Introduction

*
The Big Picture

Soils are a thin layer, called the *pedosphere*, on top of most of Earth's land surfaces. This thin layer is a precious natural resource. Soils so deeply affect every other part of the ecosystem that they often are called the "great integrator." Soils hold nutrients and water for plants and animals. Water is filtered and cleansed as it flows through soils. Soils affect the chemistry of the water and the amount of water that returns to the atmosphere to form rain. The foods we eat and most of the materials we use for paper, buildings, and clothing are dependent on soils. Understanding soil is important for knowing where to build our houses, roads, buildings, and playgrounds as well. This investigation guides you through measurements of soil characteristics, soil moisture, infiltration, and soil temperature.

One of the most important characteristics of any soil is how much water it contains. Either in the form of a vapor or a liquid, water occupies about one-fourth of the volume of a productive soil. If the soil gets too dry and is not covered by vegetation, it blows away in the wind. Yet if there is too much water, the ground becomes soggy and cannot sustain many crops or, for that matter, the foundations of buildings. The rate at which water flows into or infiltrates the surface determines how much water will runoff during a rainstorm. Dry, porous soils can absorb large amounts of rain and protect us from flash floods. Soil that is nearly saturated with water or slow to take up water can heighten the likelihood of flooding.

All terrestrial life is directly or indirectly dependent on sufficient levels of water in the soil. Soil moisture combines with other properties of the land and climate to determine what kinds of vegetation grow. Soil acts as a sponge and holds water for uptake by the roots of plants. Some soils are more effective at this than others. For example, in deserts with sandy soil which does not hold water well, cacti store their own water, while other trees send roots deep in the soil to tap water buried tens of meters below the surface.

Soil temperature acts much the same way to influence all living organisms. Soil temperature changes more slowly than that of the atmosphere. In many temperate regions the surface soil freezes in winter, but below a certain depth, the ground never freezes and the temperature is almost constant throughout the year. In some cold climates, a permanent layer of ice called permafrost is found below the soil surface. Soil acts to insulate the deeper layers of soil and whatever lives in them from the extremes of temperature variation.

Figure SOIL-I-1

Soil Properties That Change Over Time		
Properties that change over minutes or hours	*Properties that change over months or years*	*Properties that change over hundreds and thousands of years*

temperature moisture content composition of air in soil pores	soil pH soil color soil structure soil organic matter content soil fertility microorganisms density	kinds of minerals particle size distribution horizon formation

Both the temperature and moisture of the soil near the surface affect the atmosphere as heat and water vapor are exchanged between the land surface and the air. These affects are smaller than those of oceans, seas, and large lakes, but at times they significantly influence the weather. Hurricanes have been found to intensify instead of losing strength when they pass over ground that is already saturated with water. Meteorologists have found that their forecasts are sometimes improved if they factor soil conditions into their calculations. How surface soil temperature and moisture respond to changes in the atmosphere depends upon the characteristics of the surface of the soil and those of the underlying soil profile. In GLOBE, student measurements include many of the physical and chemical properties of soil which will provide insights into the role soil plays in climate.

Soil Composition and Formation

Soils are composed of three main ingredients: minerals of different sizes; organic materials from the remains of dead plants and animals; and open space that can be filled with water and air. A good soil for growing most plants should have about 45% minerals (with a mixture of sand, silt and clay), 5% organic matter, 25% air, and 25% water.

Soils are dynamic and change over time. Some properties, such as temperature and water content (a measure of soil moisture) change very quickly (over minutes and hours). Others, such as mineral transformations, occur very slowly over hundreds or thousands of years.

Soil formation (*pedogenesis*) and the properties of the soil are the result of five key factors. These factors are:

1. parent material -- The material from which the soil is formed. Soil parent material could be bedrock, organic material, an old soil surface, or a deposit from water, wind, glaciers, volcanoes, or material moving down a slope.

2. climate -- Heat, rain, ice, snow, wind, sunshine, and other environmental forces break down the parent material and affect how fast or slow soil processes go.

