Chapter 8: Soils of the Western US

It's sometimes easy to take the soil beneath our feet for granted. Yet soil has always been with us—it is the foundation of our houses and roads, and from the soil comes our food, fiber, and paper. Soil is the interface between living earth and solid rock, between biology and geology. Soils are the principal medium of plant growth, and they provide habitat for a myriad of organisms—particularly decomposers. Soils store and purify water, and they exchange gasses with the **atmosphere**. Soils support agriculture and natural ecosystems, provide a grassy surface for our parks, and fodder for our gardens. Everyone, everywhere, every day, depends upon the soil.

What is "soil"?

Generally, **soil** refers to the top layer of earth—the loose surface of the Earth as distinguished from rock—where vegetation grows. The word is derived (through Old French) from the Latin *solum,* which means "floor" or "ground." It is the most basic resource upon which all terrestrial life depends, and soil is one of the most important resources we have. The West has a wide variety of soils, and each type of soil has a story to tell of its origin.

Soils form from the top down, and typically reach a depth of about one meter (3.3 feet) at their more developed stages, although some can reach much deeper. Soils are composed of a mixture of two key ingredients. The first is plant litter, such as dead grasses, leaves, and fallen debris. Worms, bacteria, and fungi do the job of breaking these down into the nutritious organic matter that helps soil to nourish future plant growth. The second important component of soil is the sediment derived from the **weathering** of rock that is then transported by **wind**, water, or gravity. Both of these components influence the texture (*Figure 8.1*) and consistency of the soil, as well as the **minerals** available for consumption by plants.

All soils may seem alike, but there can be vast differences in soil properties even within small areas. A single acre may have several different soil types, each with its own assets and drawbacks. Some types of soil are clayey or prone to flooding, while others are stable enough to be used as a foundation for buildings. The most identifiable physical properties of soils are texture, structure, and **color**, which provide the basis for distinguishing soil **horizons**. Texture refers to the percentage of **sand**, **silt**, and **clay** that makes up the soil. The textures have specific names, as indicated in *Figure 8.1*.

Generally, the best agricultural soils are those with about equal amounts of clay, silt, and sand. A soil of that type would be called a **loam**. Soils that are mostly sand do not hold water very well and dry quickly. Soils with too much clay may never dry out.

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

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

horizon • *a layer in the soil, usually parallel to the surface, which has physical characteristcs (usually color and texture) that are different from the layers above and below it.*

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

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

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

loess • *very fine grained, wind-blown sediment, usually rock flour left behind by the grinding action of flowing glaciers.*

biota • *the organisms living in a given region, including plants, animals, fungi, protists, and bacteria.*

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

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

erosion • *the transport of weathered materials.*

humus • *a soil horizon containing organic matter.*

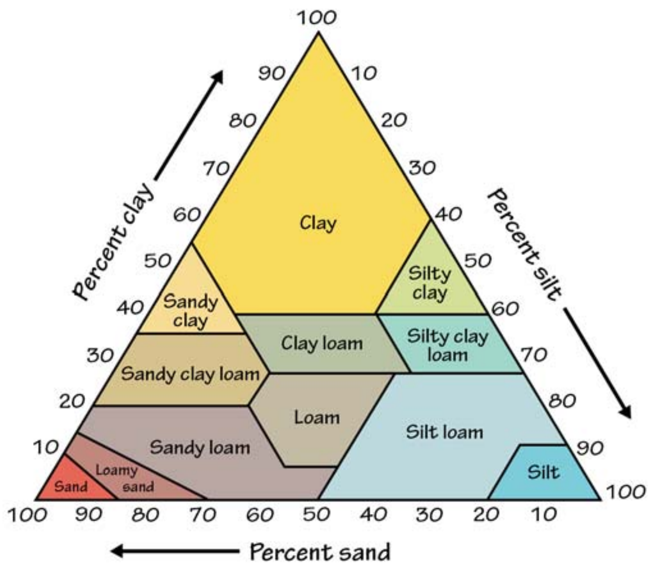

Figure 8.1: Soil texture triangle.

Soil structure refers to the way the soil forms clumps. These clumps are known as **peds**. The peds are identified by the shape of the soil clods, which take the form of balls, blocks, columns, and plates. These structures are easiest to see in recently plowed fields, where the soil is often granular and loose or lumpy.

Soil color is its most obvious physical property. The color is influenced by mineral content, the amount of organic material, and the amount of water it routinely holds. The colors are identified by a standard soil color chart called the Munsell chart.

Five main variables affect the characteristics of soil worldwide:

1. *Parent material* is the original geologic material from which the soil formed. This can be bedrock, preexisting soils, or other materials such as **till** or **loess**.

2. *Climate* strongly determines the temperature regime, amount of moisture, and type of **biota** that interact with the **parent material**. This will affect the extent of chemical and physical weathering on the soil-forming material.

3. *Topography*, or landscape, of the area is related to the relative position of the soil on the landscape; this includes the presence or absence of hills and the slopes between high and low areas. **Topography** influences natural drainage. Gravity moves water down slopes to depressions or streams and pulls free water downward through the soil. Soils on hills tend to be dry, and soils in depressions and valleys are often wet or saturated. Areas with steep slopes that are susceptible to frequent **erosion** typically have very young soils, as they do not have long to develop before the ingredients are rearranged and the clock

is reset. Other areas that are more arid and have a flatter topography, such as the deserts in the Basin and Range region of Nevada, may have more time to develop, but they have significantly less plant life and will produce a very different soil than will a wetter environment like the forests in the Cascade-Sierra region.

4. *Biota or living organisms* that live on or in the material affect soil development through their influence on the amount and distribution of organic matter in the soil. For example, plants contribute significantly to the formation of **humus**, and animals alter a soil's characteristics by leaving behind decayed remains and wastes. Decomposers like bacteria and fungi help to free up the nutrients locked away in these remains and wastes, and these freed nutrients are then recycled and used by new life forms within the same soil. In fact, more than 90% of the nutrients used by a forest in a given year are derived from the decomposition of old organic matter that had fallen to the forest floor. Animal burrows also create spaces in the soil horizons that allow for deeper penetration of air and water, which, in turn, aid plant development. For its part, organic matter impacts the water-holding capacity of the soil, the soil's fertility, and root penetration.

5. *Time* is required for soils to develop while the four elements mentioned above interact. The effects of time can be seen when comparing soils on a glaciated area to either soils formed on recent flood plain deposits or soils in a non-glaciated area at the same latitude.

