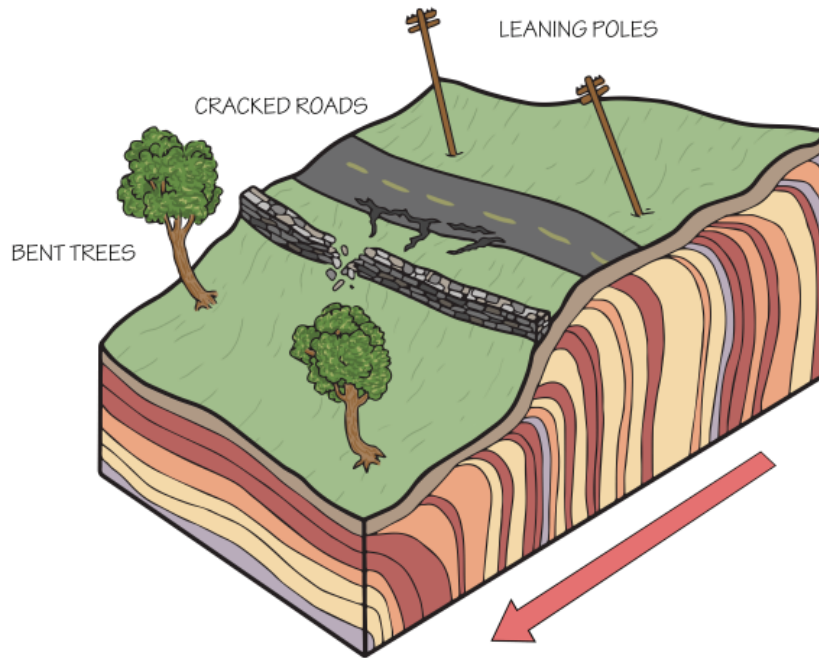


Figure 10.11: The effects of soil creep.

The coastal erosion of hillsides often results in landslides. Portuguese Bend on California's Palos Verdes Peninsula contains layers of rock that slope towards the ocean. Among these layers is **bentonite**, a very slippery clay layer. In the 1950s, houses were built on an area that soon started to slide once the city, in the process of road construction, had added material to the top of the slope. Although homeowners successfully sued the city for initiating the slide that destroyed their homes, they were also partially responsible since they added water to the slide by irrigating their lawns and using septic tanks. The land is still moving, and no houses can be built there.

Debris flows are a dangerous mixture of water, mud, rocks, trees, and other debris that move quickly down valleys (Figure 10.12). The flows can result from sudden rainstorms or snowmelt that creates flash floods. Areas that have experienced a recent wildfire are particularly vulnerable to debris flows, since there is no vegetation to hold the soil. El Niño **climate** conditions, which bring high precipitation, also increase the danger of debris flows. In response to these dangerous slides, many communities have built debris basins across their canyons to protect houses downstream (Figure 10.13). The USGS and NOAA are in the process of instituting a flash flood and debris flow early-warning system.

One of the most dangerous kinds of debris flow is a **lahar**, which is composed of water and volcanic debris such as ash. An eruption is not necessary to trigger a lahar. A melting glacier, a debris dam being breached, or a crater lake's walls collapsing can all send water and ash down the volcano at speeds up to 100 kph (60 mph). Mt. Rainier in Washington is considered the most dangerous volcano



Landslides



Figure 10.12: This debris flow occurred on February 6, 2010 in La Canada-Flintridge, California as a result of a flash flood generated in Mullally Canyon.



Figure 10.13: This debris basin in Los Angeles county is designed to capture the sediment, boulders, and other debris washed from the canyon during a storm.



Volcanoes

in the United States because of its proximity to high populations and its potential for lahars (*Figure 10.14*). The Puyallup River valley, directly downstream of the mountain, is built upon 500-year-old lahar deposits. The town of Orting is at the junction of two river valleys that descend from Mt. Rainier, making them capable of delivering a lahar. Since lahars are predicted to flow through the valley every 500 to 1000 years, the USGS has set up a lahar warning system to give people enough time to evacuate in the event of a lahar racing down the flanks of Mt. Rainier.

Volcanoes

Located along the Pacific Ring of Fire, the Western US contains many volcanoes. As can be seen in the table below, Alaska has the most volcanoes, most of which are found along the Aleutian Island Arc as a result of Pacific plate subduction. California, Washington, and Oregon contain the Cascade Range's volcanoes, which result from the subduction of the Juan de Fuca plate. All of the Cascade and Aleutian volcanoes are considered to be either active or dormant, which means they are capable of becoming active. Volcanic eruptions in the Cascades have been occurring for over 500,000 years, and have taken place at an average rate of two eruptions per century for the past 4000 years (*Figure 10.15*)

State	# of volcanoes
Alaska	97
Oregon	43
California	23
Hawai'i	17
Washington	16
Idaho	10
New Mexico	10
Arizona	7
Nevada	5
Utah	5
Colorado	3
New Hampshire	2
Virginia	2
Wyoming	1
Texas	1
South Dakota	1
Missouri	1
Mississippi	1

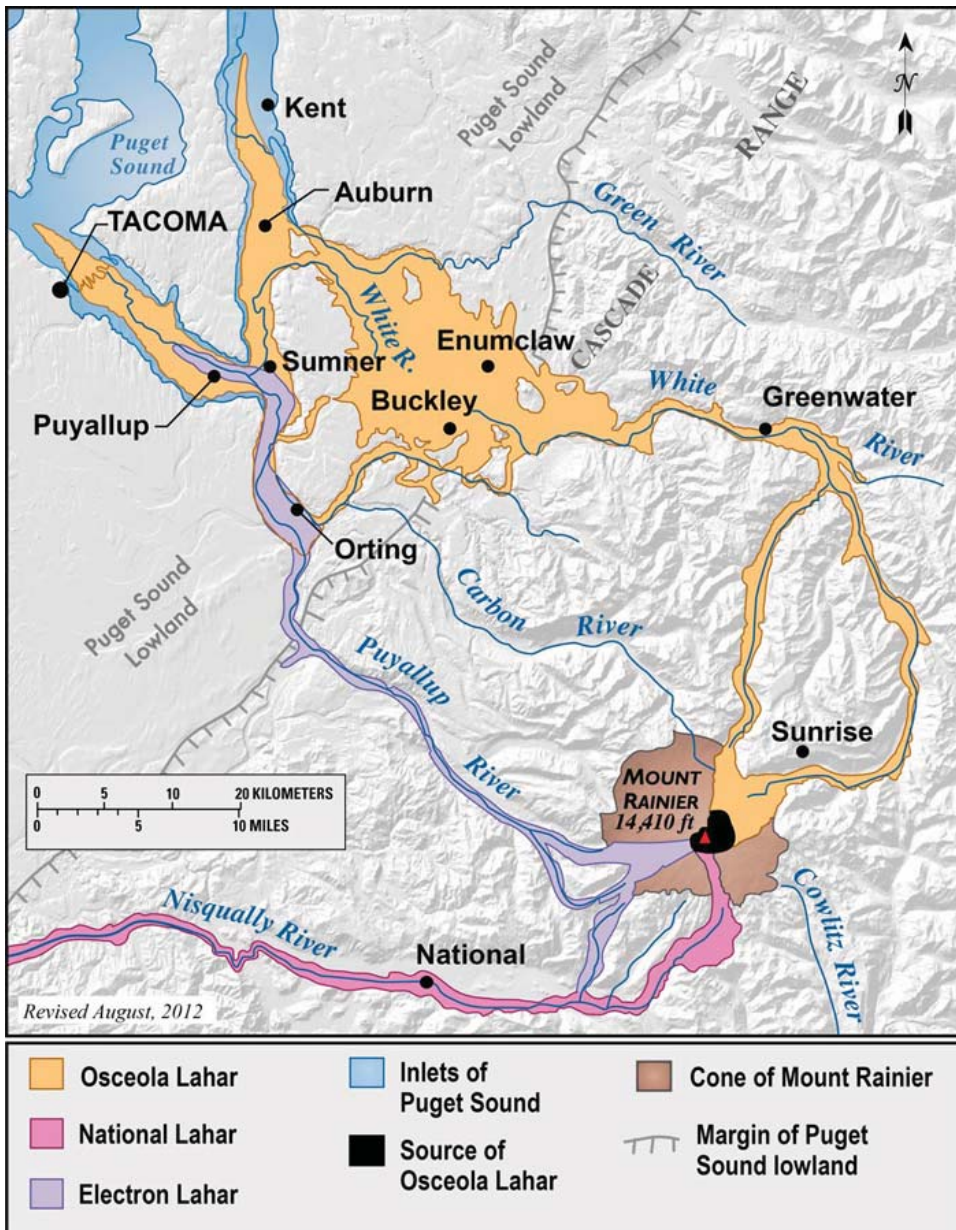


Figure 10.14: Lahar paths of Mt. Rainier. This map shows three major events that occurred in the last 10,000 years. Note how the lahars follow the river valleys. (See TFG website for full-color version.)

