Soil Formation and Properties

Background

All things on the surface of the earth are worn away over time. Organic materials decay, metals rust, and rocks weather. These ongoing processes form the soils that many organisms depend on, and they help determine the types of soil found in any environment. As these processes continue, soil changes. Some changes are accomplished relatively quickly, while others take place over millennia.

Rocks are the primary component of soil. As rocks weather, they are broken into smaller pieces, which become soil particles. These particles are composed of different minerals depending on the makeup of the parent rock, but that is only part of what makes up soil. Organic material from decomposing plants and animals supplies soil with valuable nutrients needed to sustain life. Some ecosystems, such as deserts, have a small biological community, so the soil has less organic material. Other ecosystems, such as temperate forests, produce a great deal of organic material, causing the soil to be quite rich.

Soil Formation

There are three main ways in which soils are formed. The three processes are mechanical, chemical, and biological weathering. All three processes are working at the same time to break down rocks. Mechanical weathering breaks rocks into smaller pieces. This process is called disintegration. Chemical weathering can change the mineral makeup of the rock. This is called decomposition. Biological weathering can take the form of disintegration or decomposition, but always involves living organisms.

Mechanical Weathering

There are several forces that cause physical weathering of rock. Water is one of the most powerful causes of physical weathering. Over time, rocks are worn away as water flows over them. Rocks in fast-moving streams can also be tumbled, impacting each other and chipping or fragmenting. Water also penetrates cracks in rocks. At lower temperatures, the water freezes and expands, further breaking apart the rock. Mechanical weathering also occurs from friction, for example, when wind blows sand and dust particles across the surface of rocks.

Chemical Weathering

Chemical weathering is the decomposition of rock, the result of chemical reactions between minerals in the rock and the environment. Water not only causes physical weathering by wearing away the rock, it also dissolves minerals out of rock. Some common minerals, such as feldspar, chemically react with water to form clay. Oxygen reacts with certain minerals and elements found in rocks, too, forming compounds called oxides. For example, iron-bearing minerals exposed to oxygen will form iron oxide, commonly called rust. The result is the formation of red-brown rings on the rocks. Rust can form in the presence of air, but the process is sped up when water comes into contact with iron. These processes alter the structure of minerals, allowing other weathering processes to further break down the rock.

Acids occur naturally in the environment, and many acids are created by natural processes. However, human activities such as burning fossil fuels have increased the quantity of carbon, nitrogen, and sulfur in the atmosphere. These elements react with water in the air to produce carbonic acid, nitric acid, and sulfuric acid, respectively. These acids bind with rainwater to form acid rain. Some minerals, and many living organisms, are decomposed by acid rain. Long-term exposure to acid deposition in certain areas of the world has had a profound effect, not only on the natural environment, but also on human-built structures composed of similar minerals.

Biological Weathering

Biological weathering describes any processes of disintegration or decomposition accomplished by living organisms. For example, plants roots grow into cracks in rocks and create larger crevices. Some plants grow so far into rocks that, over time, they shatter them. Lichen growing on bare rocks contribute to chemical weathering; they secrete weak organic acids that break down the minerals in rocks. Microorganisms, which contribute heavily to the development of soil, can also contribute to chemical weathering. Through cellular respiration, organisms release carbon dioxide that, when mixed with water, forms carbonic acid. Microbial activity also contributes to the nutrients found in soil. Larger animals also play a role, adding waste material that is broken down by the microorganisms.

Soil Organization

Soil is organized in layers, a product of how the soil is formed. Soil formation typically begins with the weathering of bedrock to produce very fine particles. In time, plants may grow in this material. As these plants die, their remains add organic material to the weathered rock, which brings bacteria, fungi, and microscopic animals to feed on the organic material. Their physical activities and decayed remains further alter the soil. In time, a reasonably thick, dark-colored soil layer is formed. Rain washes dissolved minerals and very fine particles through this layer, often forming a clay layer underneath. Over time, major geologic factors such as glaciers or floods may introduce new layers of soil.

The bottom soil layer rests on bedrock. The point at which the soil is saturated with water is called the *water table*. The depth of the water table varies by location and season.

Characteristics of Soil

The suitability of a specific soil for various activities depends on the chemical and physical aspects of its composition. Chemical features of soil include pH, ion content, and ion-holding capacity, and are determined by physical factors, the qualities of the soil particles and bedrock. These characteristics affect how well a particular soil can supply essential minerals to plants and filter ions out of wastewater.

Plant roots require air and water. Just as a plant can die from lack of water, it can die in waterlogged soil due to lack of air. To support plant life, soil must retain water, allow for easy root penetration, and provide physical support for the plant. Physical features of soil such as particle size and arrangement, the nature of the soil layers, texture, and slope determine how well the soil holds water, how freely water passes through it, how easily it permits root growth, and how readily oxygen permeates it. These physical characteristics not only influence the ability of a soil to support plant life, but also determine its suitability for uses such as supporting materials for buildings and roads, and hosting landfills and septic tank systems.