Several types of **chemical reactions** are important for soil development; of these, acid-base reactions are some of the most important and complex. When carbon dioxide (CO_2) dissolves in water it forms weak carbonic acid. CO_2 in soil water can come from the atmosphere, where it dissolves in rainwater. Even more CO_2 usually comes from the soil itself, where respiring organisms produce it. The amount of CO_2 in soil gases can easily reach levels ten times higher than the amount found in the atmosphere (over 4000 ppm in soil vs. 400 ppm in the atmosphere), making soil water potentially more acidic than rainwater. As this acidic water slowly reacts with fresh minerals, it buffers the soil's pH and keeps it in a range (6-8) preferred by many organisms. Acid-driven weathering breaks down the soil's primary **igneous** minerals, typically transforming them to **silica**-rich clays. As the soil's primary minerals are depleted, it loses the ability to buffer acidity, and the pH of highly weathered soil can drop to around 4. These weathered soils tend to be rich in aluminum, **iron**, and **titanium**.

A second important type of weathering reaction is **oxidation**. In Hawai‘i, for example, **basalts** mostly contain ferrous iron (Fe^{2+}), which tends to give minerals a green to black color. As this iron reacts with oxygenated soil and water, the iron is converted to ferric iron (Fe^{3+}), which generates strong red-orange colors. Ferric iron is not very soluble (as anyone knows who has ever tried to “wash off” rust), and it tends to accumulate in weathered soil profiles. The striking “red dirt” soils in Hawai‘i are excellent examples of oxidation acting on ferrous iron-rich basalt (*Figure 8.2*).

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

igneous rocks • *rocks derived from the cooling of magma underground or molten lava on the Earth's surface.*

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

iron • *a metallic chemical element (Fe).*

titanium • *a metallic chemical element (Ti).*

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

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

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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.*

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

Figure 8.2: A highly weathered Oxisol, west Kaua'i. Chemically this soil consists primarily of aluminum, iron, and titanium oxides and hydroxides. Erosion, probably caused by overgrazing, has led to a loss of organic matter at the surface. This soil has a low water-holding capacity, is highly acidic, and has very low nutrient content. These harsh conditions have prevented recolonization by plants.

In highly weathered settings, the mineral soil has lost most of its nutrients, and the store of nutrients that remains is mostly found in organic matter. In weathered soils, only the top 25 cm (10 inches) or so may be very biologically active, and rooting depths are very shallow. If this thin layer is lost to erosion, the underlying mineral soil may be infertile and incapable of rapid recovery.

Soil Orders

Just as rocks are classified into different types based on how they formed (igneous, **metamorphic**, or **sedimentary**), their mineral composition, and other characteristics, soils also have their own classification scheme. Soil develops in horizons, or layers, whose formation is dependent on the available ingredients, environmental conditions, and the time to mature. More mature soils will develop a variety of horizons unique to their environmental conditions, creating a soil profile. Some horizons are completely absent in certain profiles while others are common to most. Each horizon corresponds to a stage in the weathering of rock and decay of plant matter, and each is found at a specific position beneath the surface (*Figure 8.3*).

Soils can also be categorized by their location (northern vs. southern soils), the type of vegetation growing on them (forest soils vs. desert soils), their topographic position (hilltop soils vs. valley soils), or other distinguishing features. The system used to classify soils based on their properties is called

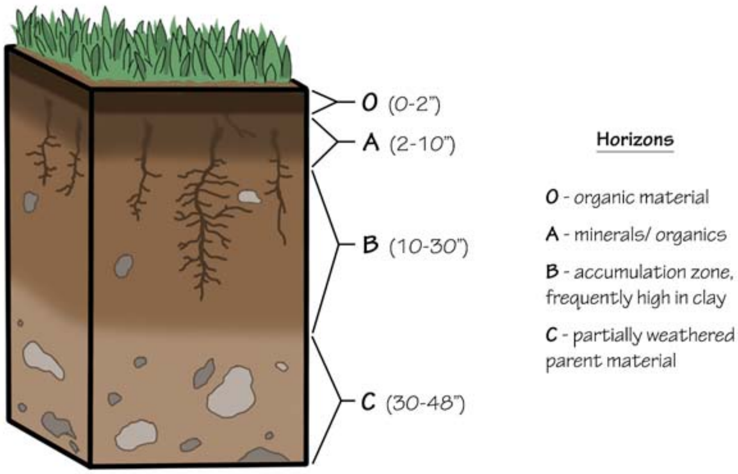

Figure 8.3: A typical soil profile shows the transition from the parent material (horizon C and the bedrock below it) to the highly developed or changed horizons (O through B). Not every soil profile will have all the horizons present.

soil taxonomy, and it was developed by the United States Department of Agriculture (USDA) with the help of soil scientists throughout the country. It provides a convenient, uniform, and detailed classification of soils throughout the country, allowing for an easier understanding of how and why different regions have developed unique soils.

In soil taxonomy, all soils are arranged into one of 12 major units, or **soil orders**. These 12 orders are defined by diagnostic horizons, composition, soil structures, and other characteristics. Soil orders depend mainly on **climate** and the organisms within the soil. These orders are further broken down into 64 suborders based on properties that influence soil development and plant growth, with the most important property being how wet the soil is throughout the year. The suborders are, in turn, separated into great groups (300+) and subgroups (2400+). Similar soils within a subgroup are grouped into even smaller families (7500+), and the similar soils within families are grouped together into the smallest category of all: a series (*Figure 8.4*). There are more than 19,000 soil series described in the United States, with more being defined every year.

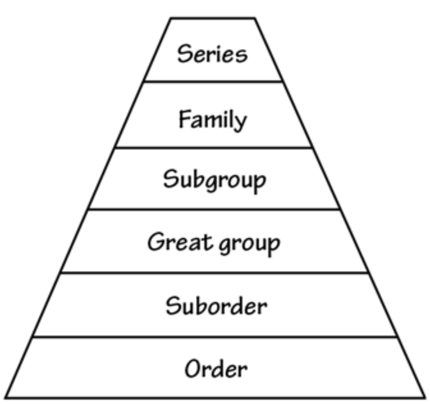

Figure 8.4: Soil taxonomy.

