APES-Smith

SOIL UNIT

FORMATION, PROPERTIES & TYPES

Readings:

- http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/soil_systems/soil_development_weathering.html
    - Click through the pages using the “continue” link at the bottom of each page.
- Other text
    - Copied pages attached – p.94-100

Supplements:

- Attached
    - Soil diagrams
    - Barron’s book
    - Soil lab

START

growth. Thus, its variation provides a key to understanding the distribution of plant species and the productivity of biological communities.

Soil defies simple definition, but we may describe it as the layer of chemically and biologically altered material that overlies rock or other unaltered materials at the surface of the earth. It includes minerals derived from the parent rock, modified minerals formed anew within the soil, organic material contributed by plants, air and water within the pores of the soil, living roots of plants, microorganisms, and the larger worms and arthropods that make the soil their home (see Figure 1.7). Five factors largely determine the characteristics of soils: climate, parent material (underlying rock), vegetation, local topography, and, to some extent, age.

Soils exist in a dynamic state, changing as they develop on newly exposed rock. And even after soils achieve stable properties, they remain in a constant state of flux. Groundwater removes some substances; other materials enter the soil from vegetation, in precipitation, as dust from above, and from the rock below. Where little rain falls, the parent material decomposes slowly and plant production adds little organic detritus to the soil. Thus arid regions typically have shallow soils, with bedrock lying close to the surface (Figure 4.17). Soils may not form at all where decomposed bedrock and detritus erode as rapidly as they form. Soil development also stops short on alluvial deposits, where fresh layers of silt deposited each year by floodwaters bury older material. At the other extreme, soil formation proceeds rapidly in parts of the humid Tropics, where chemical alteration of parent material may extend to depths of 100 meters. Most soils of temperate zones are intermediate in depth, extending to a rough average of about 1 meter.

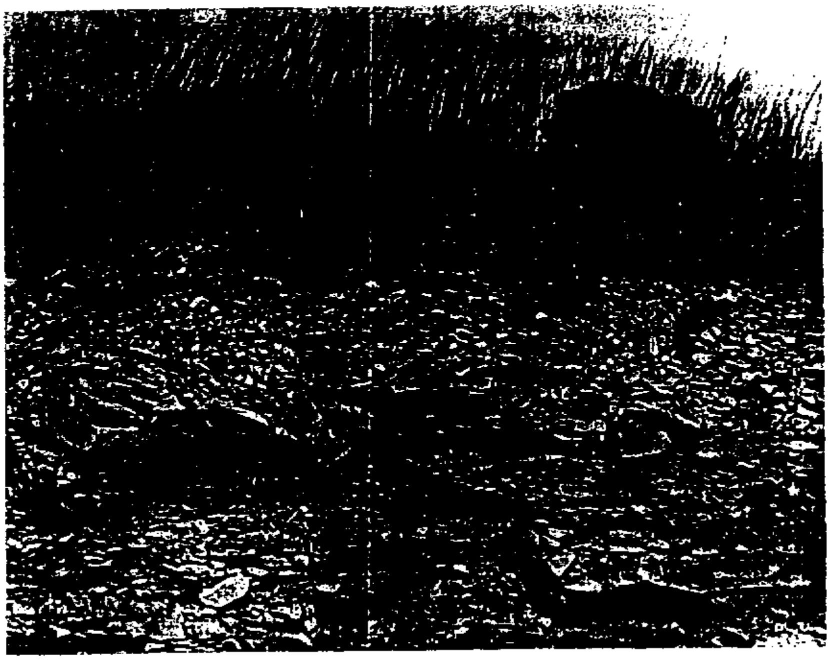


Figure 4.17 Profile of a poorly developed soil (inceptisol) in Logan County, Kansas, illustrating shallow soil depth and absence of soil zonation. Courtesy of the U.S. Soil Conservation Service.

Soil horizons

Where a recent road cut or excavation exposes soil in cross section, one often notices distinct layers, which are called **horizons** (Figure 4.18). A generalized, and somewhat simplified, **soil profile** has four major divisions, the O, A, B, and C horizons; the A horizon has two subdivisions (A_1 and A_2). Arrayed in descending order from the surface of the soil, the horizons and their predominant characteristics are as follows:

O Primarily dead organic litter. Most soil organisms inhabit this layer.

A_1 A layer rich in humus, consisting of partly decomposed organic material mixed with mineral soil.

A_2 A region of extensive leaching of minerals from the soil. Because minerals are dissolved by water—that is to say, mobilized—in this layer, plant roots are concentrated here.

B A region of little organic material whose chemical composition resembles that of the underlying rock. Clay minerals and oxides of aluminum and iron leached out of the overlying A_2 horizon are sometimes deposited here.

C Primarily weakly altered material, similar to the parent rock. Calcium and magnesium carbonates accumulate in this layer, especially in dry regions, sometimes forming hard, impenetrable layers, or "pans."

Soil horizons reveal the decreasing influence of climate and biotic factors with increasing depth. Critical to soil formation is the movement of mineral elements upward and downward through the soil profile. But before considering these processes in detail, we shall examine the initial alteration of the bedrock and how it influences soil characteristics.

Weathering

Weathering—the physical and chemical alteration of rock material near the earth's surface—occurs wherever surface water penetrates. The repeated freezing and thawing of water in crevices physically breaks rock into smaller pieces and exposes a greater surface area to chemical action. Initial chemical alteration of the rock occurs when water dissolves some of the more soluble minerals, especially sodium chloride ($NaCl$) and calcium sulfate ($CaSO_4$). Other materials, such as the oxides of titanium, aluminum, iron, and silicon, dissolve less readily.

The weathering of granite exemplifies some basic processes of soil formation. The minerals making up the grainy texture of granite—feldspar, mica, and quartz—consist of various combinations of oxides of aluminum, iron, silicon, magnesium, calcium, and potassium, along with other, less abundant compounds. The key to weathering is the displacement of certain elements in these minerals—notably calcium, magnesium, sodium, and potassium—by hydrogen ions, followed by the reorganization of the remaining oxides of aluminum, iron, and silicon into new minerals.

Feldspar, which consists of aluminosilicates of potassium, weathers rapidly because of the displacement of potassium ions (K^+) by hydrogen ions (H^+) to form new, insoluble materials, particularly clay particles. Mica grains consist of aluminosilicates of potassium, magnesium, and iron. As in feldspar, the potassium and magnesium are displaced readily during weathering, and the remaining iron, aluminum, and silicon make new minerals. Hydrated iron and aluminum silicates form various kinds of **clay** particles, which contribute importantly to the water- and cation-holding capacity of soils. Quartz, a type of silica (SiO_2), is relatively insoluble and therefore remains more or less unaltered in the soil as grains of sand. Changes in chemical composition as granite weathers from rock to soil in different climate regions show that weathering is most severe under tropical conditions of high temperature and rainfall (Figure 4.19).