Volcanoes

stratovolcano • a conical volcano made up of many lava flows as well as layers of ash and breccia from explosive eruptions.

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

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

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

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

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

The vast majority of volcanoes formed by subduction are **stratovolcanoes**, also known as composite volcanoes. Stratovolcanoes are built from the eruption of **andesitic** magma, which forms as the mantle above the subducting plate melts. This magma is viscous because of its high **silica** content, making it capable of trapping gasses and producing explosive eruptions. Stratovolcanoes eventually become layered with **lava** flows, **pyroclastics**, rock, and **volcanic ash** fragments ejected by an explosive eruption. They tend to be tall and cone-shaped, as can be seen in the picture of Augustine Volcano (Figure 10.16), located 300 kilometers

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Earth Hazards

Volcanoes

(186 miles) southwest of Anchorage, Alaska. When this volcano erupted in 1986, ash from an 11-kilometer (7-mile) high ash plume drifted over the Cook Inlet and grounded air traffic in Anchorage.

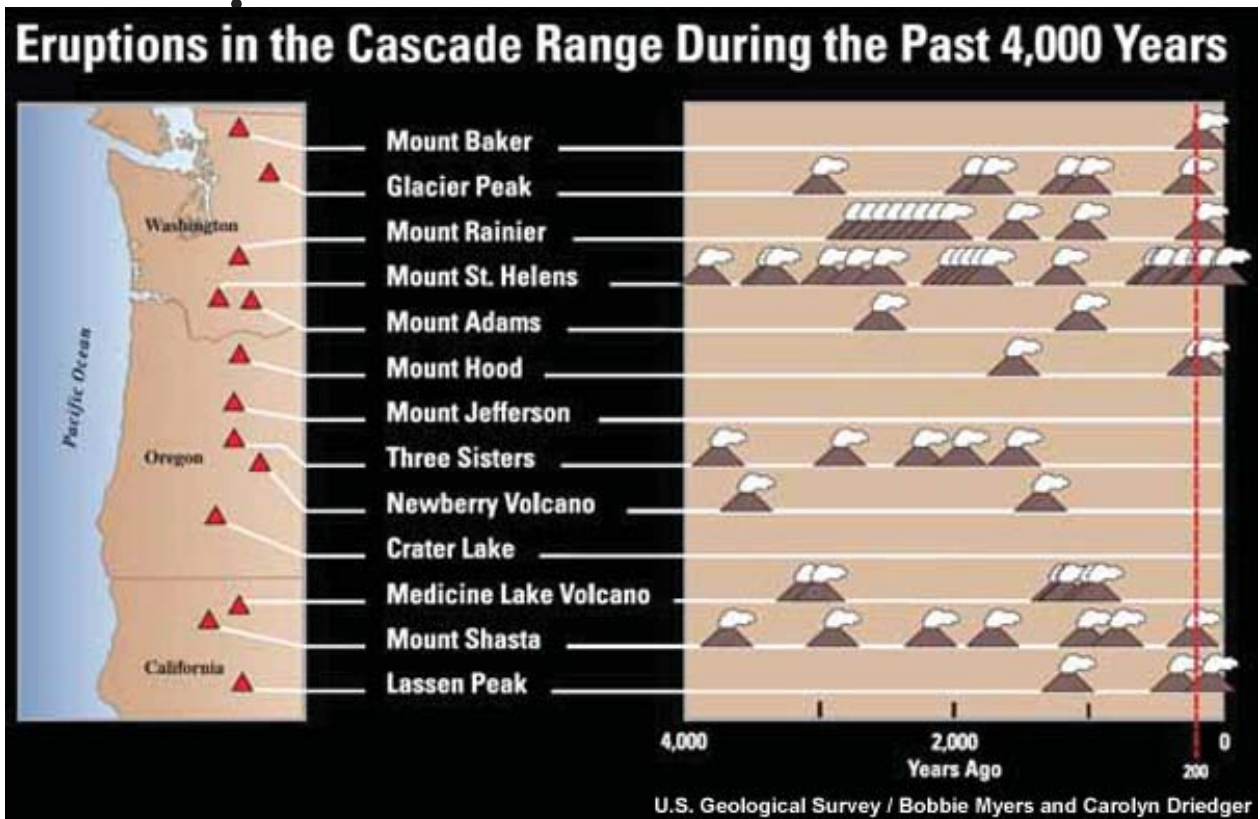


Figure 10.15: The eruptive history of the Cascade volcanoes.

Katmai National Park in Alaska is the site of the most powerful volcanic eruption in US history. In 1912, 13 cubic kilometers (3.1 cubic miles) of ash erupted from a vent on the side of Mt. Katmai. The ash completely filled a valley, which became known as the Valley of Ten Thousand Smokes for its many smoking fumaroles. The top of Mt. Katmai collapsed 1200 meters (3900 feet), creating an enormous **caldera**. After the explosive eruption, viscous **rhyolitic** lava pushed up from the vent, creating a volcanic dome, now known as Novarupta, which means “new volcano” (Figure 10.17).

Mt. Saint Helens is the most active volcano in the Cascade Range. Its most spectacular eruption occurred on May 18, 1980, when an earthquake shook the side of the mountain, triggering the largest landslide ever recorded. An explosive blast issued from the side of the mountain, reaching speeds up to 480 kph (300 mph) as it flattened forests in its path. Avalanches of hot ash and **pumice** called *pyroclastic flows* sped quickly down the side of the volcano and spread for miles. The volcano’s rapidly melted glaciers created lahars that took



Volcanoes



Figure 10.16: Augustine Volcano.

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

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

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

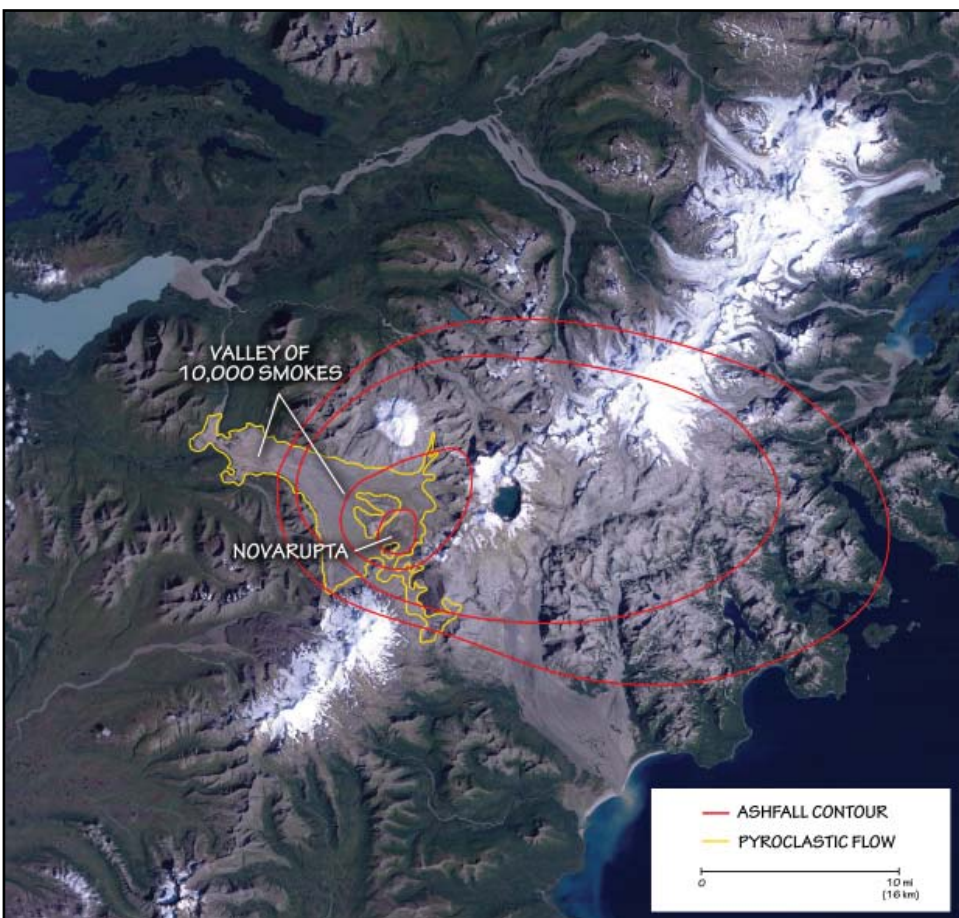


Figure 10.17: Novarupta and associated ashfalls. (See TFG website for full-color version.)