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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).*

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The 12 soil orders

Name	Description	Controlling Factors	Percentage of global ice-free land surface	Percentage of US ice-free land surface
Alfisols	Highly fertile and productive agricultural soils in which clays often accumulate below the surface. Found in humid and subhumid climates.	climate and organisms	~10%	~14%
Andisols	Often formed in volcanic materials, these highly productive soils possess very high water- and nutrient-holding capabilities. Commonly found in cool areas with moderate to high levels of precipitation.	parent material	~1%	~2%
Aridisols	Soils formed in very dry (arid) climates. The lack of moisture restricts weathering and leaching, resulting in both the accumulation of salts and limited subsurface development. Commonly found in deserts.	climate	~12%	~8%

The 12 soil orders (continued)

Entisols	Soils of relatively recent origin with little or no horizon development. Commonly found in areas where erosion or deposition rates outpace rates of soil development, such as floodplains, mountains, and badland areas.	time and topography	~16%	~12%
Gelisols	Weakly weathered soils formed in areas that contain permafrost within the soil profile.	climate	~9%	~9%
Histosols	Organic-rich soils found along lake coastal areas where poor drainage creates conditions of slow decomposition and peat (or muck) accumulates.	topography	~1%	~2%
Inceptisols	Soils that exhibit only moderate weathering and development. Often found on steep (relatively young) topography and overlying erosion-resistant bedrock.	time and climate	~17%	~10%

The 12 soil orders (continued)

Mollisols	Agricultural soils made highly productive due to a very fertile, organic-rich surface layer.	climate and organisms	~7%	~22%
Oxisols	Very old, extremely leached and weathered soils with a subsurface accumulation of iron and aluminum oxides. Commonly found in humid, tropical environments.	climate and time	~8%	~.02%
Spodosols	Acidic soils in which aluminum and iron oxides accumulate below the surface. They typically form under pine vegetation and sandy parent material.	parent material, climate, and organisms	~4%	~4%
Ultisols	Soils with subsurface clay accumulations that possess low native fertility and are often red hued (due to the presence of iron oxides). Found in humid tropical and subtropical climates.	climate, time, and organisms	~8%	~9%

The 12 soil orders (continued)

Vertisols	Clayey soils with high shrink/ swell capacity. During dry periods, these soils shrink and develop wide cracks; during wet periods, they swell with moisture.	parent material	~2%	~2%

Dominant Soils of the Contiguous Western States

Alfisols: These soils tend to develop in cooler, more forested environments, and they commonly form a band separating more arid areas from humid areas. The Sierra Nevada are a perfect example of this, as they separate the arid Basin and Range from the more humid California coast and are, not surprisingly, dominated by Alfisols (*Figure 8.5*).

Figure 8.5: Alfisols of the contiguous Western US.

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

Andisols: These form almost exclusively in the **volcanic** portions of the Pacific Northwest. They can be both weakly and heavily weathered soils that contain sediments derived from volcanic material. The presence of volcanic glass is diagnostic of this soil class (*Figure 8.6*).

Figure 8.6: Andisols of the contiguous Western US.

Aridisols: Very dry soils that form in arid environments such as the Basin and Range region. Water content is very low or even nonexistent for most of the year, and this soil type is unsuitable for plants that are not adapted to store water or to survive extreme drought (*Figure 8.7*).

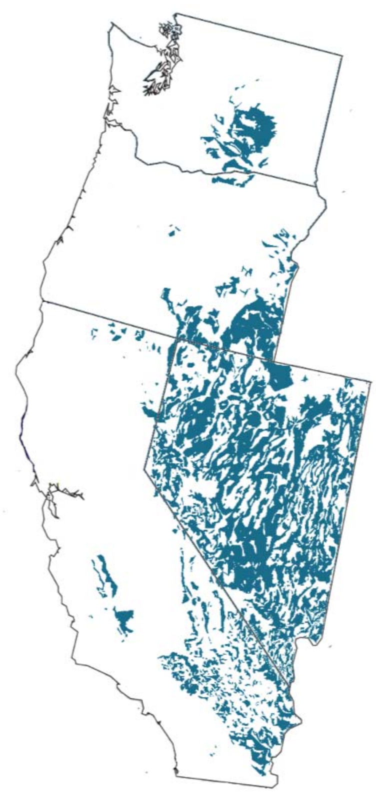

Figure 8.7: Aridisols of the contiguous Western US.

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

Inceptisols: Soils of cooler and wetter areas that have had calcium, magnesium, aluminum, and iron removed during development. Scattered throughout the US, they have a strong presence on the West Coast, especially in Oregon and northern California (*Figure 8.8*).

Figure 8.8: Inceptisols of the contiguous Western US.

Mollisols: The surface horizon of these soils tends to be very dark in color and almost black in some cases. The base-rich **topsoil** is widely used as cropland in the US, especially in the Columbia Plateau (*Figure 8.9*).

Figure 8.9: Mollisols of the contiguous Western US.

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

***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.*

***peat** • an accumulation of partially decayed plant matter.*

***conifer** • a woody plant bearing cones that contain its seeds.*

***boreal** • a cold temperate region relating to or characteristic of the sub-Arctic climatic zone.*

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

***leeward** • downwind; facing away from the wind.*

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

Dominant Soils of Alaska

Andisols: These acidic soils are associated with **volcanic ash** and debris deposits. They are especially prevalent along the southern Aleutian Islands, where they support low vegetation, and in the southeastern panhandle, where they support forests.

Entisols: These are soils with poorly developed horizons of recent origin. In Alaska, they are common along the banks of the Yukon and other large rivers, but they are also the relatively productive agricultural soils in the Matanuska-Susitna area, Alaska's "breadbasket."

Gelisols: These are soils of cold climates that contain **permafrost**. Gelisols are found throughout Alaska and are by far the most common soils in the state. Decomposition of organic matter occurs at a very slow rate in these soils.

Histosols: These soils contain high concentrations of organic matter, due to their development in wetland environments with poor drainage and a slow rate of decomposition. They are associated with **peat** bogs and mucks in southern Alaska and the Alaska panhandle, where permafrost is less common.

Inceptisols: These are soils with poorly developed horizons, associated with both Alaska's interior highlands and parts of the western coastal plains.

Mollisols: These are usually the dominant soils of grasslands, and, as such, are very uncommon in Alaska. They support forests with large proportions of spruce, birch, and aspen **trees** that are found sprinkled along the Pacific Coast.

Spodosols: These are acidic soils with an accumulation of iron and aluminum in the humus. These soils support cool, moist **coniferous** stands of forest and are associated with **boreal** forests. These are found primarily along Alaska's southern coast.

Dominant Soils of Hawai‘i

Andisols: The most abundant soil type in Hawai‘i, these soils formed from volcanic ejecta such as ash and **cinders**—materials that weather to form clay minerals. These soils are extremely rich in organic material in their upper horizons, and have a large water-holding capacity. This makes them highly productive soils for agriculture, and they are easy to cultivate. They do lose some fertility in areas of higher rainfall (over 150 centimeters [60 inches] annually), as the heavy rains wash nutrients from the soil.