An important factor in the initial weathering of parent matérial, regardless of the chemical nature of the rock, is the presence of hydrogen ions in the water that percolates down to the bedrock. These ions derive from two sources. All precipitation contains dissolved carbon dioxide, which, as we have seen, forms carbonic acid. Some of the carbonic acid dissociates into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). In regions not affected by pollution-caused acidification, concentrations of hydrogen ions in rainwater produce a pH of about 5. This acidity is supplemented by hydrogen ions generated by the oxidation of organic material in the soil. The metabolism of carbohydrate, for example, produces carbon dioxide, and dissociation

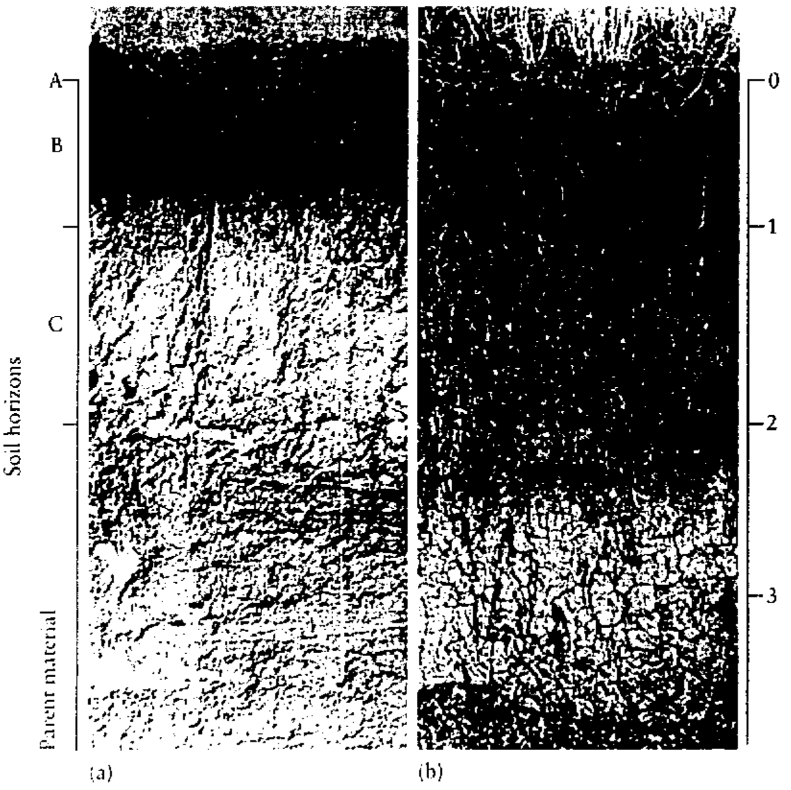


Figure 4.18 Soil profiles of mollisols (prairie soils) from the central United States, illustrating distinct layers, or horizons. (a) This profile, from eastern Colorado, is weathered to a depth of about 2 feet (0.6 m), where the subsoil contacts the parent material, which consists of loosely aggregated, calcium-rich, wind-deposited sediments (loess). A_1 and A_2 horizons are not clearly distinguished. The B horizon contains a dark band of redeposited organic materials that were leached from the uppermost layers of the soil. The C horizon is light colored and has been leached of much of its calcium. Some of the calcium has been redeposited at the base of the C horizon and at greater depths in the parent material. (b) A typical prairie soil from Nebraska. Rainfall here is sufficient to leach readily soluble ions completely from the soil; hence there are no B layers of redeposition, as in the drier Colorado soil, and the profile is more homogeneous. The A horizon is weakly subdivided into a darker upper layer and a lighter lower layer. The weathered soil lies on a parent material composed of loess, the wind-blown remnants of glacial activity.

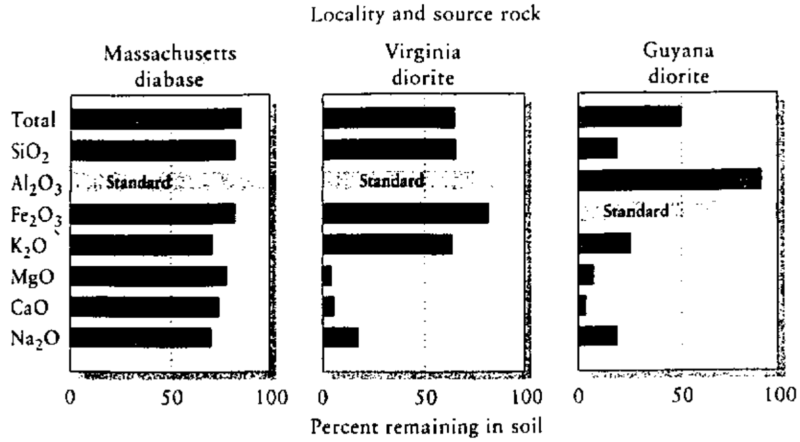


Figure 4.19 Differential removal of minerals from granitic rocks as a result of weathering in Massachusetts, Virginia, and Guyana. Values are compared with either aluminum or iron oxides (these standards = 100%), which are assumed to be the most stable components of the mineral soil. After E. W. Russell, *Soil Conditions and Plant Growth*, 9th ed., Wiley, New York (1961).

of the resulting carbonic acid generates additional hydrogen ions. In the Hubbard Brook Forest of New Hampshire, these internal processes account for about 30% of the hydrogen ions needed for the weathering of bedrock; the remainder comes from precipitation. In the Tropics, however, internal sources of hydrogen ions produced by biological oxidation of organic substrates in the soil assume greater importance and may lead to more rapid weathering.

Clay, humus, and the cation exchange capacity of soil

Plants obtain mineral nutrients from the soil in the form of dissolved ions, whose solubility derives from their electrostatic attraction to water molecules. Because ions are dissolved in water, those not immediately taken up by plants and fungi may wash out of the soil if they do not adhere strongly to stable soil particles. Clay particles and **humus** particles consisting of fine organic detritus, separately or associated in complexes, are large enough to form a stable component of the soil. These particles and complexes, known as **micelles,** have negative electric charges at their surfaces that hold the smaller, more mobile ions in the soil (Figure 4.20). The number of sites on soil particles available for binding positively charged ions (cations) is referred to as the soil's **cation exchange capacity.**

The bonds between soil particles and such ions as potassium (K^+) and calcium (Ca^{2+}) are relatively weak, so they constantly break and form anew. When a potassium ion dissociates from a micelle, its place may be taken by any other positive ion close by. Some ions cling more strongly to micelles than others—in order of decreasing tenacity: hydrogen, calcium, magnesium, potassium, and sodium. Hydrogen ions thus tend to displace calcium and all other cations in the soil. If cations were not added to or removed from the soil, the relative proportions of the various cations associated with clay-humus particles would achieve a steady state. But carbonic acid in rainwater and organic acids produced by the decomposition of organic detritus continuously add hydrogen ions to the upper layers of the soil; these readily supplant other cations, which are then washed out of the soil and into the groundwater. The influx of hydrogen ions in water percolating through the

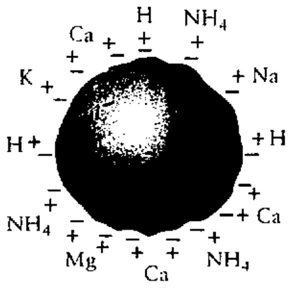


Figure 4.20 Schematic representation of a clay or humus particle (micelle) with hydrogen ions and mineral ions attracted by negative charges at its surface. After S. R. Eyre, *Vegetation and Soils*, 2d ed., Aldine, Chicago (1968).

soil largely accounts for the mobility of ions in the soil and for the differentiation of layers in the soil profile.

Negative ions that are important to plant nutrition, such as nitrate, phosphate, and sulfate, can be adsorbed onto clay particles by means of ion "bridges." These bridges form under acid conditions by the association of an additional hydrogen ion with a functional group such as the hydroxyl group (OH). Let's represent the hydroxyl group on compound R in a soil micelle as ROH. $ROH + H^+$ produces the positively charged ROH_2^+, which in turn makes possible the binding of anions (for example, $ROH_2^+ \cdots NO_3^-$).

Because of the cation-binding properties of clay and humus particles, the potential long-term fertility of soil—its capacity for storing nutrients—depends in large part on its clay content. Furthermore, because hydrogen ions displace others from soil particles and influence the electric charges on the surfaces of these particles, the retention of ions in the soil and the immediate availability of ions to plants depend to a large degree on the acidity of the soil.

Podsolization

The qualities of soils depend on the underlying parent rock and on the climate (Table 4.1). Under mild, temperate conditions of temperature and rainfall, sand grains and clay particles resist weathering and form stable components of the soil skeleton. In acid soils, however, clay particles break down in the A horizon of the soil profile, and their soluble ions are transported downward and deposited in lower horizons. This process, known as **podsolization,** reduces the ion exchange capacity, and therefore the fertility, of the upper layers of the soil.