Volcanoes

out 27 bridges and 200 homes. Despite evacuations in the weeks leading up to the eruption, 57 people died during the explosion. It was the deadliest and most costly volcanic event in US history. Mt. Saint Helens continues to be active, and it has built a lava dome inside its crater.

The Long Valley Caldera of California (*Figure 10.18*) was the site of a colossal eruption 760,000 years ago. The eruption created the Bishop Tuff ash layer (deposits of which cover an area nearly 2200 square kilometers [850 square miles] in size), and is estimated to have released 600 cubic kilometers (145 cubic miles) of ash, compared to the 1.2 cubic kilometers (0.3 cubic miles) of ash that was emitted by Mt. Saint Helens. There is still no good explanation for the basaltic and rhyolitic magmas that underlie the area, since there is no associated hotspot or subducting plate. There are many related volcanic features in the area, including Mammoth Mountain (a ski resort that sits atop a lava dome complex), Panum Crater (a rhyolitic lava dome), and numerous hot springs such as Hot Creek, which is located on a resurgent dome in the center of the caldera.

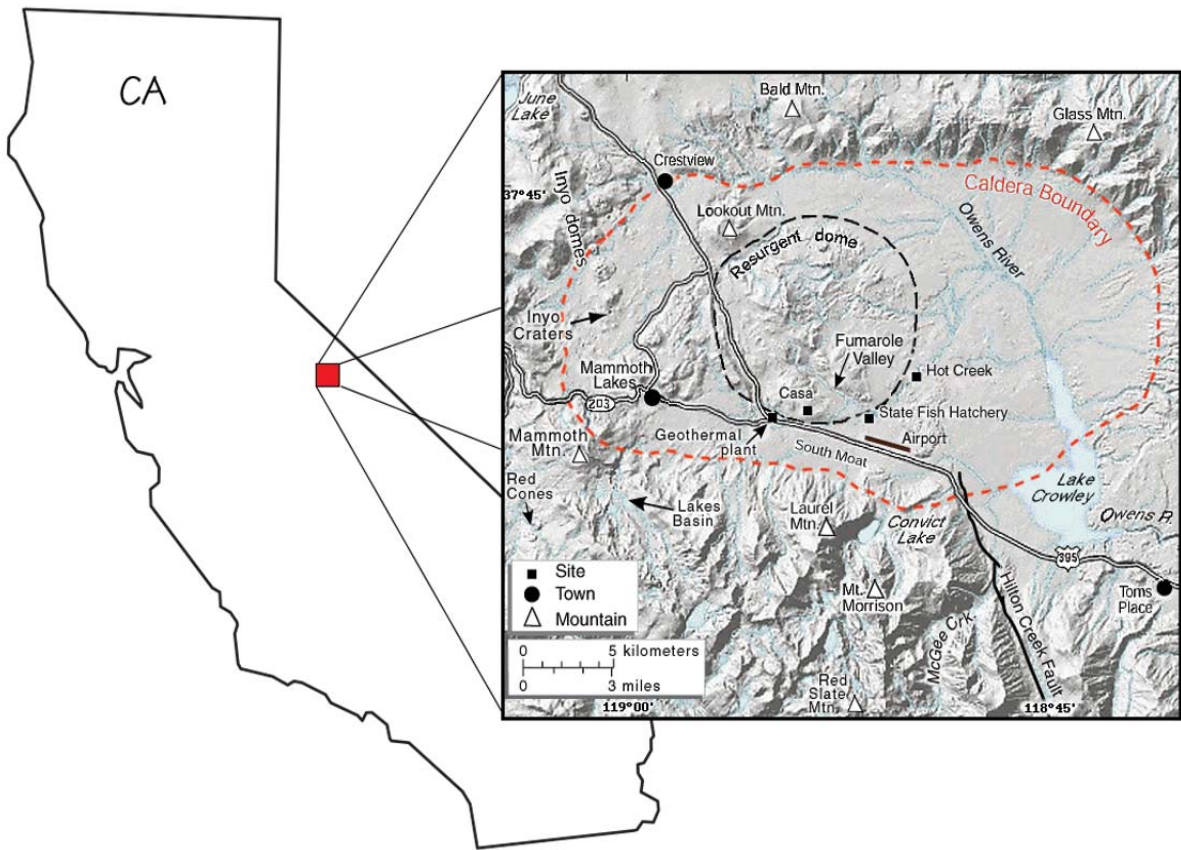


Figure 10.18: Extent and location of the Long Valley Caldera. (See TFG website for full-color version.)



Volcanoes

The Mojave Desert is dotted with **scoria** cones and their associated basaltic lava flows. Scoria cones, also known as cinder cones, form as basaltic lava spews into the air and falls back onto the ejection site. The lava cools so quickly that volcanic gases become trapped in it as bubbles called **vesicles**. Scoria cones are small, steep, and short-lived. Amboy Crater and the Cima volcanic field of the Mojave National Preserve are excellent examples, among which the youngest scoria cone is only 10,000 years old. The Boring Lava Field, located near Portland, Oregon is an extinct lava field with 32 scoria cones (*Figure 10.19*). Scoria cone landscapes may appear ominous, but their effects are local, and they rarely cause a hazard to humans.



Figure 10.19: Beacon Rock is part of the Boring Lava Field in Oregon. It is the central core of a cinder cone whose outer layers were stripped away 57,000 years ago by the Missoula Floods.

scoria • a highly vesicular form of basalt.

hydrothermal solution • hot, salty water moving through rocks.

shield volcano • a volcano with a low profile and gradual slope, so named for its likeness to the profile of an ancient warrior's shield.

The USGS constantly monitors volcanoes in Alaska, California, Hawai'i, Oregon, and Washington, as well as the Yellowstone area in Wyoming. Although the exact timing of a volcanic eruption is difficult to predict, there are many signs that a volcano is becoming active. Volcanologists on the watch for eruptions look for earthquake swarms, changes in the level of the land, changes in **hydrothermal** activity, and changes in the gases emitted by the suspect volcano. Because ash plumes can destroy jet engines in less than a minute, the USGS also issues warnings for aviation. Luckily, the most active volcanoes in the United States are either in Alaska, far from population centers, or in Hawai'i, where **shield volcanoes** erupt without significant explosions or loss of life.



Hawai'i

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

water table • the upper surface of groundwater.



Natural Hazards in Hawai'i

The Hawaiian Islands are vulnerable to many of the same environmental hazards that are a cause for concern anywhere on Earth, and also to a few that are particular to the residents of Hawai'i. As both a coastal region and an active volcanic area, hazards associated with oceanic and volcanic processes and their related effects are of greatest concern.

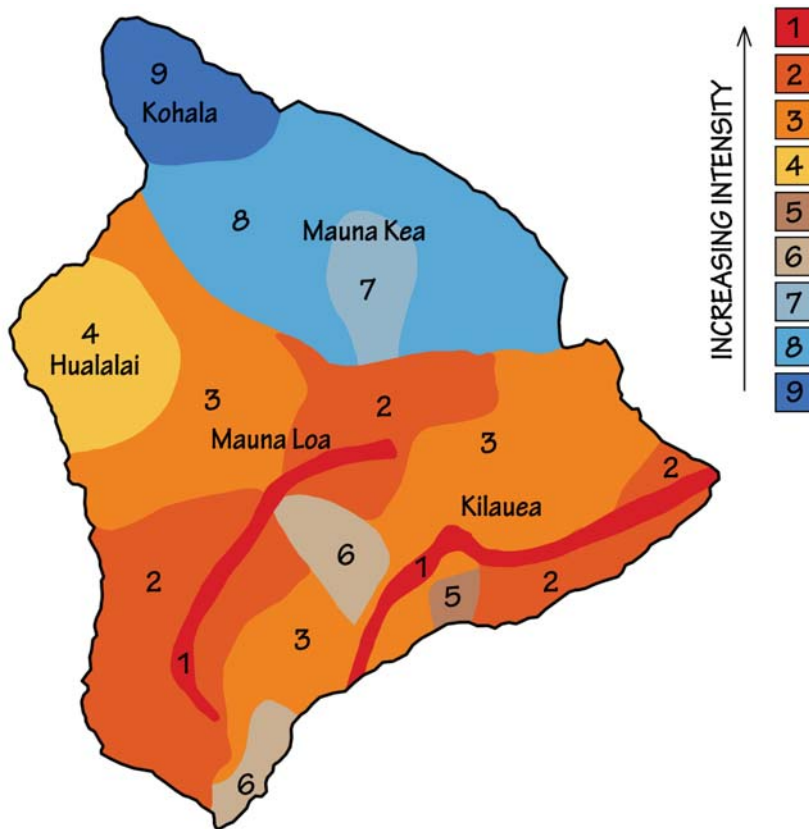
Four main hazards characterize the Hawaiian Islands:

- Volcanic eruptions
- Earthquakes
- Tsunamis
- Floods and coastal hazards

Volcanic Eruptions

Volcanic hazards include lava and ash eruptions, and the emission of corrosive volcanic gasses. The Hawaiian volcanoes erupt basaltic magma, which is characterized by low-viscosity—and therefore highly fluid—lava flows. These flows are often channelized, allowing them to move over long distances at relatively high speed (10s of kph [mph]), but affecting a well-defined and narrow zone (*Figure 10.20*). Hawaiian lava flows pose little hazard to human life. However, structures or other immobile features (such as roads, agricultural areas, or other types of infrastructure) are often the victims of lava flows (*Figure 10.21*). As of 2011, the ongoing eruption of Kīlauea produced 3.5 cubic kilometers (1 cubic mile) of lava, covered 123 square kilometers (48 square miles) of land, added 206 **hectares** (509 acres) of land to Hawai'i Island, destroyed 213 structures, and buried 14 kilometers (9 miles) of highway. Historically, Kīlauea's neighbors Mauna Loa and Hualālai have also experienced rapid, high-volume eruptions that would pose a hazard to the modern, more densely populated and urbanized flanks of these volcanoes today.