Aridisols: These desert soils are formed in areas where the rainfall is so low that vegetation is almost completely absent, such as on the **leeward** side of the islands. They are shallow with no developed horizons, and they become saturated with **salts**, as there is no rainfall to wash the salts away. With irrigation, however, they can become useful agricultural soils.

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Figure 8.10: The dominant soil orders of Alaska. (See TFG website for full-color version.)

Entisols: These are poorly developed soils with a high mineral component and no real developed horizons. They occur on sands formed from coral **reefs** or on **alluvium** in drier areas.

Histosols: These soils develop from accumulations of organic materials on top of **lava** flows. They occur in cooler, moist conditions where anaerobic (low oxygen) environments are common. In areas of higher rainfall, they can become very acidic. The typical types of vegetation found on this soil order are Ohiʻa trees and ferns.

Inceptisols: These young, poorly developed soils are found on active slopes or in river valleys where material is constantly being deposited. They are most common on the older islands, and also occur in river valleys on the older volcanoes of the younger islands.

Mollisols: In other parts of the globe these rich, dark-colored soils are found on grasslands. In Hawaiʻi, however, the Mollisols are reddish in color, due to their high iron content, and they are found on the coastal plains and gentle slopes up to around 300 meters (1500 feet) above sea level in drier areas (65–130 centimeters [25–50 inches] of rain or less annually). In the past, these areas were extensively used for sugarcane crops.

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.*

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

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

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kaolinite • *a silicate clay mineral, also known as china clay.*

Oxisols: These are highly weathered soils that are very low in fertility and develop in hot tropical climates. They are found on low-elevation dry areas, or in some of the very wet highland areas. They are very common on the older islands of Kaua‘i and O‘ahu, but they are not found on the younger islands.

Spodosols: These soils form in forests in moist to wet areas on some of the uplands in Kaua‘i and Moloka‘i. They are not used for any form of agriculture.

Ultisols: These weathered soils are rich in the clay mineral **kaolinite** and form in warm humid climates with distinctive wet-dry seasons. They zone into Oxisols on some islands when rainfall decreases. They are acidic and yet, with the proper use of fertilizers, have become highly productive agricultural soils in Hawai‘i.

Vertisols: These are very dark soils, rich in swelling clays. Their distinguishing feature is that they form deeply cracked surfaces during dry periods, but they swell again in the wet season, which seals all the cracks. As a result, they are very difficult soils to build roads or other structures on.

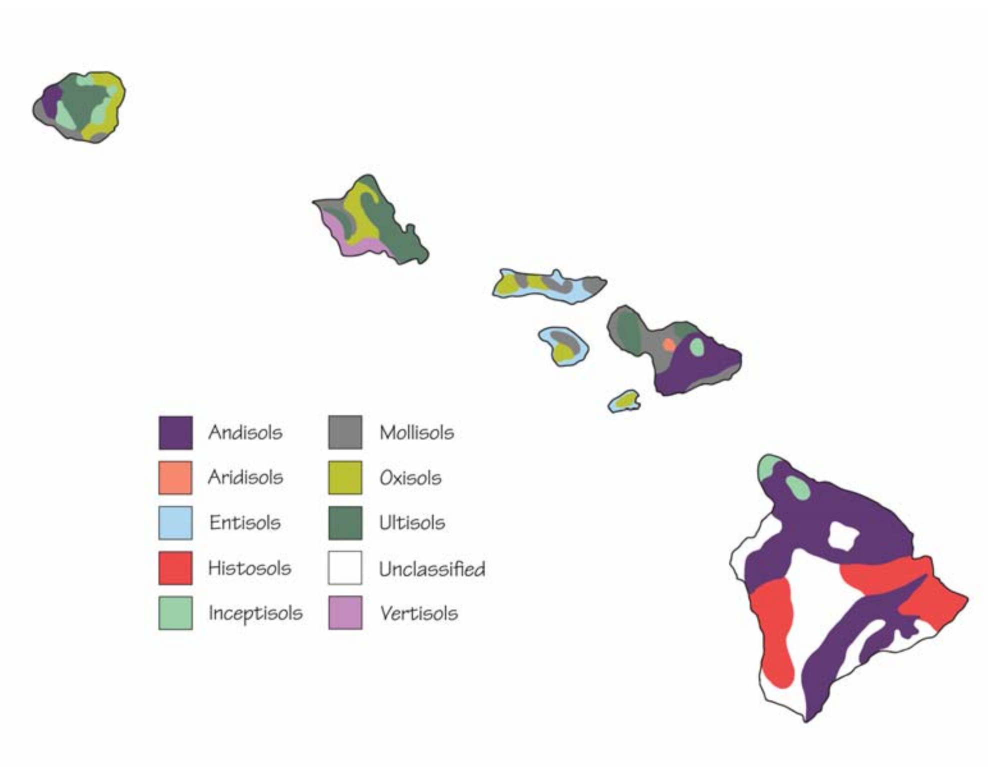

Figure 8.11: The dominant soil orders of Hawai‘i.
(See TFG website for full-color version.)

Soils of the Basin and Range
Region 1

The Basin and Range is the vast expanse of land that runs along the eastern edge of the Cascades and Sierra Nevada, down through Nevada, and toward the nation's southwestern portions. It formed as the result of extreme tension on the continental **lithosphere** that underlies the Western US. A series of extensional **faults** led to the very prominent, zebra stripe-like pattern of sharp cliffs and wide valleys that make up the region's topography.

See Chapter 4: Topography for more information about the landscape of the Basin and Range.

The Basin and Range contains a vast **watershed** called the Great Basin (*Figure 8.12*), so named because it lacks an outlet for surface water. Although very little