Acid soils (spodosols) occur primarily in cold regions where needle-leaved trees dominate the forests. The slow decomposition of plant litter produces organic acids. In addition, rainfall usually exceeds evaporation in regions of podsolization. Under these moist conditions, because water continuously moves downward through the soil profile, little clay-forming material is transported upward from the weathered bedrock below.

In North America, podsolization advances furthest under spruce and fir forests in New England and the Great Lakes region and across a wide belt of southern and western Canada. A typical profile of a highly podsolized soil (Figure 4.21) reveals striking bands corresponding to the regions of leaching and redeposition. The topmost layer of the profile (A_1) is dark and rich in organic matter. This is underlain by a light-colored horizon (A_2) that has been leached of most of its clay content. As a result, the A_2 horizon consists mainly of sandy skeletal material that holds neither water nor nutrients well. One usually finds a dark band of deposition immediately below the A_2 horizon. This is the uppermost layer of the B horizon, where iron and aluminum oxides are redeposited. Other, more mobile minerals may accumulate to some extent in lower parts of the B horizon, which then grades almost imperceptibly into a C horizon and the parent material.

TABLE 4.1 The major soil groups

NAME	CHARACTER	DISTRIBUTION IN THE UNITED STATES
Alfisols	Moist, moderately weathered mineral soils	Ohio Valley, Great Lakes region, Rocky Mountains, central California
Aridosols	Dry mineral soils with little leaching and accumulations of calcium carbonate	Great Basin, southwestern deserts
Entisols	Recent mineral soils lacking development of soil horizons	On hard rock in the Rocky Mountains, on sands in the Southwest
Histosols	Organic soils of peat bogs; mucks	Northern Minnesota, Mississippi Delta, Florida Everglades
Inceptisols	Young, weakly weathered soils	New York, Pennsylvania, West Virginia; alluvial soils of Mississippi Valley, northwestern states, Alaska
Mollisols	Well-developed soils high in organic matter and calcium; very productive	Most of the prairie soils of the Great Plains
Oxisols	Deeply weathered, lateritic soils of moist tropics	Tropical South America and Africa; not present in the United States
Spodosols	Acid, podsolized soils of cool, moist climates with a shallow leached horizon and a deeper layer of deposition	Forested regions of New England; northern Michigan and Wisconsin
Ultisols	Highly weathered soils of warm, moist climates with abundant iron oxides	Most of the southeastern United States, the Pacific Northwest
Vertisols	High content of swelling-type clays developing deep cracks in dry seasons	Southern Texas

Laterization

The warm, wet climates of many tropical regions weather the soil to great depths. One of the most conspicuous features of weathering under these conditions is the breakdown of clay particles, which results in the leaching of silica from the soil and leaves oxides of iron and aluminum to predominate in the soil profile. This process is called **laterization,** and the iron and aluminum oxides give lateritic soils (oxisols) their characteristic reddish coloration. Even though the rapid decomposition of organic material in tropical soils contributes an abundance of hydrogen ions, these are quickly neutralized by the bases formed by the breakdown of clay minerals; consequently, oxisols usually are not very acidic. Laterization is enhanced in certain soils that develop on parent material deficient in quartz (SiO_2) but rich in iron and magnesium (basalt, for example); these soils contain little clay to

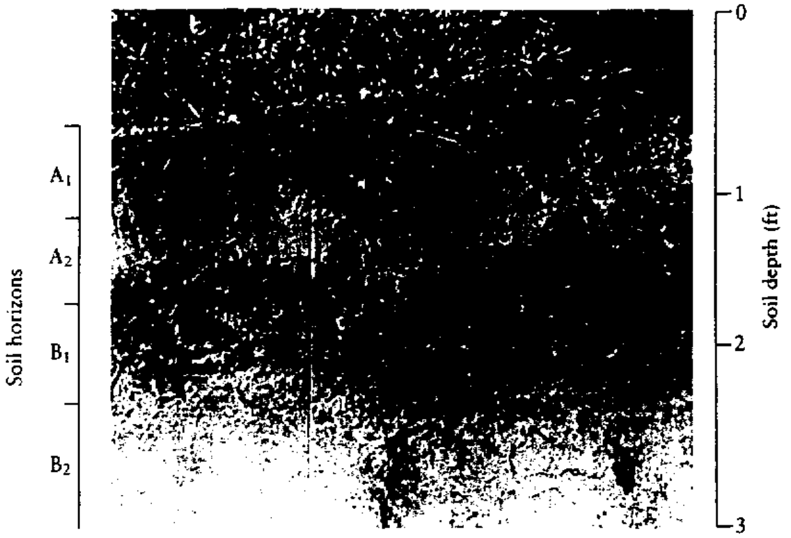


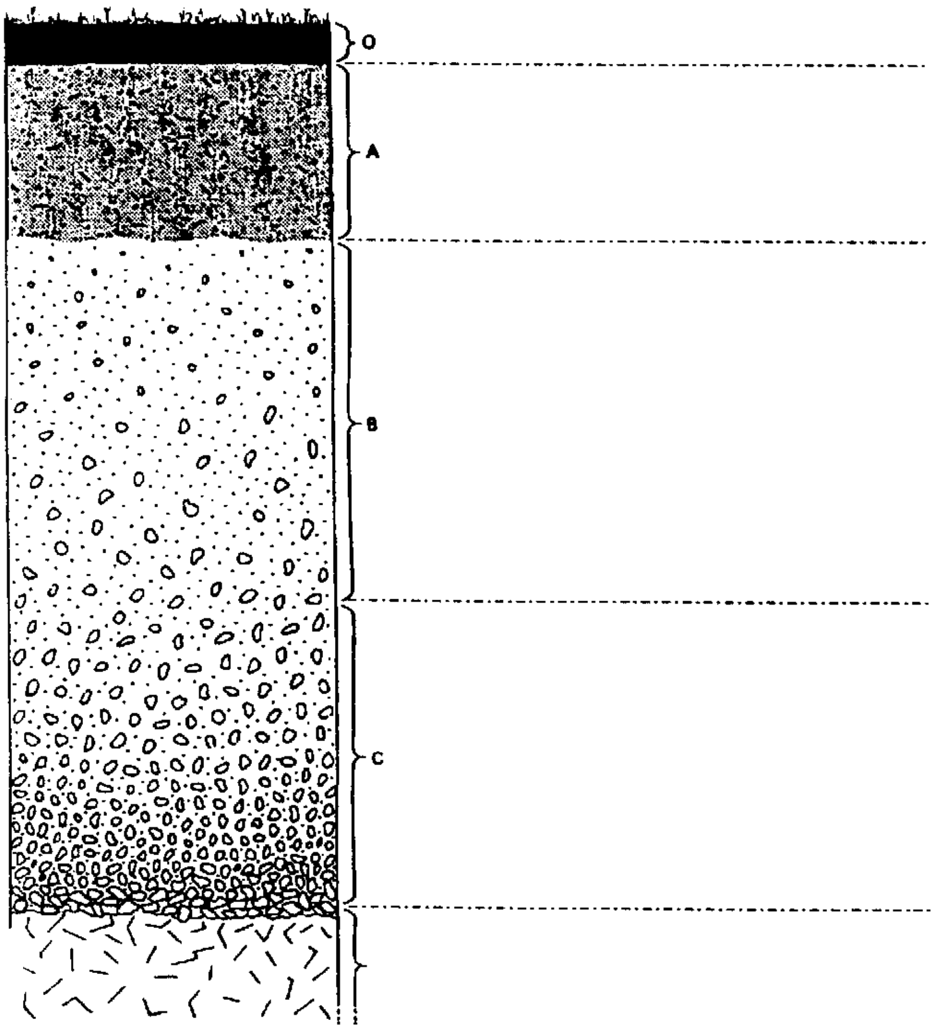
Figure 4.21 Profile of a podsolized soil in Plymouth County, Massachusetts. The light-colored A_2 horizon and the dark-colored B_1 horizon immediately below it form distinct bands. Compare the general absence of roots in the A_2 horizon with their presence in the lower B_1 horizon. Courtesy of the U.S. Soil Conservation Service.

begin with because they lack silicon. Regardless of the parent material, weathering reaches deepest and laterization proceeds furthest on low-lying soils, such as those of the Amazon Basin, where highly weathered surface layers are not eroded away and the soil profiles are very old.