3. organisms -- All plants and animals living in or on the soil (including micro-organisms and humans!). The amount of water and nutrients plants need affects the way soil forms. Animals living in the soil affect decomposition of waste materials and how soil materials will be moved around in the soil profile. The dead remains of plants and animals become *organic matter* which enriches the soil. The ways humans use soils affect soil formation.

4. topography -- The location of a soil on a landscape can affect how the climatic processes impact it. Soils at the bottom of a hill will get more water than soils on the slopes, and soils on the slopes that directly face the sun will be drier than soils on slopes that do not.

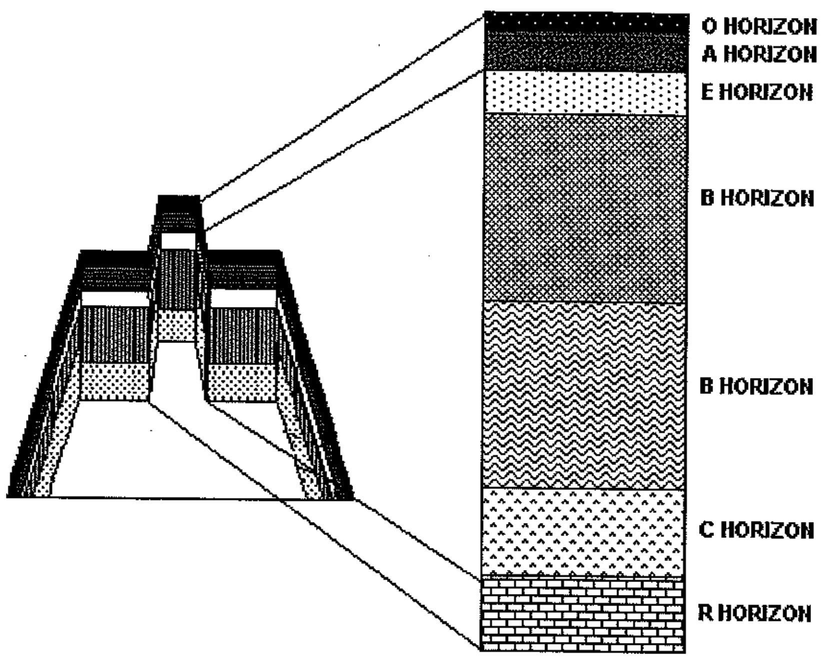
5. time -- All of the above factors assert themselves over time, often hundreds or thousands of years.

Soil Profiles

Due to the interaction of the five soil-forming factors, soils differ greatly. Each section of soil on a landscape has its own unique characteristics. The *face* of a soil, or the way it looks if you cut a section of it out of the ground, is called a *soil profile*, just like the profile of a person's face. When you learn to interpret it, the profile can tell you about the geology and climate history of the landscape over thousands of years, the archeological history of how humans used the soil, what the soil's properties are today, and the best way to use the soil. In a sense, each soil profile tells a story about the location where it is found. To read some examples of these stories, see *Soils Around the World* at the end of this section.

Every soil profile is made up of layers called *soil horizons*. Soil horizons can be as thin as a few millimeters or thicker than a meter. You can identify the individual horizons because they will have different colors and different-shaped particles. They will feel different and have other properties that differ from those above or below them. Some soil horizons are the result of erosion. Soils are washed downstream and deposited over hundreds or thousands of years, creating extensive new layers of soil and gravel that can be identified in road cuts and trenches. most are not.

Figure SOIL-I-2



Soil scientists label horizons with a special code to identify them. Not all soils have the same horizons, and the horizons in your soil will depend on how it has formed. Some of the codes used to describe horizons are listed below:

O Horizon

The O horizon is so named because it is made of *organic* material. This horizon is found on the soil surface and contains mostly organic material which has fallen from the vegetation above (such as leaves, logs, and twigs). It also includes the remains of animals and insects. Sometimes this organic material is decomposing so that it is difficult to recognize the leaves, twigs, or other material that were originally there. O horizons are most commonly found in forested areas. Agricultural fields, deserts, and grassy areas do not have O horizons in their soil profiles.