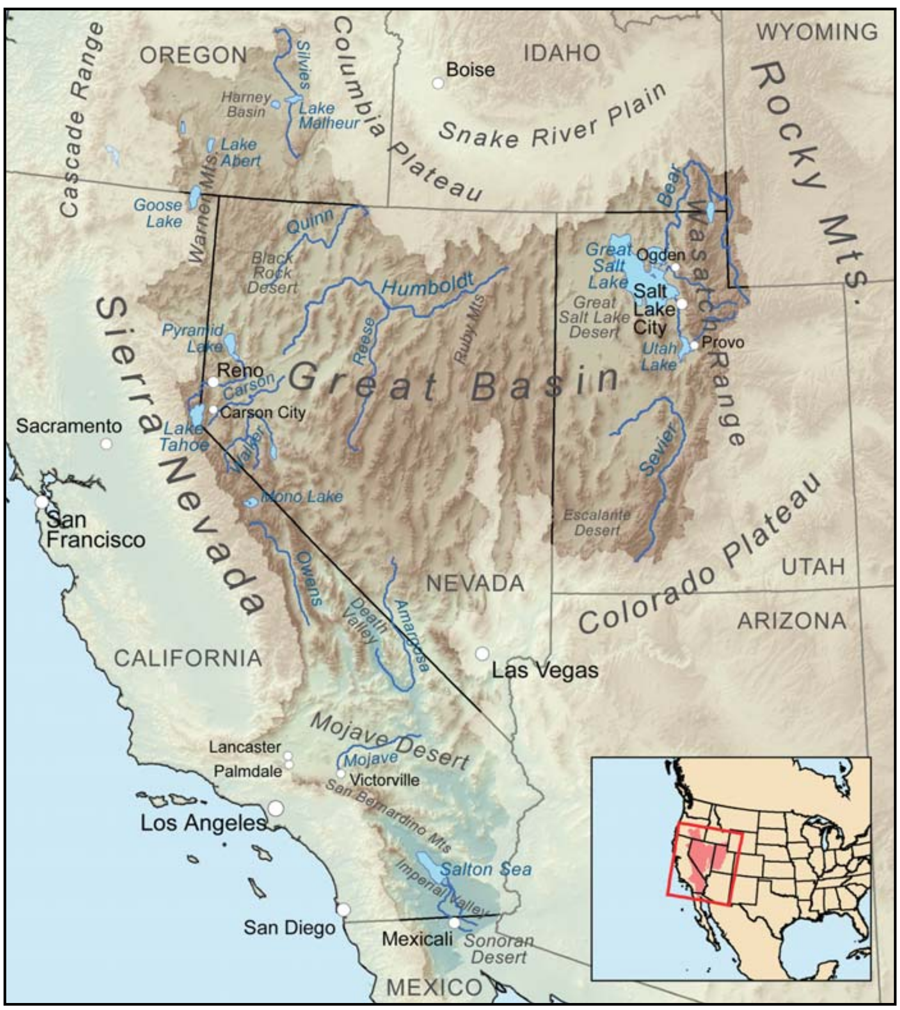

Figure 8.12: Extent of the Great Basin.

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

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.*

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

playa lake • *ephemeral or dry lakebed that occasionally contains only a thin layer of quickly evaporating water.*

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

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

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

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

rain falls in this arid place, what does fall never reaches the ocean but instead drains into the valleys and collects in **playa lakes**, where it soon evaporates. This results in either dry soils or barren desert with sediment surfaces that have not become soil.

As a result of this harsh climate, Aridisols dominate the Basin and Range. One of the identifying characteristics of these soils is their inherent dryness. There is very little plant life in much of the region, so an organic soil horizon takes either a long time to form or does not form at all. Sediments that are introduced from weathered outcrops vary. More **calcium carbonate**-rich soils, called Calcids (a suborder of Aridisols), are common in the southern portions, while more silica-rich Argids (a suborder of Aridisols) are common in the northern areas. Traces of Mollisols and Entisols can be found around the edges of the region, and small amounts of Gelisols can be found in eastern Nevada.

Soils of the Columbia Plateau
Region 2

This region's geology, and therefore its soil, is dominated by the Columbia River Flood Basalts. Beginning in the **Miocene** (17 million years ago) and leading up to the **Pleistocene**, flood basalts erupted in numerous locations throughout the region and flowed over the landscape, leaving few places untouched. These **effusive** lavas resulted from a **hot spot**. This hot spot now rests under Yellowstone National Park, the site of considerable **hydrothermal** activity. Wind-transported sediments known as loess are also important to the region. The Palouse Loess, for example, is famous for supporting productive agricultural lands.

See Chapter 2: Rocks to learn more about the Columbia River Flood Basalts.

The Columbia Plateau is mostly covered by grasslands and some forests, and is composed primarily of Mollisols. These soils tend to be dry in the summer and are later re-moistened by the fall and winter rains. They typically rest on top of gently sloped surfaces, in this case loess-covered flood basalts. **Mafic** minerals, a result of past volcanism, are common in the loess that these soils are derived from. This region experiences slower erosion than the more steeply sloped and continuously changing mountainous regions nearby. This allows the soils ample time to develop a rich and dark topsoil horizon, one that is perfect for supporting grasslands and farming. Agriculture is widespread in this region and is supported by irrigation from several rivers flowing through the area, which help to soak the summer-dried soils. Some of Washington's best apples are grown on the Columbia Plateau.

Some Aridisols can be found in the Channeled Scablands of eastern Washington (*Figure 8.13*)—a barren, eroded area scoured clean by the Missoula Floods—as well as in the southeast corner of this region.

See Chapter 4: Topography for more information about the Missoula Floods.

Figure 8.13: Aridisols in the Channeled Scablands near Wenatchee, Washington.

Soils of the Northern Rocky Mountains
Region 3

The Northern Rocky Mountains provide only a glimpse of the Rocky Mountains that nearly bisect the country. The Rockies formed as the result of both volcanism and **terrane accretion**. From the **Jurassic** to the **Cenozoic**, oceanic lithosphere was **subducted** under the continent at a very shallow angle, driving volcanism farther inland than is typical. The subducting **plate** also brought terranes towards the continent, which accreted during events like the **Laramide Orogeny**. The coastline of the continent began to grow and move farther from the Rocky Mountains, also pushing the subduction zone farther away. With the lack of nearby subduction, volcanism ceased and the Rockies were left far from the coast, tectonically inactive and gradually eroding.

The mountainous terrain and past volcanism are equally responsible for the soil types present in the region. Inceptisols are common due to the steep slopes and wet conditions found in elevated areas. The rapid erosion and frequent washing away of soils means that soils in many areas are poorly developed. Although the bulk of Inceptisols occur on the East Coast, there are parts of the

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

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

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

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

Western US, like the Rockies, that are both humid and forested enough for them to form. The Northern Rockies are unique to the rest of the Rockies in that they also harbor Andisols, a relict of the region's volcanic past that are more dominant in the Cascade-Sierra region.

Soils of the Cascade-Sierra Mountains

Region 4

The Cascades and Sierra Nevada are each the result of distinct volcanic arcs that produced one long span of mountainous terrain. Stretching from Canada all the way down to northern California, the younger Cascade Range was produced by intense volcanism brought on by the continuing subduction of oceanic lithosphere under the North American plate. The frequent ejection of volcanic material contributed greatly to the sediments and minerals present in the area, and this set the stage for the formation of soils that are found almost exclusively in the Pacific Northwest.

See Chapter 1: Geologic History for more detail about subduction and accretion in the formation of the Western states.