Soil Horizons

Soils have a layered structure, a consequence of the way in which soil is formed. Scientists call layers of soil having properties different from adjacent layers *horizons*. The kinds of *horizons* found at any one location are the result of the climate, biology, and geology of the region.

Soil scientists have identified major classes of soil *horizons* that share characteristics and formation history. These horizons are designate with capital letters: A, E, B, C, and O (see Figure 1). Additionally, R is the bedrock horizon. Many modifiers can be applied to these classes, according to specific site characteristics. For example, the designation *n* indicates an accumulation of sodium, *f* indicates frozen soil (permafrost), and *p* indicates plowing or another disturbance. This system gives soil scientists a shorthand language to describe the structure of soil at any location.

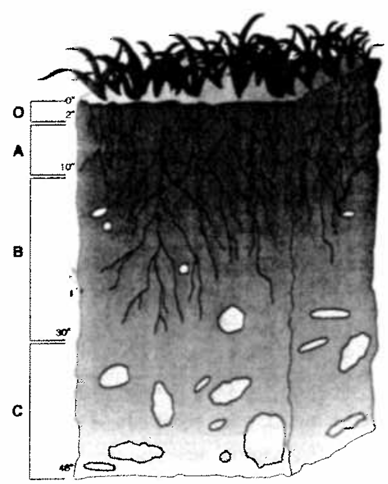

Figure 1. Soil horizons.

Imagine soil being formed from bedrock—very slowly, solid bedrock is weathered into looser material. Eventually, the upper portion of the unconsolidated mineral material supports plants, which remove nutrient ions from the mineral material and replace them with hydrogen ions. This replacement, together with the gradual action of water, slowly changes the chemical composition of the mineral material. Processes of plant growth, death, and decay deposit organic materials near the surface of the soil. Animals, bacteria, and fungi feed on these remains, contributing their own organic residues to the upper regions of the soil.

In time, the surface region of the soil acquires a composition and appearance that is distinctly different from that of the underlying material; it is darker, because of the organic material. This dark surface layer that is relatively rich in organic matter is called an *A horizon*. The A horizon is the topsoil layer. Depending on the environment, the soil may have a layer of relatively whole, decomposing organic matter on top of the A horizon. This is called an *O horizon*. In forests, the O horizon consists of leaf litter and other decomposing plant material.

Water percolating through the A horizon rinses some components into the underlying soil. The components that accumulate underneath the A horizon are usually clay, some organic matter, and oxides of iron and aluminum. This layer is the *B horizon*, the subsoil. (There may be an additional light-colored horizon between A and B, called the *E horizon*.) Beneath the B horizon is a layer that sits on the bedrock and contains broken-down rock. This is the *C horizon*. An analysis of soil that identifies the horizons, their thickness, and the individual properties of each layer is called a *soil profile*.

Soil Texture, Structure, and Consistence

Soil Texture

Soil texture is determined by the ratio of sand, silt, and clay in the sample. By definition, organic matter does not contribute to soil texture. Sand, silt, and clay are mineral components of soil and are distinguished by particle size. Particles with a diameter greater than 0.05 mm are sand. Particles with a diameter between 0.002 mm and 0.05 mm are silt; and particles with a diameter less than 0.002 mm are clay. Soil scientists group soil into three classes based on texture: sands, loams (mixtures of sand, silt, and clay), and clays.

A common field test to determine soil texture is the ribbon test. A small amount of soil is moistened, formed into a ball, and then squeezed and pinched. The behavior of the sample during the test (for example, whether it forms a ball or a ribbon—and, if so, how long a ribbon) determines its classification.

Soil Structure

Primary soil particles (sand, silt, and clay) are arranged into secondary units called *peds* (see Figure 2). The shape of the peds and the way in which they aggregate in soil is referred to as *soil structure*. Soil structure affects how easily air, water, and plant roots move through soil. Human activity such as repeated trampling of soil or plowing wet soil can alter soil structure.