Occasionally, Hawaiian volcanoes erupt explosively. Kīlauea has had three explosive eruptive events in the last 100 years (1924, 2008, 2011) and six others in the last 1500 years. Although still gentle on the scale of global volcanism, these explosive eruptions are capable of blanketing large areas of Hawai'i Island with ash and pyroclastic debris. When there is an unusual buildup of pressure within the magmatic plumbing system, an explosive eruption can result. Hawaiian volcanologists believe that the most common cause of explosive eruptions is the interaction of magma with groundwater. At Kīlauea this occurs when the floor of the summit caldera subsides to a depth near the **water table**: currently about 500 meters (1640 feet) below the surface. The most dangerous type of explosive behavior is a *pyroclastic surge*. Ash and volcanic gases race along the surface at extreme speed, with temperatures of several hundred degrees Celsius. The most recent pyroclastic surge from Kīlauea was in 1790, when a number of Hawaiians were overcome and killed. The estimated number of fatalities is between 80 and 5000; even the lower figure makes this the most deadly eruption in US history.



Hawai'i

Figure 10.20: USGS Hawaiian Volcanoes Observatory map of Lava Flow Hazard Zones on Hawai'i Island. (See TFG website for full-color version.)



Figure 10.21: Remains of Waha'ula Visitor's Center in Hawai'i Volcanoes National Park.





Hawai'i

trade winds • a major tropical wind system, involving the flow of high-pressure subtropical air to the low-pressure equatorial zone.

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

aerosol • tiny solid or liquid particles in the air.

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



Some large explosions from Kīlauea's summit in the past have sent eruption clouds so high that they entered the west winds of the jetstream. As a result, their ash deposits were dispersed mainly in easterly directions. This is known to have occurred during explosive eruptions in 850–950 CE, about 1650 CE, and in 1790 CE. By contrast, the spectacular lava fountains of the 1959 eruption, the largest in the past 200 years, only sent material some hundreds of feet into the air, where it was dispersed to the southwest by the prevailing low-level *trade winds*. Although the on-land extent of the ash deposits is fairly well known, all the ash layers extend offshore for unknown distances.

Throughout a volcano's period of activity, it also emits a suite of volcanic gases. At Kīlauea and Mauna Loa—Hawai'i's two most active volcanoes—the main gas plume components are water vapor, carbon dioxide, and **sulfur** dioxide (SO₂). Of these, SO₂ is of the greatest concern. Sulfur dioxide can react with water in the atmosphere to form sulfuric acid, and it reacts with sunlight and **aerosols** to form volcanic smog, or “vog.” Vog has been a problem throughout Kīlauea's eruption from 1983 to present, with especially elevated levels since activity returned to the summit in 2008 (*Figure 10.22*). In the post-2008 eruption period, emissions of SO₂ averaged 4000–6000 metric tons per day. This is a threat to people with respiratory ailments, and it also causes damage to agricultural crops in areas downwind of the summit eruption.

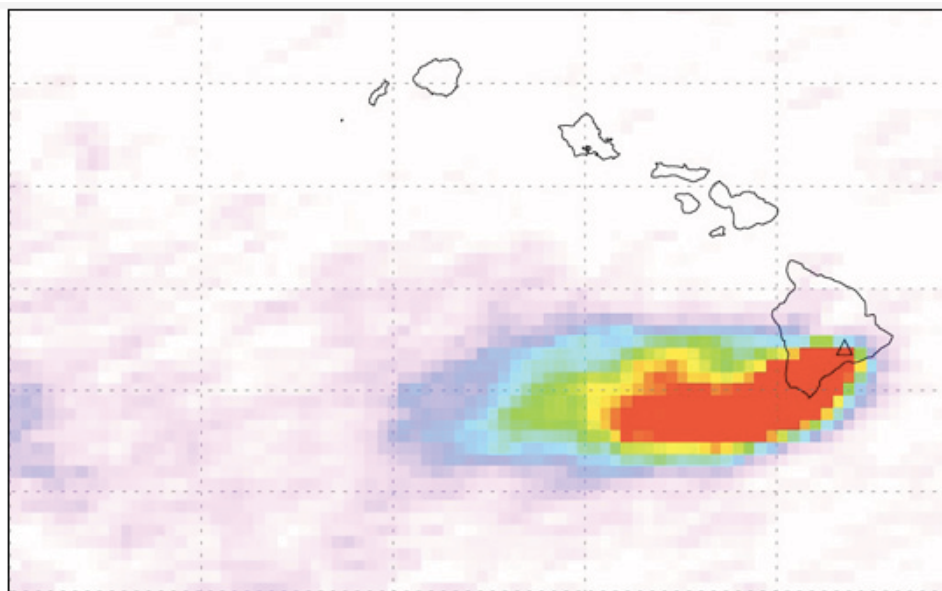
In order to understand volcanism and minimize volcanic hazards, the USGS has operated the Hawaiian Volcanoes Observatory on Kīlauea volcano since 1912. Volcanologists make visual observations and monitor ground deformation, seismicity, magma chemistry, and gas emissions in order to detect changes in volcanic behavior prior to an eruptive event. Hawaiian volcanoes commonly show clear precursors that signal the start of a new eruptive phase: most often an inflation of the volcano's summit and increased seismicity beneath the volcano. The state of Hawai'i has a robust civil defense warning system for volcanic (and other) hazards that alerts residents to potential threats.

Earthquakes

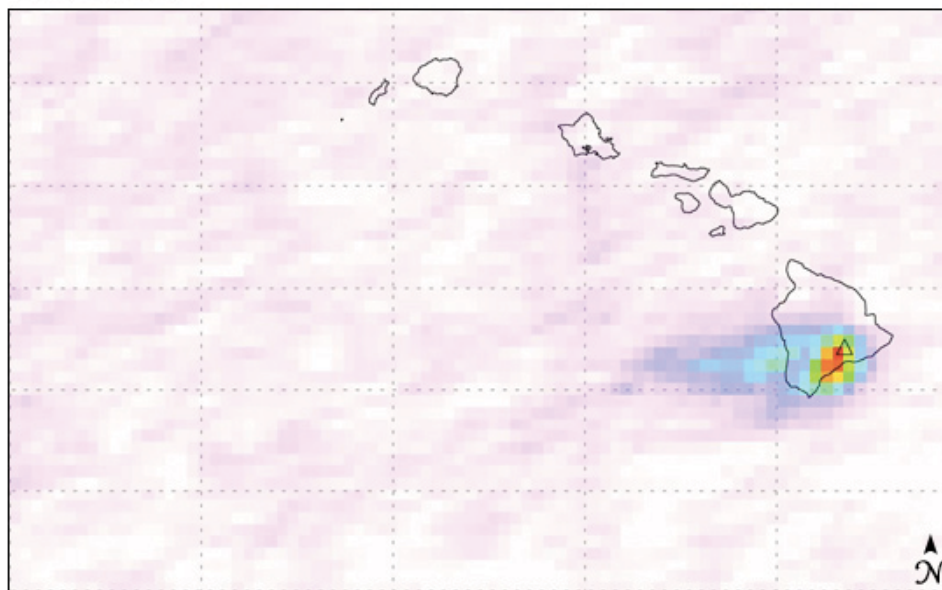
Hawai'i is seismically active; each year thousands of earthquakes occur in the Hawaiian Islands. Most earthquakes are linked to volcanism or the processes that form volcanoes. The seismicity map of Hawai'i shows that earthquakes occur most frequently near Hawai'i Island, the site of recent and active eruptions (*Figure 10.23*). From examination of the depth and distribution of seismicity, scientists recognize three types of earthquakes in Hawai'i. The deepest earthquakes (16–56 kilometers; 10–35 miles) occur within the **lithosphere** and are related to stresses created by flexure of the lithosphere in response to the



Hawai'i



March 20-27, 2008



March 1-7, 2008

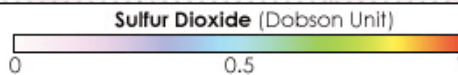


Figure 10.22: Sulfur dioxide plume after and before the Kīlauea summit eruption March 19, 2008. (See TFG website for full-color version.)

large mass load of the Hawaiian volcanoes. In 2006, an M6.7 earthquake of this type caused widespread damage across northern Hawai'i Island (Figure 10.24).