Andisols compose most of the Washington area of the Cascades, while Inceptisols dominate the Oregon Cascades. Uniquely identified by the presence of volcanic glass and minerals derived from igneous rocks, many of these soils formed under dense coniferous forests. As in the Rocky Mountains, erosion is frequent in this terrain, making prolonged and deeper soil development difficult.

The Sierra Nevada are located in California, directly south of the Cascades. The Sierra's distinctive **granite** originally formed from ancient **magma intrusions** that have long since cooled and are now heavily weathered (*Figure 8.14*). Even without active volcanism, the range was able to grow due to **exhumation** and **uplift**, and its **relief** became more pronounced with the formation of the lower Basin and Range region to the east. The Sierra act as a transition zone between the arid climate in the east and the coastal climate to the west, and Alfisols tend to form in this type of zone. Although these soils form throughout the nation, and over a greater area east of the Mississippi River, the unique suborder of Xeralfs make up the majority of the Alfisols in the region. These soils can be forested, or even used as crop and grazing lands.

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

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

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

exhumation • *the erosional uncovering or exposing of a geological feature that had been previously covered by deposited sediments.*

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

Figure 8.14: The heavily weathered soils of Temple Crag in the Sierra Nevada consist of carbonate-rich Alfisols and Inceptisols.

relief *• the change in elevation over a distance.*

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

Soils of the Pacific Border
Region 5

The Pacific Border Region has a notable range of soil orders because of its varied topography, nearby volcanism, coastal processes, and the past glaciation of its northern areas. High-energy beaches in the north and lower-energy beaches in the south provide a range of sediments for soil building. Soil material is also contributed by streams descending from the mountains, which create unique **fluvial** deposits. An amazing history of chaotic events, including repeated glaciations during the Pleistocene, the Missoula Floods, and the Columbia River Flood Basalts, have all left their mark on the coast. All of the dominant soil types previously discussed can be found in this region due to the variance in climate, vegetation, and geology that exists from north to south. Andisols are found mostly along the Washington coast, Inceptisols cover the coasts of Oregon and northern California, and Mollisols are scattered around the rest of California's coast.

Region 6

volcanic island • *one of a string of islands created when molten rock rises upward through oceanic crust.*

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

greenhouse gas • *a gas in the atmosphere that absorbs and emits heat.*

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

patterned ground • *patterns and sorting in the soil caused by repeated freezing and thawing, which causes repeated heaving upwards and settling of the rocks and pebbles in the soil.*

Soils of Alaska
Region 6

Alaska's cool climate and rugged terrain limits the agricultural and forestry-related uses of its soil. Accordingly, less than a tenth of the state has been surveyed beyond the "exploratory" level. The United States federal government owns 65% of the state: a conglomeration of national parks, national forests, and national wildlife refuges.

Although Alaska's cooler climate limits the number of soil types present there, its diverse topography does allow for 7 of the 12 soil orders to occur. The state has two major mountain chains, a vast interior highland, remote stretches of frozen plains, and more coastline than the 49 other states combined. It is also home to the Aleutian Islands, a **volcanic island** chain built of basaltic lava and ash deposits that create prevalent Andisols. Of course, the frigid temperatures have an influence on soil regimes, particularly in the interior and on the Arctic coast. Cold temperatures also slow the rate of chemical reactions, while ice can increase erosion. Much more of the state was glaciated in the recent past, though extreme aridity seems to have kept significant swaths ice-free. **Ice sheets** were predominantly found in the south central and panhandle areas, grinding rock to produce sediment.

Precipitation in Alaska generally decreases to the north, varying from less than 18 centimeters (7 inches) per year on the Arctic coast, to more than 630 centimeters (250 inches) per year in parts of the southeast. This increased rainfall in Alaska's southern portion and panhandle contributes to the wetlands and peat bogs found there, where poor drainage and slow decomposition leads to the development of Histosols.

Approximately 332,000 square kilometers (128,000 square miles) of Alaska (nearly twice the size of Washington State) are mountainous, and 39,000 square kilometers (15,000 square miles) of that are glaciated. Other than in parts of the high Rockies, the only permafrost found in the United States is in Alaska. More than 80% of the state has some amount of permafrost—it is nearly ubiquitous north of the Brooks Range but thins to the south, where it is primarily found only in the mountains of the panhandle. Permafrost usually forms anywhere that the average annual air temperature is below -1°C (30°F). The longer the area remains frozen, the deeper the ice can reach, sometimes extending thousands of meters (yards) below the surface. In southern Alaska, where it is too warm to form today, there are still stretches of relict permafrost that remain frozen from the Pleistocene, when conditions were cold enough for it to form (*Figure 8.15*). Unsurprisingly, the permafrost-associated Gelisols are the most common soil type found here.

Subfreezing temperatures affect soil by altering erosional processes, decomposition, the movement of soil particles, and the types of organisms that live in and on the soil. Most permafrost is overlain by no more than a meter (3.3 feet) of annually thawed soil, known as the active layer. The active layer comprises the O and A soil layers, while the lower beds are frozen, effectively removing them from the soil profile. This is precisely why Gelisols are high in organic content and low in nutrients: minerals are prevented from reaching the surface, and organic materials accumulate above the frozen layers.