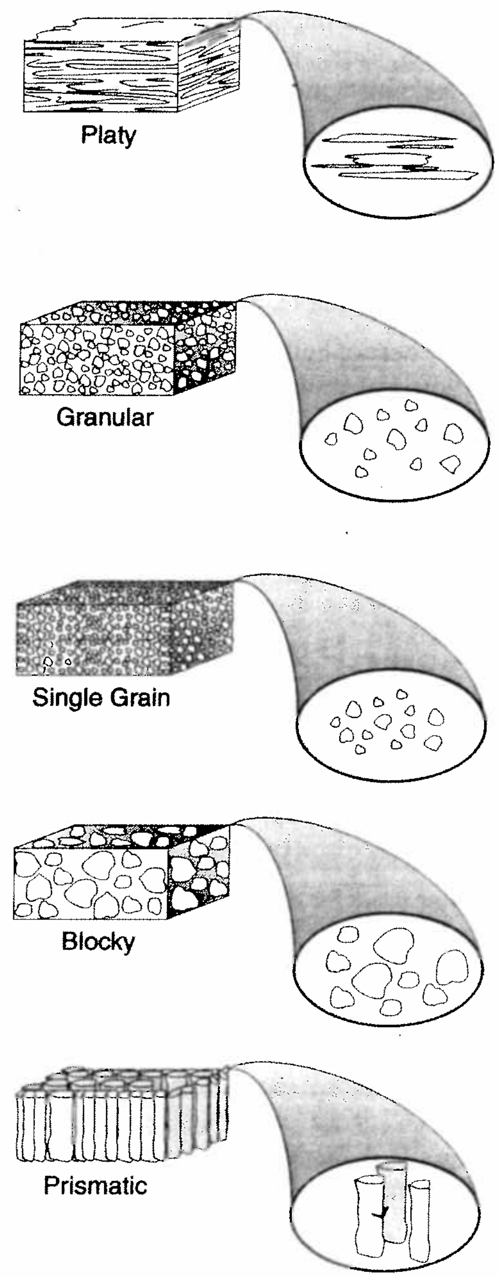

Figure 2. Examples of soil peds.

Soils that separate easily into rounded peds are called *granular* soils. Granular soils do not pack tightly and have high permeability. They are usually found near the surface, where organic matter is abundant. Granular soils are particularly suitable for plant growth, because their structure permits air, water, and plant roots to easily penetrate the soil. Clay and loamy soils often have *blocky* peds, which are angular and somewhat irregular in shape. Their irregularity ensures that soils composed of blocky peds contain pore spaces that permit passage of air and water. Soils with plate-shaped peds are tightly packed and difficult for air and water to penetrate. These are called *platy* soils; they usually have high clay content and often occur in frequently flooded areas. These soils are also called "clay-pan" soils. Sand itself is a structureless soil; the primary particles do not aggregate, but fall apart instead.

Soil Consistence

The degree to which soil resists pressure is referred to as its *consistence*. Vehicles, farm and construction machinery, a herd of cattle, and even human footsteps can put a great deal of pressure on soil, so consistence is important when considering how land should be managed. The terms *loose*, *friable*, *sticky*, *nonsticky*, *plastic*, *nonplastic*, *soft*, *firm*, and *hard* are used to describe the consistence of soil and how well the soil resists the effects of wind, water, machinery, etc.

Bulk Density and Compaction

Bulk density (BD) expresses how much a soil weighs per unit volume. Soil is comprised of soil particles and pore space. Bulk density depends on both the amount of pore space in a particular soil and the density of the soil particles. Determining bulk density is simple: mass a sample of soil and measure its volume. Therefore, bulk density is expressed as mass/volume.

The aspect of bulk density that is important for understanding other properties of soil is *porosity*, the volume percentage of the total pore space. Soil contains both large and small pores (spaces between soil particles) that are occupied by air or water.

To determine porosity, a core of soil with a known volume is oven dried and weighed. A core of identical size is placed in a pan of water until it is completely saturated, and than it is weighed. The difference between the weight of the saturated core and the oven-dried core indicates the weight of water the core can hold. This indicates the volume of pore space in the soil.

For example, assume that a 200 cc soil core weighs 260 g when oven dried and 360 g when saturated. The core can hold 100 g of water, which is equivalent to 100 cc of water, so total pore space is 100 cc. Porosity is 100 cc/200 cc × 100%, or 50%. A 50% pore space is typical for medium-textured soil.

By definition, sand has a larger particle size and is coarser than loam, silt, or clay. Because there are fewer particles in a given volume of sand, there are fewer pore spaces than in finer-textured soil. Sand typically has a porosity of approximately 40%. Finely textured soils usually have a variety of particle sizes and shapes that do not pack tightly. A clay-textured A horizon with a granular structure may have 60% porosity.

Water usually runs through sandy soil faster than through soil with a high percentage of clay. The explanation for this odd fact is that most pores in sandy soil are large and permit air and water to pass easily through the soil. Clay has more total pore space than sand, but the pores are much smaller, so water cannot pass through them as quickly.

If the particle density (PD) is known, bulk density can be used to calculate porosity:

$$\text{Porosity} = 100\% - [\text{BD/PD} \times 100]$$

The BD/PD ratio gives the fraction of the soil volume occupied by solids. As bulk density decreases (PD remaining the same), the total pore space increases and the volume occupied by solids decreases.