A second group of earthquakes occurs along the boundary between the Hawaiian volcanoes and the older oceanic crust on which they sit. Under the influence of gravity, the flanks of the volcanoes tend to spread. This spreading motion causes



10



Earth Hazards

Hawai'i

earthquakes along a nearly horizontal fault between ancient oceanic crust and the overlying, much younger, volcanic edifice. An M7.2 earthquake of this type occurred in Kalapana on the south coast of Hawai'i Island in 1975. Similarly,

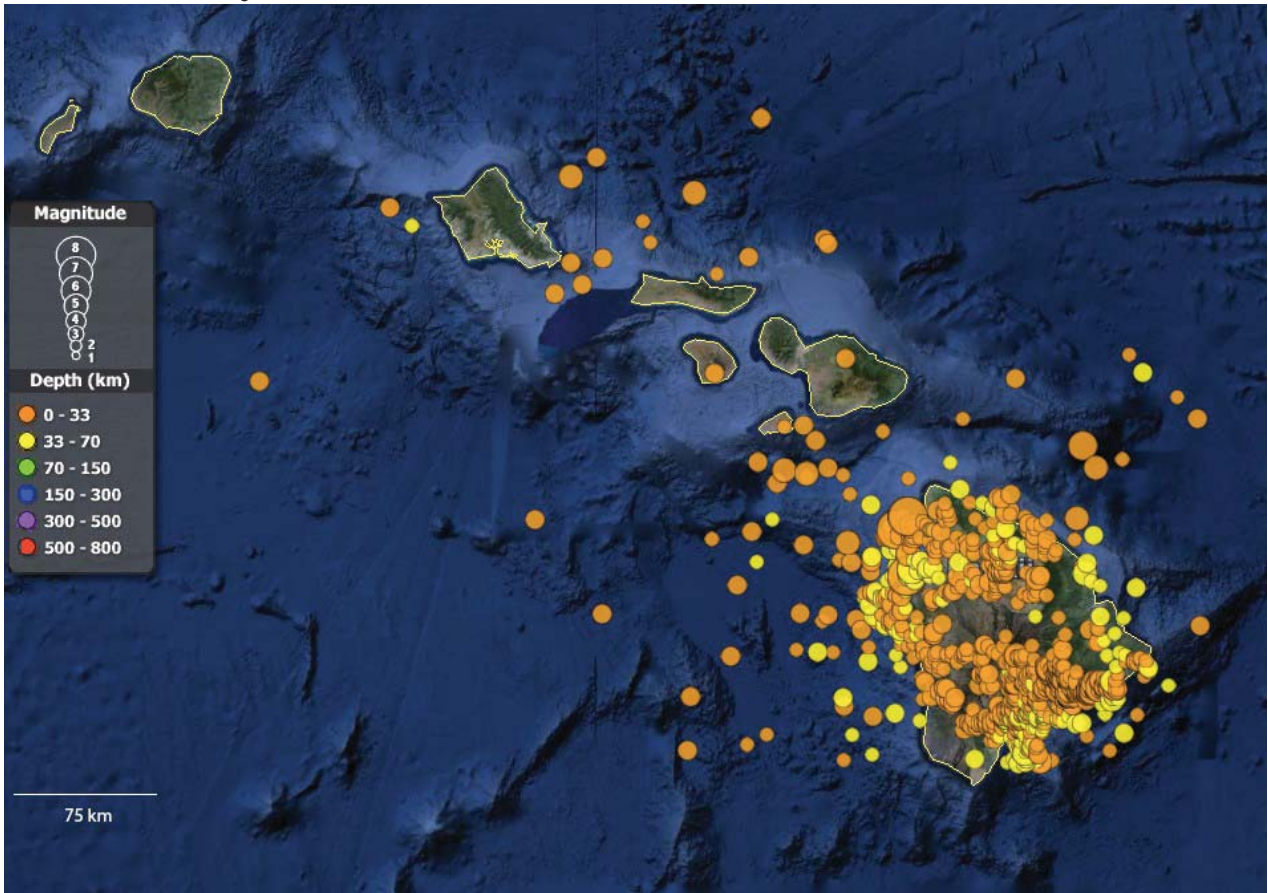


Figure 10.23: Ten years of M2+ earthquakes (2004–2014).
(See TFG website for full-color version.)

seismometer • an instrument that measures seismic waves (movements) within the ground.



faults visible on the surface appear to be related to this seaward motion of the volcanic flanks. In 1983, an M6.6 earthquake on Mauna Loa's Ka'oiki fault sent portions of Chain of Craters Road sliding into Kīlauea caldera.

The third suite of earthquakes are those caused by the migration of magma through volcanic conduits beneath the magma chamber. A common precursor to a volcanic eruption is an earthquake swarm known as *harmonic tremor*, which involves a set of early, continuous, low-magnitude vibrations (too small to be felt by people) that accompany the movement of magma toward the surface (Figure 10.25).

Although considered a hazard, earthquakes are also useful tools for probing the interior structure of Hawai'i's volcanoes. An array of **seismometers** on Hawai'i Island detects small earthquakes that delineate fault zones dissecting



Hawai'i



Figure 10.24: Kalāhikiola Church, Kapa'au, Hawai'i Island, 41 kilometers (25 miles) from the epicenter of the 2006 Kīholo (M6.7) earthquake.

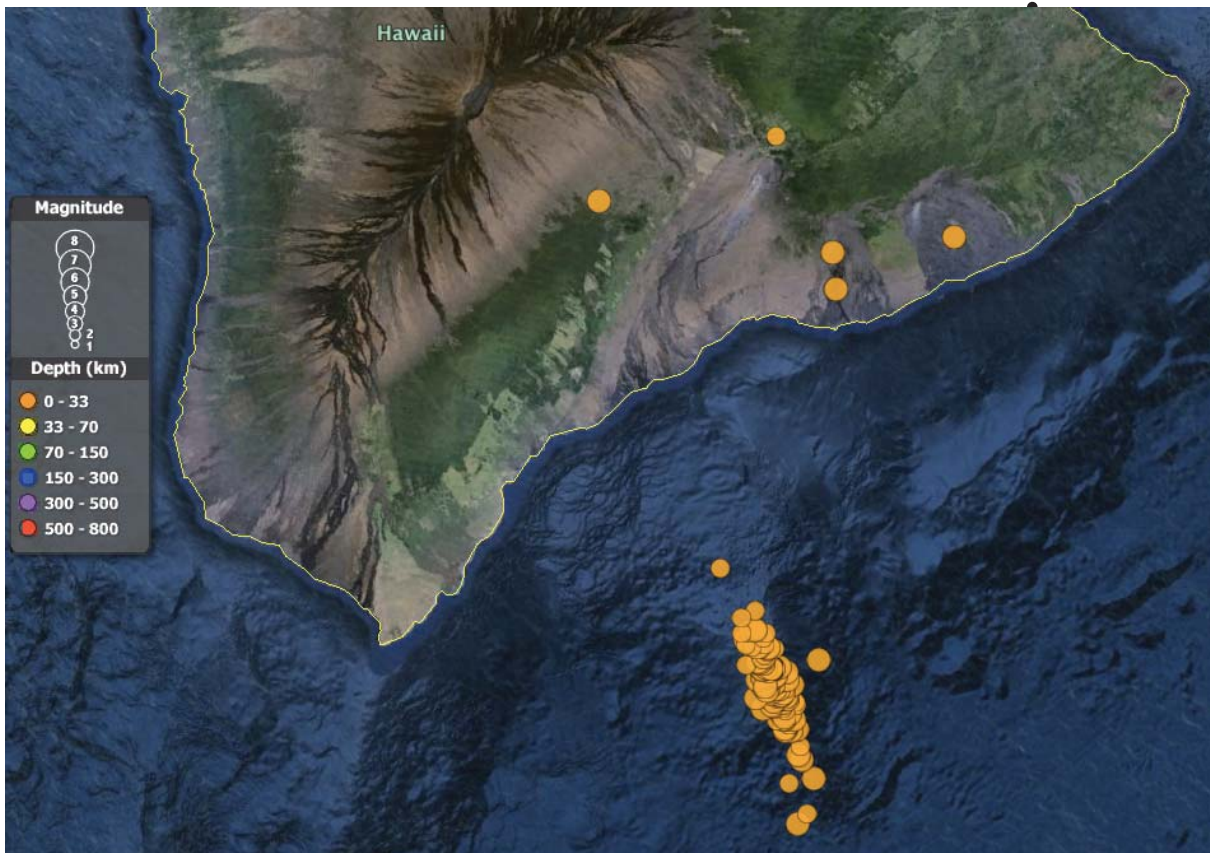


Figure 10.25: Earthquake swarm associated with the 1996 eruption of Lō'ihī volcano. (See TFG website for full-color version.)