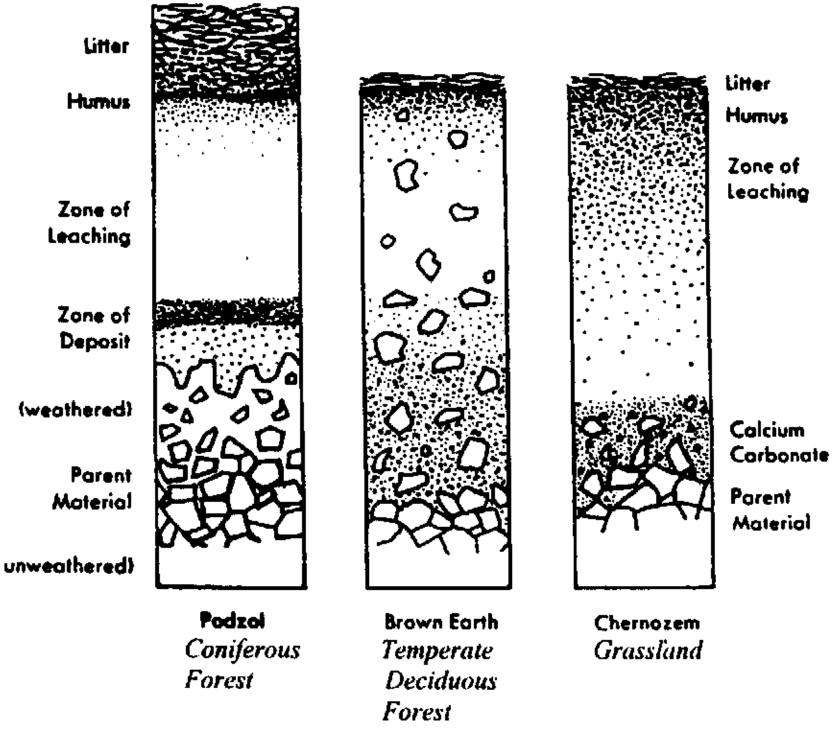
One of the consequences of laterization in many parts of the Tropics is that the capacity of the soil to hold nutrients is very poor. Without clay and humus, cation exchange capacity can be low, in which case mineral nutrients are readily leached out of the soil. Where soils are weathered deeply, new minerals formed by the decomposition of the parent material are simply too far from the surface layers of the soil to contribute to soil fertility. Besides, heavy rainfall keeps water moving down through the soil profile, preventing the upward movement of nutrients. In general, the deeper the ultimate source of nutrients in the unaltered bedrock, the poorer the surface layers. Rich soils do, however, develop in many tropical regions, particularly in mountainous areas where erosion continually removes nutrient-depleted surface layers of the soil, and in volcanic areas where the parent material of ash and lava is often rich in such nutrients as potassium.

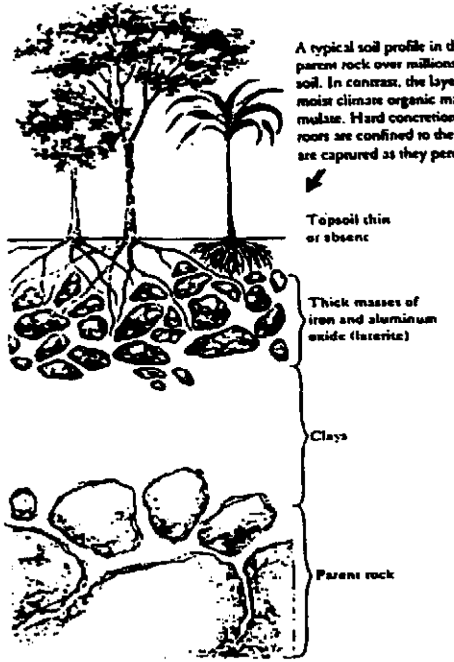
Soil formation emphasizes the role of the physical environment, particularly climate, geology, and landforms, in creating the tremendous variety of environments for life that exist at the surface of the earth and in its waters. In the next chapter, we shall see how this variety affects the distribution of life forms and the appearance of biological communities.

GENERALIZED SOIL PROFILE



SOME MAJOR SOIL CATEGORIES





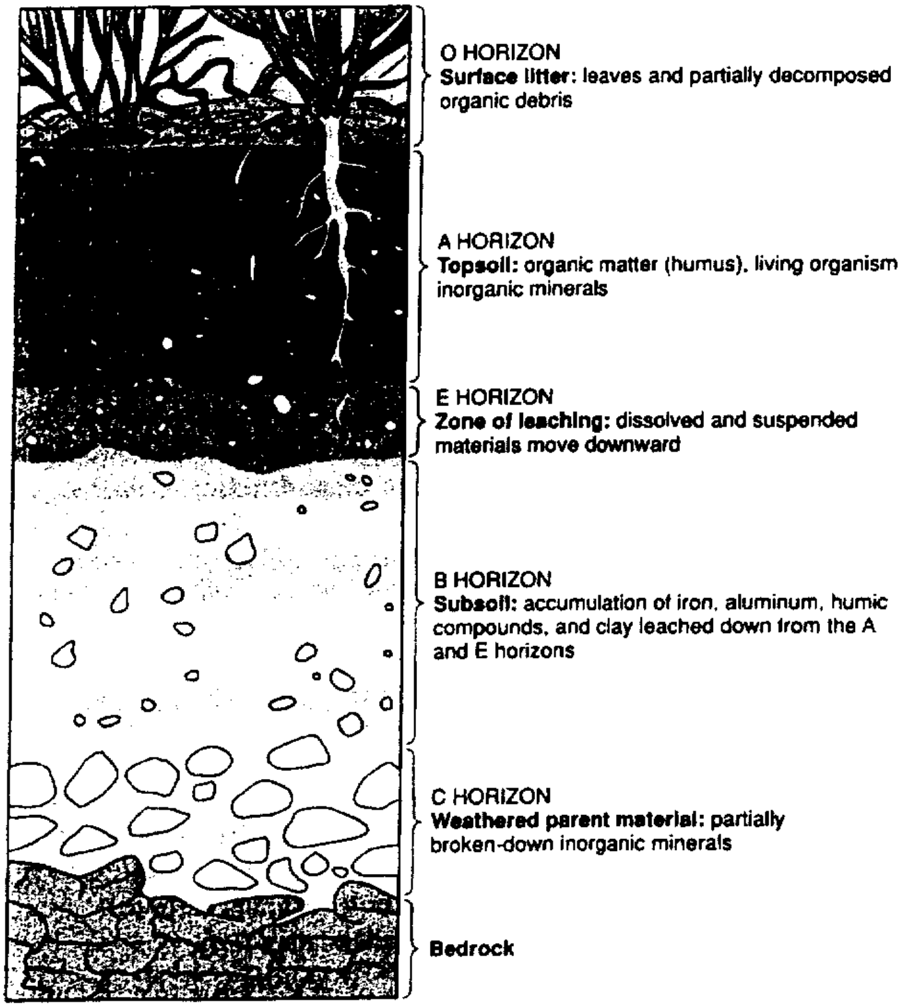
A typical soil profile in the humid tropics. Weathering of the parent rock over millions of years has produced a deep bed of soil. In contrast, the layer of topsoil is thin because in the warm, moist climate organic matter decomposes too rapidly to accumulate. Hard concretions often form below the surface. Tree roots are confined to the superficial layers from which nutrients are captured as they percolate downward.