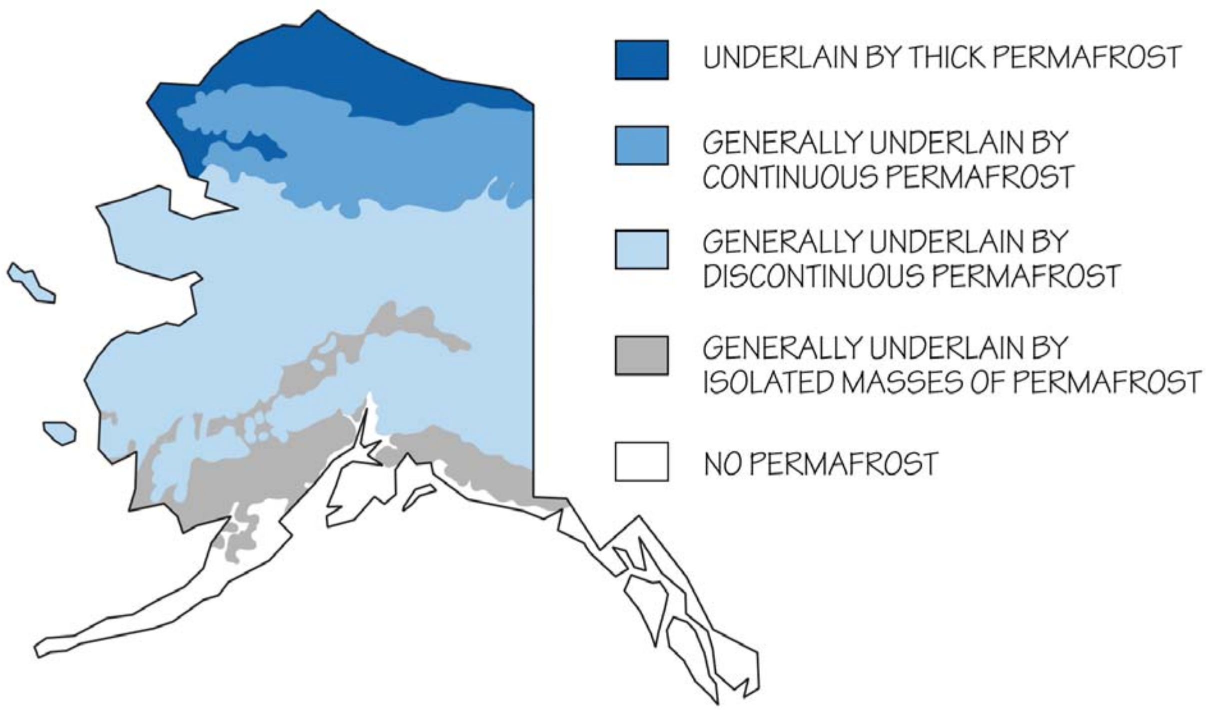

Figure 8.15: The location (and types) of permafrost in Alaska. (See TFG website for full-color version.)

As organic-rich Gelisols build up at the surface, older layers become deeply buried and eventually freeze. Once frozen, organic materials cease to decay, effectively sequestering the carbon they contain in the ground. When permafrost thaws, decay begins again, and carbon-based molecules—perhaps most significantly methane—are released. Methane is an extremely potent **greenhouse gas**, and climatologists believe permafrost thaw will be one of the most important feedbacks driving **global warming** in the coming decades. The buildup and explosive release of methane-rich gases has also been implicated in unusual landforms such as craters and hollows that can form suddenly in permafrost landscapes.

Thawing and freezing can cause soil to move and mix. For example, cold and dry conditions cause the surface to contract, creating cracks that may then fill with sediment. Warmer and wetter conditions cause the ground to expand, and the sediment in the cracks can be forced up. An area in which this process is repeated creates a network of landforms called **patterned ground**. (*Figure 8.16*)

Thawing permafrost can also cause the soil to shift and sink. In some parts of Alaska, these shifts have resulted in trees growing at unusual angles in order to compensate for their changing footing, a phenomenon known as “drunken trees.” (*Figure 8.17*)

Figure 8.16: An overhead view of patterned ground in Alaska.

Figure 8.17: A clear example of drunken trees.

Entisols represent the most productive agricultural soils of the state, and are found on **floodplains** and **outwash plains** where new sediment is deposited at frequent intervals. The Matanuska-Susitna area is also known as "Alaska's breadbasket," due to the fertile Entisols that produce over 75% of the state's agricultural output.

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

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

Soils of Hawai'i
Region 7

Hawai'i's climate, topography, and substrate age are all characterized by large gradients, and there is a similarly large variation in the types of soils found here, despite the somewhat uniform lithology of the underlying basaltic lavas. Of the 12 soil orders classified by the USDA, 10 are found in this state—Alfisols and Gelisols being the only orders not found on the island chain. As might be expected, fewer soil orders are found on the younger islands.

Unlike a continental system, each Hawaiian volcano begins as a blank slate—a barren basalt flow on which soil begins to develop only a few years after the eruption of the substrate. Soil development follows the arrival of early colonizing organisms, both plants and soil microbes, that begin to transform rock into soil. These early soils are relatively rich in nutrient elements derived from the parent material, but are relatively poor in nitrogen, a product of biological activity. Nitrogen-fixing lichens are among the first colonizers of lava flows, and they are critical to the creation of soils capable of supporting a young ecosystem (*Figure 8.18*).

Figure 8.18: Sword ferns and small gray dots of lichen colonize a lava flow on Kīlauea volcano. The lichen is a nitrogen fixer, and the fern contributes organic matter to the soil.

8 Soils

Region 7

Soil development is rapid in the tropics, where high temperatures and locally abundant rainfall accelerate the process. Once soils are established, rainfall also dissolves and mobilizes compounds in the soil, mediating chemical reactions that alter pH and the availability of nutrients. The rate of soil development in Hawaiʻi depends strongly on rainfall. Dry areas evolve in the same direction as wet areas do, but much more slowly. Soluble compounds such as sodium, magnesium, and calcium are leached from the soil, while insoluble compounds such as oxides of iron and aluminum are left behind.

As Hawaiian soils develop, nitrogen also becomes more abundant due to its addition by nitrogen-fixing bacteria. Phosphorous is gradually leached from the soil at a rate faster than it is replaced. In very old soils, where nearly all the phosphorous in the soil profile has been lost, it can only be replaced by deposition from the atmosphere. Interestingly, in Hawaiʻi this input is principally via long-distance atmospheric transport of dust from Asia (*Figure 8.19*).

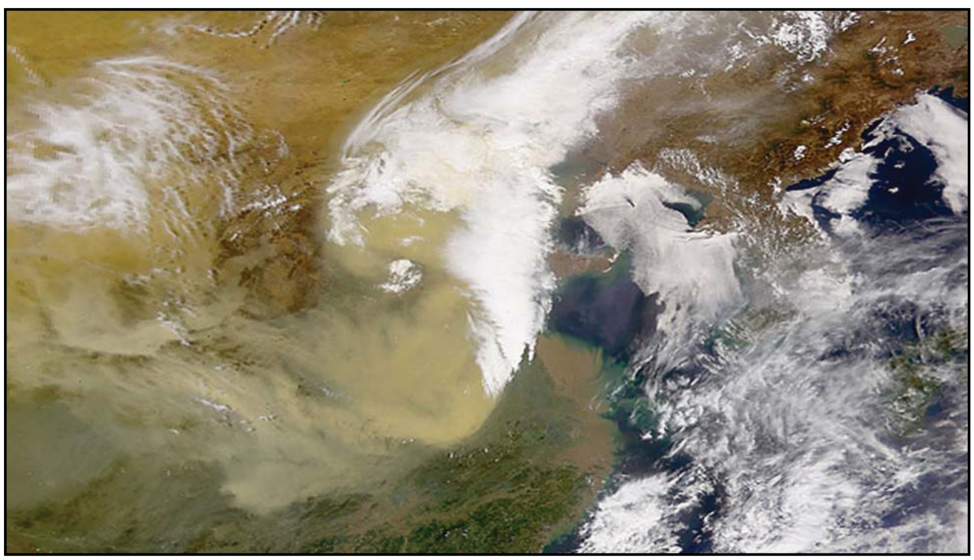

Figure 8.19: Satellite image of China, where continental dust (tan patch at center) blows off of the Gobi desert in a spring storm. Dust storms such as these are important for transporting nutrients to Hawaiian ecosystems. (See TFG website for full-color version.)