Hawai'i

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

the volcanoes. These instruments also allow volcanologists to map magma chambers and **rift** zones.

There is an inverse relationship between the size of earthquakes and their frequency. Large earthquakes release large amounts of energy stored within the crust and lithosphere of the Earth, so they are infrequent. Smaller earthquakes occur all the time, releasing small amounts of energy. In Hawai'i, microearthquakes occur every day. Fortunately, because Hawai'i is not located on an active tectonic plate boundary there are no very large (M8.0+) earthquakes there.

Tsunamis

As mentioned previously, tsunamis are ocean surges usually caused by large earthquakes that displace the ocean floor. Displacements can also occur because of large landslides triggered by an earthquake. The sudden displacement generates a shock wave that in turn can generate a series of waves in the ocean. These waves travel at high speeds across the ocean basins, up to 800 kph (500 mph). They have long wavelengths (200 kilometers; 120 miles) but low amplitudes and are only 30 to 120 centimeters (1–4 feet) in height. When such a wave train reaches shallow water the wave velocity slows and the wavelength decreases, but the amplitude increases, sometimes dramatically (see *Figure 10.10*). The heights of tsunamis close to large earthquakes have exceeded 15 meters (50 feet) in Hawai'i. Unfortunately, the use of the term "height" in tsunami reports can be confusing. In some cases it refers to the height of the oncoming surge of water above mean local sea level. In other cases it is used to describe the highest point reached by the wave, known as the "runup." Runup heights are greater than wave heights, but descriptions do not always make the distinction clear.

Much of the Pacific Ocean is bordered by subduction zones, where many of the world's largest earthquakes (and accompanying tsunamis) are generated. Because Hawai'i is far from any subduction zone, there is usually ample warning time (5–15 hours) between the occurrence of a great earthquake and the arrival of a tsunami. Since earthquake waves travel through the solid earth ten times faster than tsunami waves cross the ocean, a large earthquake can be detected well before the arrival of a tsunami.

Historically, tsunamis have caused significant damage in Hawai'i. For example, the great earthquake of 1946 in the Aleutian Islands (M8.1) generated tsunamis that caused substantial damage and loss of life in Hawai'i. Wave heights reached more than 15 meters (50 feet) on Hawai'i Island, and 159 people were killed in the state. This disaster led to the establishment of the first tsunami warning system, now known as the Pacific Tsunami Warning Center (PTWC). It monitors earthquake activity around the Pacific (*Figure 10.26*), and it also monitors pressure sensors deployed in the ocean that are sensitive to the passage of a tsunami wave (*Figure 10.27*). In 1960, the largest earthquake ever recorded (M9.5) occurred off the Chilean coast, and again the damage was severe on Hawai'i. Although the PTWC issued a warning, many people were complacent because large earthquakes in Kamchatka in 1952 and the





Hawai'i

Aleutians in 1957 had not produced significant tsunamis in Hawai'i. The 1960 wave heights were highest (10 meters; 35 feet) in Hilo Bay, killing 61 people. The Chilean Maule earthquake of 2010 (M8.8) and the Japanese Tōhoku earthquake (M9.0) both produced smaller tsunamis in Hawai'i, with wave heights of 1–3 meters (3–10 feet). Both were well predicted by the PTWC, and no fatalities occurred. Heightened public awareness after the 2004 Sumatran earthquake and tsunami in the Indian ocean may have played a role.

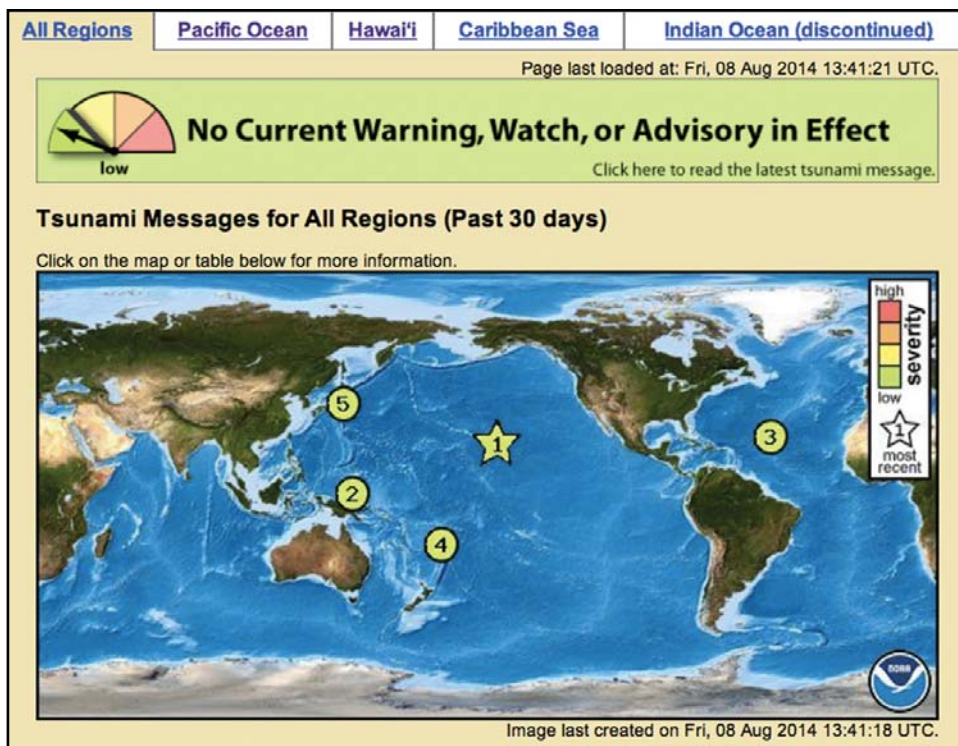


Figure 10.26: Tsunami alert map from the PTWC, generated on August 8 2014. Earthquakes with the potential to generate a tsunami are displayed and ranked by predicted tsunami severity. On this date the five events mapped each carried a low tsunami risk, including an M4.5 earthquake in Hawai'i.

There is no simple relationship between the magnitude of an earthquake and the magnitude of tsunamis it may generate. The direction of the tsunami wave's arrival and how it interacts with local sea floor topography can greatly influence the wave's height. Tsunami waves can "bend" or refract around topographic features, as occurred in the case of the 1960 Hilo Bay tsunami.

Local earthquakes in Hawai'i can also generate tsunamis, for which warning times will naturally be much shorter. In 1975, an M7.2 earthquake off the southeast coast of Hawai'i generated a pair of tsunami waves, the second of which reached a height of 8 meters (26 feet) at Halapē and caused two fatalities.





Hawai'i

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

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.

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

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

tropical depression • an organized, rotating system of clouds and thunderstorms.

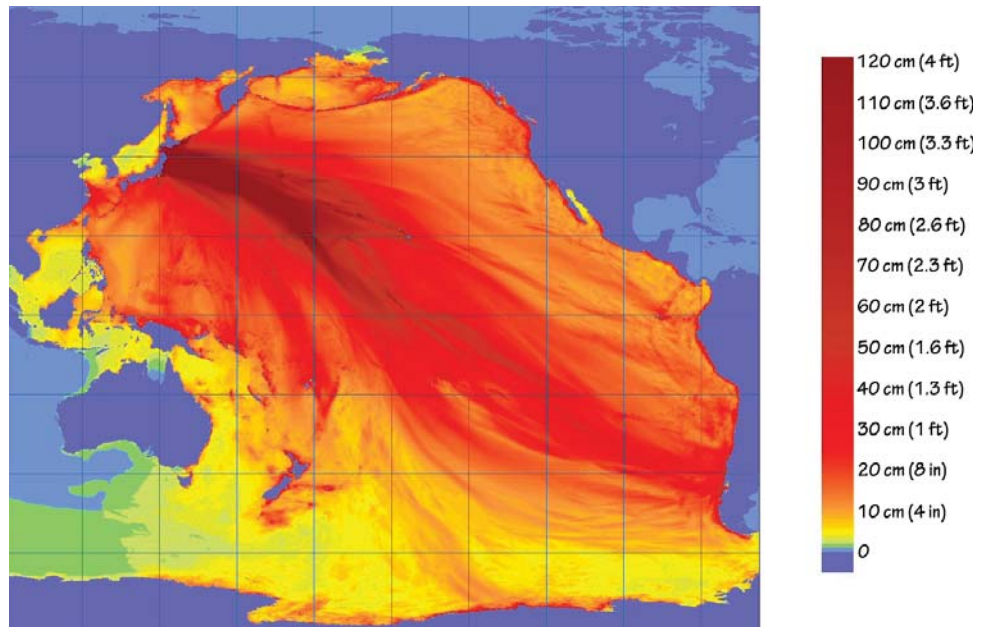


Figure 10.27: NOAA energy model and predicted wave height from the 2011 Tōhoku Japan tsunami. These are open-ocean wave heights; as the tsunami approaches a coastline the local landforms influence the wave height when it reaches shore. (See TFG website for full-color version.)