Lateritic Soil

Tropical Rain Forest

More Soil Stuff

FROM BARRON'S BOOK



SOIL FORMATION AND PROFILES

O horizon—top surface litter layer. Decomposed leaves and organic matter. Normally brown or black. Rich in bacteria, fungi, insects, and earthworms.

A horizon—topsoil layer. Humus and minerals. Roots are in this area. Also rich in living organisms. If dark brown or black (rich in nitrogen and organic material), good for crops. If gray, yellow, or red (low in organic matter), poor for crops.

B horizon—subsoil layer. Mostly inorganic (minerals). Clay particles present. Receives material from A horizon through illuviation. May be colored by iron oxides (red), aluminum oxides (yellow) or white due to calcium carbonate.

C horizon—weathered parent material. Consists of broken fragments of parent rock.

R horizon—unweathered bedrock.

TYPES OF SOIL

Clay—very fine particles. Compacts easily. Forms large, dense clumps when wet. Low permeability to water therefore upper layers become waterlogged. Holds positively charged ions. Less than 0.002 mm in size.

Gravel—coarse. An unconsolidated mixture of rock fragments or pebbles.

Loams—a mixture of clay, sand, silt, and humus. Best soils for crops. Holds water but does create waterlogging.

Sand—a sedimentary material coarser than silt. Water flows through them too fast for most crops. Good for crops requiring low amounts of water. 0.06–2.0 mm.

Silt—a sedimentary material consisting of very fine particles intermediate in size between sand and clay. 0.002–0.06 mm.

PRINCIPAL SOIL PROCESSES

Process	**Description**
Calcification Chernozem	Common in grasslands. Occurs when the rate of evapotranspiration exceeds the rate of precipitation. This results in the upward movement of alkaline salts (calcium carbonate) from groundwater into the B horizon. Caliche may form.
Gleization	Common in areas of cold climate (which limits percolation) and poor drainage—bogs. Organic matter accumulates in the upper layers. Clay layers limit the porosity of the soil, causing plant litter and animal waste to be accumulated on the surface. Soil depth is limited and humus collects along the surface.
Laterization Latisol	Common in tropical and subtropical soils. High temperatures and moisture cause rapid weatherization of rock. Rainfall causes the leaching of soil nutrients, except for iron and aluminum compounds. Soils are typically acidic due to the loss of basic cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+). Eluviation (movement of nutrients downward through soil profile) is high. Nutrients are stored in vegetation. Nutrient level in soil is low.
Podzolization Podzol Soils	Common in cold, midlatitude areas. Supports coniferous plant life (evergreens, needles, scalelike leaves). Soil is acidic due to decomposition of coniferous litter. Leaching removes basic cations from soil (Ca^{2+}, Mg^{2+}, K^+, and Na^+). Aluminum and iron compounds found in A horizon.
Salinization	Occurs in dry climates. Similar to calcification except it lacks rainwater and its downward action to keep the alkaline salts from reaching the A horizon. In this case, the alkaline salts occur near the surface.

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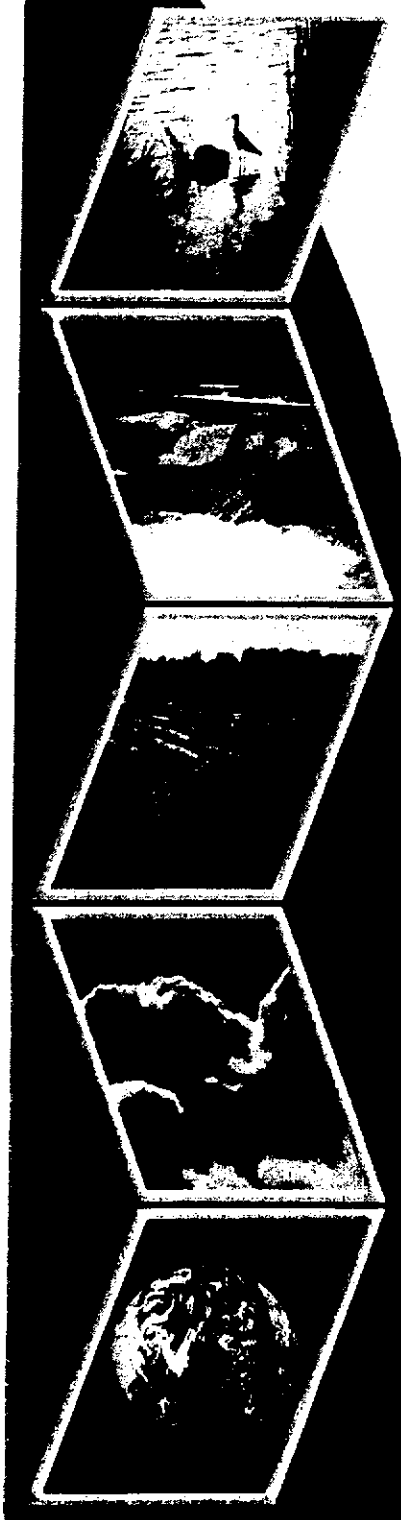

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Carolina™ Soil Formation and Properties Kit

STUDENT GUIDE

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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.

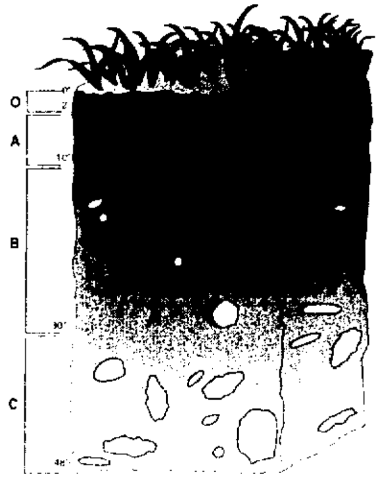


Figure 1. Soil horizons.

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.

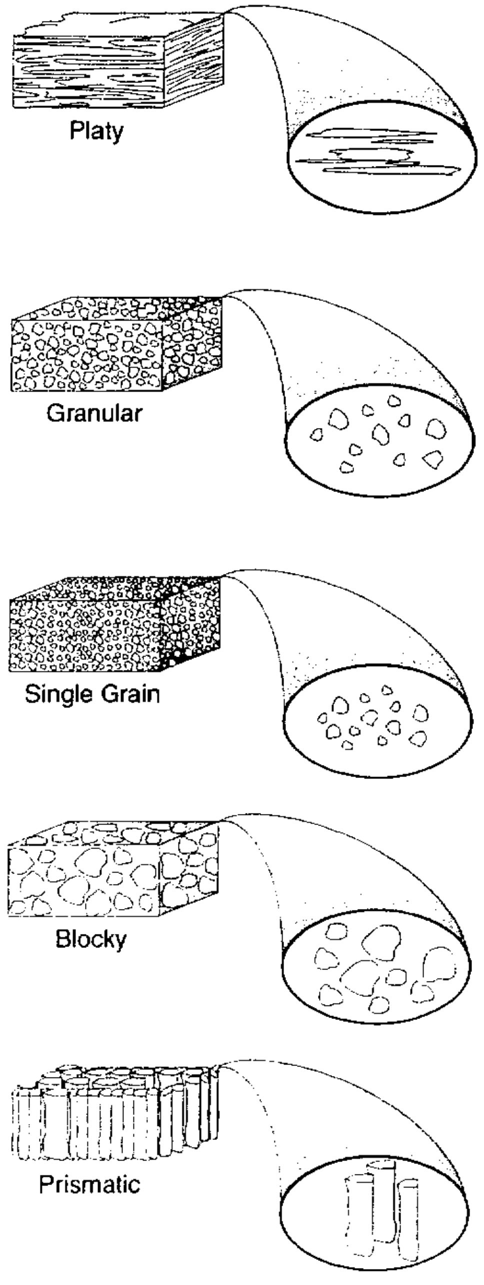


Figure 2. Examples of soil peds.