The youngest soils and the oldest soils in Hawaiʻi are not well suited for agriculture. The youngest soils are thin, do not have much water-holding capacity, and are poor in nitrogen. In contrast, the oldest soils are acidic, have high levels of aluminum that can be toxic to plant roots, and are poor in phosphorous. But many soils in Hawaiʻi are quite fertile, making the islands highly productive for both traditional and modern methods of cultivation. Harvesting crops tends to remove the most nutrient-rich parts of plants from the system, and this can lead to nutrient depletion over time. Crop rotation and fallow periods can help limit nutrient losses, as can fertilizer use. In traditional wet taro cultivation, where taro is grown in flooded paddies, new sediment brought in by streams provides nutrient-rich material to the taro patch each year, supporting high yields over time. Traditional dry land taro cultivation tended to focus on the “sweet spots”

where there was enough rain to support the crops but not so much that the soil had become too weathered, acidic, and nutrient poor.

In many parts of the world, certain types of soils were valued for the clays they contained that could be made into pots and vessels. Weathering processes in Hawai‘i tend to produce clays that are not well suited for pottery, and thus pottery was not an important traditional craft, unlike in some other Polynesian areas.

State Soils

Just as many states have official state flowers, birds, and **fossils**, they also have official soils. State soils are most often determined by a vote of soil scientists in the state, and, absent any political wrangling, usually represent the most productive soils and those that most closely resemble everyone’s favorite soil: loam. As mentioned earlier, loam soils are almost equal parts sand, silt, and clay.

fossil • *preserved evidence of ancient life.*

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

hardpan • *a dense layer of soil, generally found below the topsoil layer, that is generally impervious to water.*

Alaska

The Alaska state soil is a Gelisol called the Tanana series. These are important agricultural soils in Alaska, and when they are developed for agriculture, they can be used for hay, pasture, grains, and vegetables.

California

California’s state soil is the San Joaquin series, which covers more than 200,000 **hectares** (500,000 acres) of the Great Central Valley. Grapes, oranges, figs, and almonds are just a few of the crops grown on this Alfisol. This soil is also a favorite for urban development due to the presence of **hardpan**, roughly a meter (3.3 feet) below the surface, which restricts water percolation.

Hawai‘i

Given Hawai‘i’s volcanic history, it should be no surprise that its state soil is an Andisol. The Hilo series covers more than 5,900 hectares (14,500 acres) and is a highly productive agricultural soil formed principally from weathered volcanic ash.

Nevada

The Orovada series is the state soil of Nevada. An Aridisol, this soil is deep and well drained, having formed in loess that is high in volcanic ash. The presence of ash reduces the amount of water needed for irrigation, making this a valuable agricultural soil. It is primarily used to grow crops such as barley, winter wheat, alfalfa, and grass (for hay and pasture). Located mainly in the Great Basin portion of the Basin and Range, it covers more than 150,000 hectares (360,000 acres) of northern Nevada.

State Soils

Oregon

An Ultisol known as the Jory series is the state soil of Oregon. This series can be found on more than 120,000 hectares (300,000 acres) of land in the western part of the state. It is a very productive agricultural soil that is a favorite of the local wine industry. The name comes from Jory Hill in Marion County, which owes its name to a family that settled in the area in 1852.

Washington

The state soil of Washington is the Tokul series, an Andisol that formed in volcanic ash and loess over a dense glacial till containing high concentrations of manganese and iron. The name comes from a small community and creek located in King County. The state has more than 400,000 hectares (1,000,000 acres) of Tokul soils, the majority of which are located on the western side of the Cascade Range.

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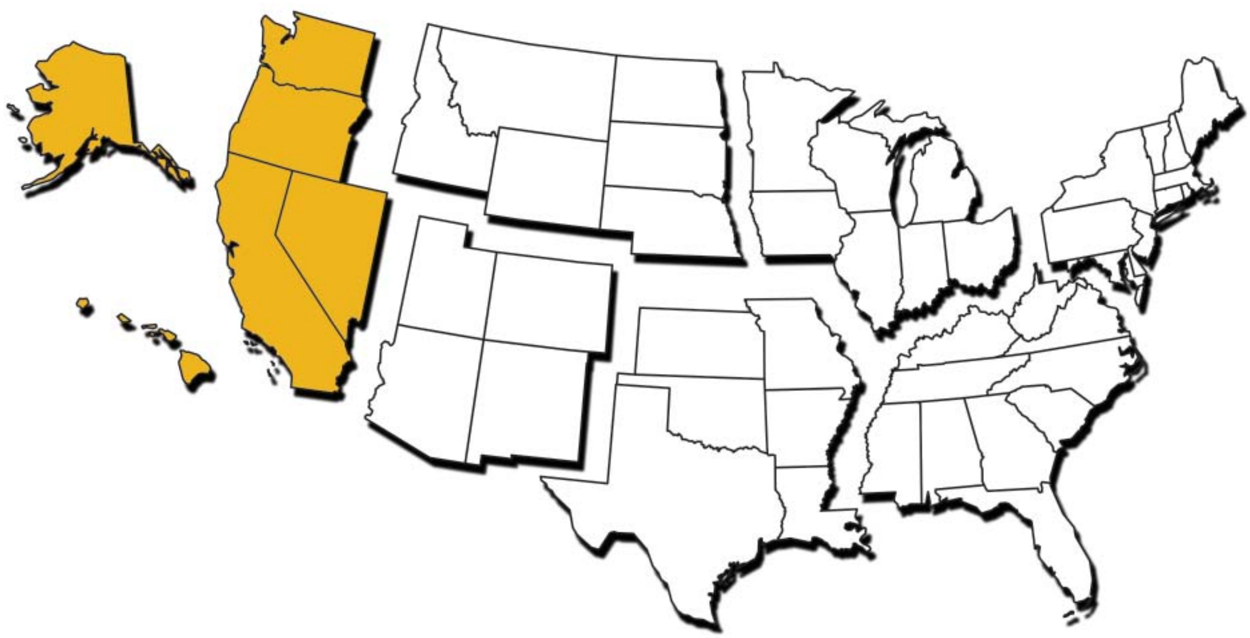
to the Earth Science of the Western US



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