Floods and Coastal Hazards

Hawai'i is a mountainous tropical archipelago, thus floods are a frequent occurrence. Flash floods occur, on average, eight times a year in Hawai'i, with the highest frequency seen during the rainy season from October to April (Figure 10.28). Hawai'i's **watersheds** are small and its streams are "flashy," meaning that they can change quickly from dry to overflowing in a matter of minutes. Flood events cause landslides that can block roadways, or sometimes wash away a section of highway or infrastructure (e.g., water pipes, bridges, agricultural ditches). The rural nature of most of the Hawaiian Islands means that a washed-out road is a significant disruption, since few alternate routes exist. In addition, flash floods carry high sediment discharge, particularly in areas with degraded or highly modified terrestrial ecosystems. Hawai'i's fringing coral **reefs** are negatively impacted by pulses of flood-borne sediment, as corals require sunlight and clear water to maintain ecosystem health.

Like any coastal region, Hawai'i is subject to **hurricanes** and storm surge. Hurricanes occur when a warm and moist tropical low-pressure air mass forms over portions of the ocean. These storms gather strength because the warm summer ocean water evaporates, creating very humid, low-pressure air. The air rises and condenses into water droplets that form clouds and release latent **heat**. The latent heat provides energy for even greater evaporation of warm ocean water, and thus the cycle continues until the low-pressure center moves over land. These storms are considered **tropical depressions** when wind



**Flash Flood Events
1960 through 2005**

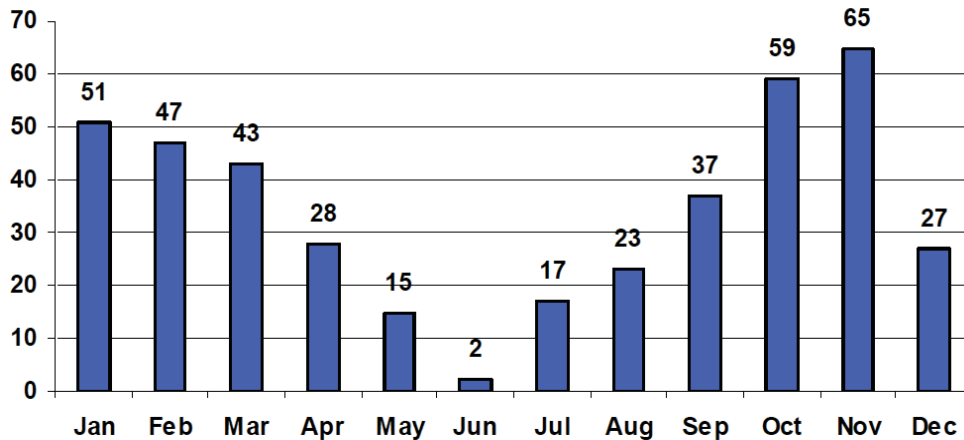


Figure 10.28: NOAA data on flash flood frequency in Hawai'i.

speeds are below 63 kph (39 mph). As the storm develops a more organized structure, however, with more concentrated rising warm air in the center and bands of rain, it will officially become a tropical storm when its wind speeds reach the 63 to 117 kph (39 to 73 mph) range. Once winds have reached 119 kph (74 mph), the storm is classified as a hurricane. About four to five hurricanes occur in the central Pacific every year, but almost every storm system that reaches Hawai'i has degraded to a tropical storm or tropical depression by the time it makes landfall. In terms of loss of human life, storm surge and high surf are the deadliest natural hazards in the Hawaiian Islands. Storms from any part of the Pacific can cause big swells and high surf on Hawaiian coasts. Hawai'i's north shores are famous for winter surf arising from storms in the north Pacific, while in summer, big waves strike south-facing shores.

Hazard Preparedness and Response

The historical record of natural disasters in Hawai'i has prompted the creation of a robust system of warning and response for island communities. USGS seismometers, GPS, and associated instrumentation monitor earthquake and volcanic hazards, while NOAA buoys across the Pacific monitor marine conditions and NOAA/NASA satellites monitor the atmosphere and ocean (Figure 10.29). These inputs are networked with real-time response systems, including NOAA's National Weather Service and PTWC, and Hawai'i's state and county Civil Defense offices. Hazard information is broadcast to the public through computerized warning services (e.g., radio, internet, reverse-911) and through an island-wide system of civil defense sirens.





Climate Change

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

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

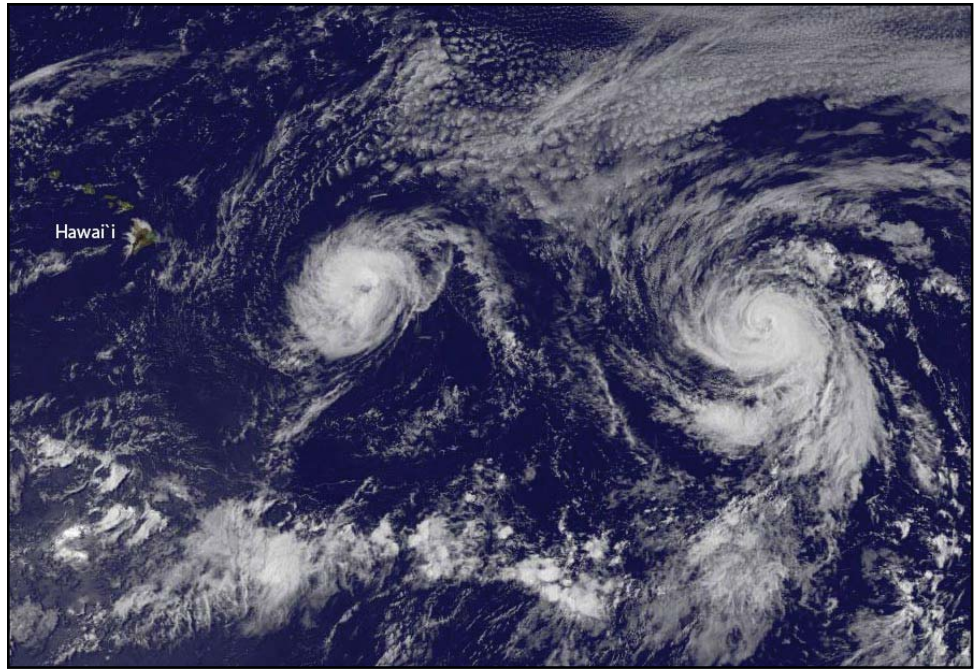


Figure 10.29: NASA MODIS image of hurricanes Iselle (left) and Julio (right) lining up on the Hawaiian Islands, August 6, 2014. Modern hazard forecasting and warning systems reduce the impact on humans.

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 West has been accompanied by more frequent **heat waves**, shorter winters, and an increased likelihood of drought and wildfires. The contiguous Western states are currently experiencing severe drought throughout, with the worst effects occurring in California and parts of Nevada (Figure 10.30). Increased dryness contributes to fire risk—in September 2014, the Eldorado National Forest near Sacramento, California experienced a massive wildfire that consumed more than 39,254 hectares (97,000 acres) of land and required the efforts of more than 8000 firefighters to combat the blaze.

See Chapter 9: Climate to learn more about how climate change will affect the West.