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.

Compaction

Just as soil structure can be changed by disturbances, so can porosity. If soil is subjected to pressure, pore spaces can collapse, decreasing total pore space. Studies have shown that a single pass of a motorcycle in the Mojave Desert increased the bulk density of loamy sand soils from 1.52 to 1.60 g/cc. Soil from the area around picnic tables and tent sites in Rocky Mountain National Park was found to have a bulk density of 1.60 g/cc, as compared to 1.03 g/cc in less-traveled areas of the park. Compaction reduces the permeability of soil to water and air.

The Slope of the Land

One of the most important features of a soil survey is the slope of the land. The slope of the land can help determine whether a piece of land should be planted with grass, trees, or cultivated crops, or if it can be used as a site for a home, parking lot, landfill, septic tank system, etc.

Slope is categorized by percentages, in the following way:

<2% slope	nearly level
2–6% slope	gentle
6–10% slope	sloping
10–15% slope	strongly sloping
15–25% slope	steep
>25% slope	very steep

Slope and Erosion

Surface erosion by water is influenced by the slope of the land. Water's erosive potential is a function of its volume and kinetic energy. The kinetic energy of rainfall is determined by how fast the raindrops fall. In addition to having more kinetic energy, hard rain is less likely to be absorbed by the land upon which it falls, and is therefore more likely to become runoff water. The kinetic energy of runoff water is a function of how fast it flows, which in turn is a function of slope; a doubling of the velocity of runoff water leads to a quadrupling of its kinetic energy ($KE = mv^2/2$).

In considering the damage done by erosion, it is important to remember that most of the eroded soil is topsoil, the layer that contains the most organic matter and nitrogen. In addition, eroding of the A horizon exposes the subsurface soil, which usually has a higher clay content. This soil is less permeable to water and its exposure reduces infiltration and increases runoff, leading to still more erosion.

The eroded soil is not lost. Instead, it is eventually deposited somewhere. Some eroded soil is deposited in river deltas, such as those of the Nile and Mississippi rivers. Some ends up in water reservoirs, gradually reducing their water-storage capacity. An extreme example of this type of capacity loss is the Washington Mills Reservoir in Virginia. Over the course of 33.5 years, the reservoir lost 83% of its storage capacity.

Sediment is the most abundant water pollutant in the US. Its presence in water can be measured as *turbidity*, how much a water sample scatters light. Sediment covers fish eggs, provides a carrier for pesticide residues, and reduces penetration of sunlight, thereby decreasing aqueous plant growth. It leads to the dredging of channels and harbors, and to the necessity of filtering municipal drinking water.

Signs of Erosion

One of the most obvious signs of erosion is the presence of gullies. Gullies can be produced by water falling over a bank until the bank is undermined and the edge collapses; the waterfall moves back and leaves a U-shaped trench. Gullies can also be produced by concentrated flow of water through soft soil.

Evidence of erosion can also be found through examination of the surface and subsurface layers of soil pits. Scientists classify soil into three erosion categories: no or slight erosion, moderate erosion, and severe erosion. For a soil to be classified in the *no to slight* erosion category, the surface layer of the pit must show no signs of mixture between the surface and subsurface layers, either in the color or the texture of the soil. In moderately eroded soil, the top 6 inches of the surface layer contains soil from a subsurface layer and shows signs of having a mixture of textures and structures. In severely eroded soil, more than 75% of the original topsoil layer has been lost, and at least 75% of the top 6 inches of the soil is composed of subsurface layer soil.

Activity 1: Mechanical and Chemical Weathering

Procedure

A. Mechanical Weathering

1. Acquire about 10 g each of presoaked granite, basalt, and marble; a hand lens; 3 small, capped vials; forceps; and a large beaker.
2. Fill the beaker with at least 200 mL of water.
3. Using paper towels, dab each rock so that there is no water dripping from it.
4. Weigh the granite, basalt, and marble samples. Record the "Initial" weights in Table 1.
5. Using a hand lens, inspect each group of rocks. In your lab notebook, make notes about surface texture, sharp edges, and general appearance.
6. Place the granite, basalt, and marble samples in three separate small, capped vials.
7. Fill each vial with just enough water to cover the rocks.
8. Secure the lids to the top of the vials.
9. With your lab partners, shake all of the vials continuously for three minutes.
10. Using forceps, remove the rocks from the vials, towel them off, and reweigh each group. Record the weights in Table 1 in the "3 min" column.
11. Place the rocks back in the vials. Add water if necessary, so that the rock are submerged, and then shake the vials continuously for another three minutes. Record the weights in Table 1 in the "6 min" column.
12. Repeat Step 10 and Step 11 two more times and record the results in Table 1.
13. Using a hand lens, inspect each group of rocks. In your lab notebook, describe any changes in surface texture, edges, size, or general appearance.
14. Plot the weight results for the granite, basalt, and marble samples on a line graph, showing weight changes over time.
15. Answer the Laboratory Questions for the "Mechanical Weathering" section.

Materials (per student group)

20 g of presoaked granite
20 g of presoaked basalt
20 g of presoaked marble
hand lens
3 small, capped vials
large beaker
forceps
paper towels
lab coat
gloves
safety goggles

Table 1: Mechanical Weathering

Rock Type	Weight				
	Initial	3 min	6 min	9 min	12 min
Granite					
Basalt					
Marble					

B. Chemical Weathering

Lab Day 1

1. Acquire about 10 g each of presoaked granite, basalt, and marble; 3 small, capped vials; and forceps.
2. Using paper towels, dab each rock so that there is no water dripping from it.
3. Weigh the granite, basalt, and marble samples. Record the "Initial" weights in Table 2.
4. Using a hand lens, inspect each group of rocks. In your lab notebook, make notes about surface texture, sharp edges, and general appearance.
5. Place the granite, basalt, and marble samples in three separate small, capped vials.
6. While wearing a lab apron, gloves, and safety goggles, pour enough hydrochloric acid (HCl) into each vial to cover the rocks. Observe the results.

   Caution: Wear a lab coat, gloves, and safety goggles, and pour carefully when adding the acid to the vials. The acid may react with the rocks, resulting in bubbling and spray that could escape the vial. Any reaction will settle down after several minutes, at which time it will be safe to move and cap the vials.
7. Do not cap the vials immediately. After several minutes have passed, secure the lids to the vials and place them in a secure area to be stored overnight.

Lab Day 2

8. While wearing a lab apron, safety goggles, and gloves, carefully uncap the vials. Without disturbing the rocks, drain the acid into the sink. Turn on the faucet and wash the acid away with copious amounts of water.
9. Wash the acid from the rocks; fill the vials with water and, without disturbing the rocks, pour the water into the sink. Repeat this step two more times.
10. Using forceps, remove the rocks from the vial and place them on paper towels to absorb the excess water.
11. Once there is no water dripping from the rocks, reweigh each sample and record the results in the "Final Weight" column.
12. Using a hand lens, inspect each group of rocks. In your lab notebook, describe any changes in surface texture, edges, size, or general appearance.
13. Plot the weight results for the granite, basalt, and marble samples on a bar graph, showing the mass before and after the rocks were weathered by the acid.
14. Answer the Laboratory Questions for the "Chemical Weathering" section.

Table 2: Chemical Weathering

Rock Type	Initial Weight	Final Weight
Granite		
Basalt		
Marble		

Laboratory Questions

A. Mechanical Weathering

1. In terms of mass and shape, which rock type seems most affected by mechanical weathering? Which seems least affected?

2. Calculate the mass of each rock type (granite, basalt, and marble) if the samples were shaken in the vials for 24 hours.

3. List some regions where mechanical weathering caused by water is likely to have a significant impact. What regions are less likely to experience this type of weathering?

4. What are some signs of mechanical weathering on rocks?

B. Chemical Weathering

1. In terms of mass and shape, which rock type seems most affected by chemical weathering? Which seems least affected?

2. Describe the difference between physical and chemical weathering of rocks.

Activity 2: Soil Texture, Structure, and Consistence

Materials (per student group)

collected unknown soil sample
clay sample
sand sample
3 paper cups
spray bottle of tap water (may be shared)
hand lens or stereomicroscope (optional)

Procedure

A. Determining Soil Texture

In this activity, you will use the "Texture by Feel Analysis of Soil" flow chart to determine the texture of your unknown soil sample. First, familiarize yourself with the procedure by practicing the soil analysis using the known samples, sand and clay. Then, determine the texture of the unknown sample.

During the known sample analysis, sand should not form a ball even after water is added. Use the clay sample analysis to practice forming a soil ribbon. Clay should form a ribbon that is at least 5 cm long before it breaks. If you have trouble getting a 5-cm ribbon, make sure the ribbon is of uniform thickness and width. Practice with the clay until you can confidently make a ribbon. Then, use this technique to determine the texture of your soil sample.

1. Put samples of clay, sand, and your unknown soil into separate paper cups, and then take them to your workstation.
2. Follow the "Texture by Feel Analysis of Soil" procedure for the three samples.
3. Record the texture of the unknown sample in Table 3 in your lab notebook. (Sand and clay textures are known and may already be recorded.)

B. Determining Soil Consistence

You will test sand, clay, and your unknown soil sample. Consistence is determined by analyzing the sample's characteristics under three conditions—when the soil is dry (loose, hard, or soft), moist (loose, friable, or firm), and wet (sticky or nonsticky, and plastic or nonplastic). Follow this procedure to determine the consistence of soil.

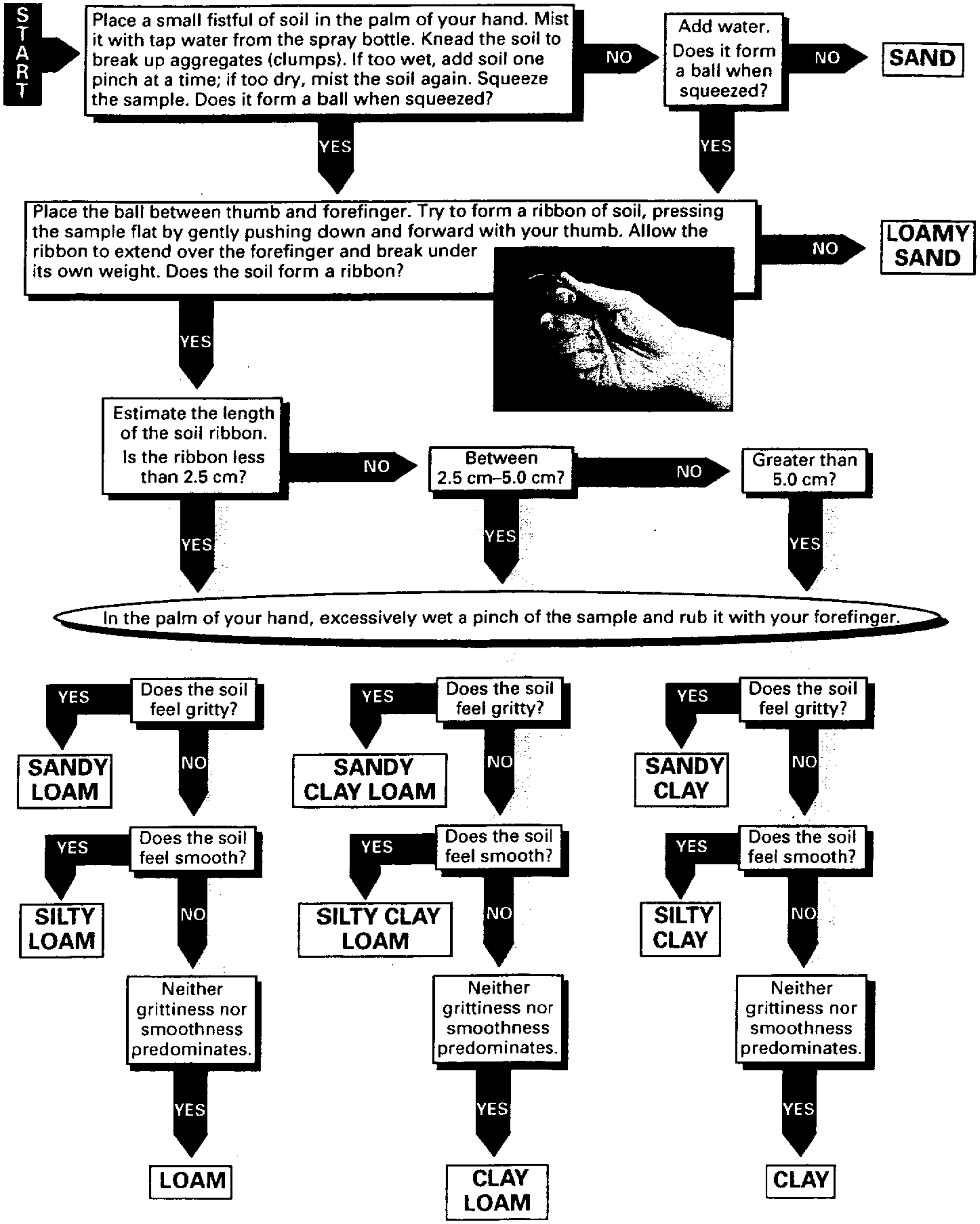
1. Start with dry soil. Obtain a solid, intact clump of your dry soil sample.
2. **Dry Test**

   Hold and squeeze the soil between your thumb and forefinger until it breaks apart. Is it (a) *loose* (falls apart easily and peds are not easily defined), (b) *soft*, or (c) *hard*?
3. **Moist Test**

   Moisten the soil with the spray bottle. Is it (a) *loose* (falls apart easily and peds are not easily defined); is it (b) *friable* (breakable once a small amount of pressure is applied); or is it (c) *firm* (requires significant pressure to break)?
4. **Wet Test**

   Wet the soil with the spray bottle. Now, determine two traits. Is the soil (a) *sticky* or (b) *nonsticky*? Record your answer in Table 3. Is the soil (c) *plastic* (capable of being molded or permanently deformed) or (d) *nonplastic*? Record your answer in Table 3.
5. Record the consistence of each sample analyzed in Table 3 in your lab notebook.

Texture by Feel Analysis of Soil



C. Observing Soil Structure

1. Rub some of the dry, unknown soil sample between your fingers. Does it fall apart easily into roundish lumps? Does it stick together in angular clumps? Is it platy? If possible, observe some of the soil using a hand lens or a stereomicroscope.
2. In Table 3, record what you believe to be the structure of the soil.

Laboratory Questions

1. Consider all of the samples analyzed by your class. Describe the relationship between texture and consistence.

2. How might the consistence of soil affect the growth of plants? Think about both wet and dry conditions.

Table 3: Soil Texture, Structure, and Consistence

	A. Texture	B. Consistence				C. Structure
		Dry	Moist	Wet		
Sand	Sand					Granular
Clay	Clay					Blocky
Unknown Soil Sample						

Activity 3: Soil Organization

Procedure

1. Acquire 3 plastic columns, 3 large vials, cheesecloth (enough to cut three 1-in squares), a pipet, a pair of scissors, 3 rubber bands, 6 twist ties, a large beaker, and a measuring spoon.
2. Go to the sink and fill the large beaker with at least 100 mL water.
3. Cut a square of cheesecloth that will fit securely over the end of the plastic column. Secure the cheesecloth over the end of the column with a rubber band. Use just enough cheesecloth to cover the end (you will need to be able to see the soil in the column). Try to minimize the amount of water that will be absorbed by the cheesecloth. Repeat this procedure for the other two plastic columns.
4. Put samples of humus, clay, sand, and coarse sand into separate paper cups and take them to your workstation.
5. Create three different soil profile models: a desert, a temperate rainforest, and a prairie. Use the sand, coarse sand, humus, and clay to create the O, A, B, and C horizons. Mix the soil quantities shown in the Soil Profiles table to create each soil profile.