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

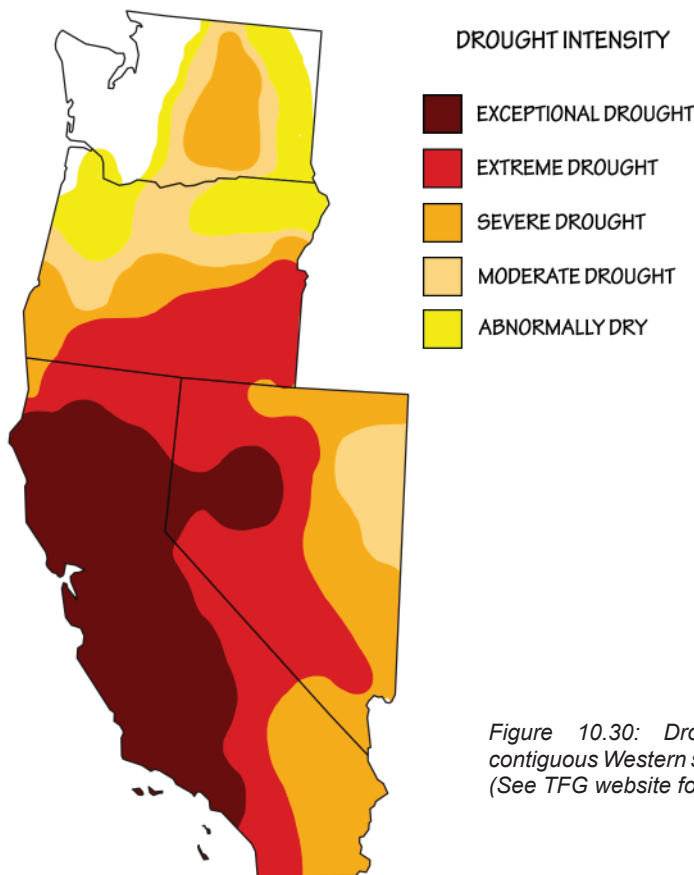


Figure 10.30: Drought severity in the contiguous Western states, as of August 2014. (See TFG website for full-color version.)

different impacts on rural and urban settings. In rural settings, agriculture and livestock can be greatly affected. Heat stress recommendations are issued to help farmers protect their animals, particularly pigs and poultry, which, unlike cattle, do not have sweat glands.

The impacts of heat waves on urban settings include a combination of the natural conditions of excessive heat and the social conditions of living in a densely populated space. Cities contain a considerable amount of pavement, which absorbs and gives off more heat than vegetation-covered land does. Air conditioning units that cool down the inside of buildings produce heat that is released outside. Pollution from cars and industrial manufacturing also elevates the outdoor temperature 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 cause an increase in 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 2014, California broke a 120-year record for heat, with temperatures 2.5°C (4.6°F) hotter than average. Southern parts of the state also experienced severe heat waves in September and October of that year. The heat wave in September 2014 led to the cancellation of over 20 athletic events, as well as

10



Earth Hazards

Climate Change

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

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

over 100 schools shortening their school days. Los Angeles set a record for daily **energy** use, as people turned up their air conditioners in an effort to cool down. During the same month, Hawaii's electric utilities struggled to generate enough electricity to power an associated spike in energy demand.

Water supply is also a critical issue for the Western states. Much of the West obtains its water from precipitation, snowmelt, and runoff, which will dramatically decrease in quantity as temperature and aridity rise. The Arctic is warming nearly twice as fast as the rest of the planet—summer sea ice around Alaska has decreased by about 12% every decade since the 1970s (*Figure 10.31*). With melting ice comes an increase in sea level, and all of the Western states except Nevada have a considerable amount of oceanic coastline which will be affected by sea level rise.

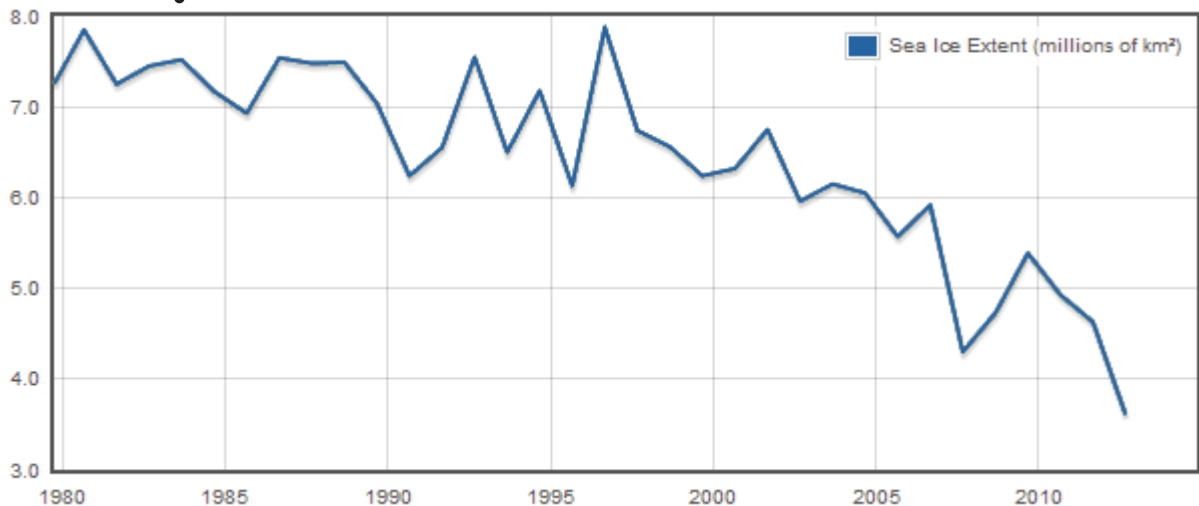


Figure 10.31: Extent of Arctic sea ice from 1979 to present. Measurements are made via satellite each September.

Increasing temperatures also allow for certain pests, such as ticks and mosquitoes, to live longer, thereby increasing the risk of contracting the diseases they carry. In addition, invasive insects that damage ecosystems, such as the spruce bark beetle in Alaska, will be better able to survive warmer winters, and will therefore increase and spread.

Another concern regarding hazards exacerbated by climate change in the West is whether or not there has been or will be an increase in the number or severity of storms, such as hurricanes and **tornadoes**. 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 10.32*).

Climate Change

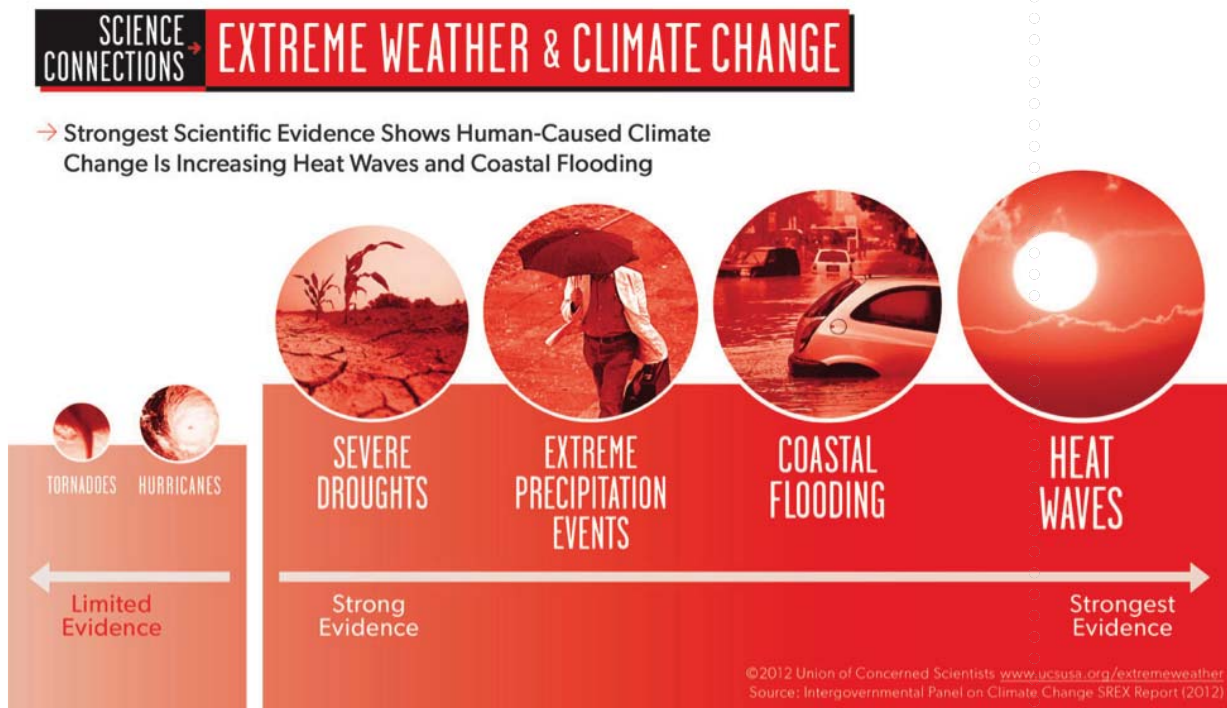


Figure 10.32: The strength of evidence supporting an increase in different types of extreme weather events caused by climate change. (See TFG website for full-color version.)



Resources

Resources

General Resources

- Maddougall, 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, <http://earthobservatory.nasa.gov/NaturalHazards/>. (Monthly images of Earth hazards occurring globally.)

Websites: Storms

(See also resources on climate change in Chapter 9: Climate)

- Floods: Recurrence Intervals and 100-year Floods*, US Geological Survey, 2014, <http://water.usgs.gov/edu/100yearflood.html>.
- Effects of Urban Development on Floods*, US Geological Survey Fact Sheet FS-076-03, 2012, <http://pubs.usgs.gov/fs/fs07603/>.
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to the Earth Science of the
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