   Important: Work from the lowest horizon upward to the topmost. That is, create the C horizon first, then B, then A. Create the O horizon last.

Materials (per student group)

- sand sample
- clay sample
- humus sample
- coarse sand sample
- 3 plastic columns
- 3 rubber bands
- 4 paper cups
- scissors
- 3 one-inch squares of cheesecloth
- 3 large vials
- bottle of food coloring
- large beaker
- 6 twist ties
- measuring spoon
- pipet

Soil Profiles

Habitat	Horizon			
	O	A	B	C
Desert	none	¼ tsp of sand	½ tsp of sand ¼ tsp of clay	½ tsp of coarse sand
Prairie	¼ tsp of humus	¼ tsp of humus ¼ tsp of sand ¼ tsp of clay	¼ tsp of sand	¼ tsp of coarse sand
Temperate Rainforest	¼ tsp of humus	¼ tsp of humus ¼ tsp of sand ¼ tsp of clay	¼ tsp of clay	¼ tsp of sand

6. Use twist ties to suspend the columns in the vials. The cheesecloth end should be about 3 cm above the bottom of the vial, as shown in Figure 3.
7. Add one drop of food coloring to the top layer of each column. This represents the organic nutrients available at the surface of each habitat.
8. Using a pipet, add 2 mL of water to each column. This simulates the rainfall for each habitat.
9. Observe the colored water as it penetrates each of the horizons.
10. Continute to add water to each column, 2 mL at a time, until water washes through the column and drips into the vial.
11. Record your observations in your lab notebook, and answer the Laboratory Questions.

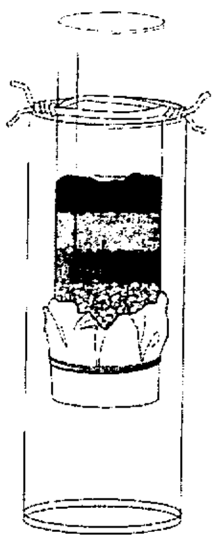


Figure 3. Column with soil profile suspended in vial.

Laboratory Questions

1. Which of the three habitats did the organic nutrients (blue water) pass through most rapidly?

2. What is the correlation between the speed in which the nutrients pass through the soil layers and the amount of rainfall each habitat receives?

3. Which habitat has the greatest potential for groundwater contamination, and why?

4. Why do desert habitats have a larger C horizon than other habitats? Why are the A and B horizons similar? How does this relate to the yearly rainfall that deserts receive?

Activity 4: Bulk Density and Compaction

Procedure

Before beginning the determination of bulk density, use particle size data to predict the relative densities of the different soils being analyzed.

1. Collect a sample of soil in your paper cup.
2. After breaking up any clumps, place a paper towel on your bench and empty the soil onto it.
3. Weigh the paper cup; then weigh out 70 g of your soil sample.
4. Return the extra soil on the paper towel to the proper container, or dispose of it.
5. Place a funnel into the mouth of the graduated cylinder.
6. Carefully pour the 70 g soil sample into the graduated cylinder through the funnel. As the soil sifts through the funnel, tap the bottom of the graduated cylinder on the work surface to pack the soil.
7. Record the volume of the soil in Table 4.
8. Empty the cup and repeat the activity with sand and clay. Be sure to break up all the clumps of clay.
9. Answer the Laboratory Questions for this activity.

Materials (per student group)

sand
clay
soil sample (air-dried)
paper cup
paper towels
graduated cylinder
funnel (make a paper one, if necessary)

Laboratory Questions

1. Calculate the bulk density for each soil (your sample, sand, and clay). Divide the volume of the soil by its mass (70 g), and record the value as grams per cubic centimeter (g/cm^3). In Table 4, record the bulk density of each sample.

2. Compare the bulk densities of soils with different particle size distributions and textures. Is there any correlation between particle size, texture, and bulk density?

3. Calculate the particle density (PD) of the soil with 50% porosity described in the Background section, "Bulk Density and Compaction."

4. Demonstrate mathematically why BD/PD gives the fraction of soil volume occupied by particles.

Table 4

	Clay	Sand	Soil Sample
Volume of 70 g sample			
Bulk density (70/volume)			

Activity 5: Determining the Slope of the Land

Objective

You will use surveying methods to determine the slope of land, and link the effects of slope with other soil characteristics to predict its effect on erosion. The slope of the land is determined in the same way that the slope of a line is determined: the change in y divided by the change in x. In the method outlined below, you first find two points 50 feet apart (the change in *x*) and determine the change in y.

Materials (per student group)

line level
50-inch stick (e.g., broom handle)
yardstick or meterstick
graphing paper

Procedure

1. Your group should have a 50-inch stick, a yardstick or meterstick, a line level, and a way to record your measurements.
2. Go to the site where you will measure the slope of the land. Two students are to stand 50 feet apart, so the area must have at least 50 feet of visually unobstructed clear space.
3. Have one student use a yardstick or meterstick to determine how long his or her heel-to-toe steps are. Determine how many heel-to-toe steps equal 50 feet, and step off this distance. Have one student stand at the starting and stopping point. The other students in the group stand by to assist.
4. The student at the uphill site holds the 50-inch stick horizontally, pointing at the student at the downhill site. The uphill student's assistants help by using the line level to make sure the stick is perfectly horizontal, and help hold it that way. Use the yardstick or meterstick to measure how far the uphill end of the stick is above the ground. Record this measurement as y1.
5. While the 50-inch stick is being held level and steady, the assistant sights down the stick and locates the downhill student. It may be necessary for the downhill student to raise his or her arm. Determine exactly where on the downhill student's body the stick points (nose, upraised elbow, waist, etc.).
6. Measure from the ground to the location on the downhill student's body at which the stick points. Record this measurement as y2.
7. Return to the classroom and complete the Laboratory Questions.

Laboratory Questions

1. Compute the slope of the land.

   Slope = (y2 – y1)/50 feet*

   Multiply this value by 100 to give the percent slope.

   *y2 and y1 must also be in feet, or all measurements must be in the same alternative unit (e.g., if using a meterstick, convert 50 feet to the same unit of measure as y2 and y1).

2. Using your data, graph the slope of the land on graphing paper to see a side view of the terrain.

Overview Questions

1. Of the soils analyzed by your class, which is best suited to plant growth? Defend your answer.

2. Provide an explanation for the following scenario. A couple buys a wooded lot in a hot and dry climate. They want to build a house on the lot, and at the same time preserve the trees. The contractor levels the building site, pours a concrete foundation, and builds the house. The trees are left untouched around the house. The next summer is hot and dry, as usual, and the trees around the house die. Why?

3. Clear-cut logging involves driving heavy machinery to a logging site, and then cutting down and removing every singe tree. Discuss the effects that clear-cut logging would have on the soil in the logged area.

4. Why would responsible hikers walk single file along a trail, but walk abreast when hiking in wilderness areas without trails?

5. In conventional farming, the soil is plowed after each harvest. The plowed soil sits bare until a new crop is planted. In the alternative method called no-till farming, fields are not plowed between crops. Instead, the stubble of the old crop stays in place, a slit is cut down the middle of each row for planting the new crop, and the soil is left otherwise undisturbed. List all the effects you can think of that no-till farming would have on soil.