A Horizon

The A horizon is given its name because, like the first letter of the alphabet, it is the first mineral horizon of the soil and is commonly known as *topsoil*. The A horizon is made up mostly of mineral matter, although it may also include thoroughly decomposed organic material giving it a dark color. This horizon is usually darker than the horizon below it. In agricultural areas, the A horizon is the one that is tilled. When there has been much root decomposition and organic matter accumulation, the soil structure is granular. If compacted, the structure of the A horizon may be platy.

B Horizon

The B horizon is so named because it is generally the second major horizon in the profile, just as the letter B is the second letter of the alphabet. This horizon is primarily composed of parent material which has been severely weathered to the point that it is different in appearance. This horizon is commonly known as *subsoil*. Weathering causes changes in soil color, texture, and structure (which can be blocky or prismatic because of clay particles and chemical elements that move into the B horizon or columnar because of a high sodium content in dry regions). Also, the B horizon is called the accumulation (or *illuvial*) horizon because it is where the material leached from the A and E horizons has been deposited. Due to this accumulation, the B horizon may be rich in clays, [redacted], iron, aluminum, and other soil constituents that have moved in from above. Many B horizons have a reddish, yellowish brown, or tan color that is lighter than the A horizon. If the soil is saturated with water for long periods of time, the color may be gray or gray with red or orange streaks (mottles) through it.

Note: B Horizons may be very thick and may be broken down into two or more different layers. If there is more than one B horizon, they can be labeled as B1, B2, B3, etc. Look for changes in color, texture, structure, or consistence to help separate the B horizons from each other.

C Horizon

Like the letter C in the alphabet, the C horizon is usually the third major horizon in a soil profile. The C horizon is the most similar to the original parent material of the soil with no change in color, no structure formed (the soil is massive or single grained), no removal or deposition of soil materials through leaching, no coatings, no organic matter accumulation.

E Horizon

In certain soils (usually forested or under some wet conditions), an E horizon forms. The E horizon was named from the word *eluvial* meaning that clay, iron, aluminum, organic, and other minerals have been removed (leached) from it. It will appear white or lighter in color than the horizons above and below it. Many times, the soil structure is platy or single grained. This horizon is commonly found in forests where coniferous trees grow.

R Horizon

The R horizon represents a layer of rock that is sometimes found under the soil profile. The soil might have formed from this bedrock, or the soil parent material (such as *alluvial*, glacial or volcanic material) may have been deposited on top of the rock before the soil was formed.

Note: In a soil profile, you may not find all the horizons listed above in this table. For example, usually O and E horizons are found only in forested areas. If your soil profile is in an agricultural, desert, or grassy area, it will probably start with an A horizon and not have an E horizon at all. If the area has been eroded, your soil profile may start with a B horizon. Shallow soils, or soils that have not been extensively weathered may go from an A to a C horizon with no B horizon at all.

Your soil may have been altered by human activity at some time in the past. This could be a result of construction, when the builders placed soil *fill* from another location on this site, or when the horizons were not replaced in the same order as they were removed. Also, there may be more than one parent material from which your soil was formed. Parent material transported by water, wind, glaciers, volcanic activity, or landslides can
be deposited on top of other parent material, or already existing soil profiles. This may become evident on the face of the soil profile by a sharp change in color, texture or other properties that indicate the soil did not all form from the same parent material.

Soils Around the World

Following are six different soil profiles and an example of what the landscape looks like at each location.

Figure SOIL-I-3: Grassland soils sampled in the southern part of Texas in the USA.

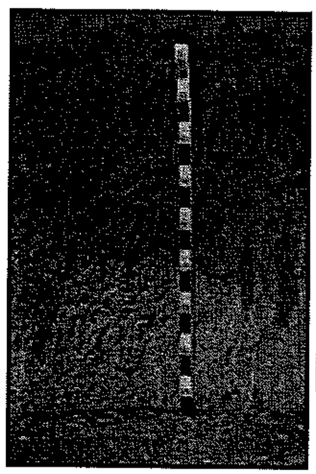
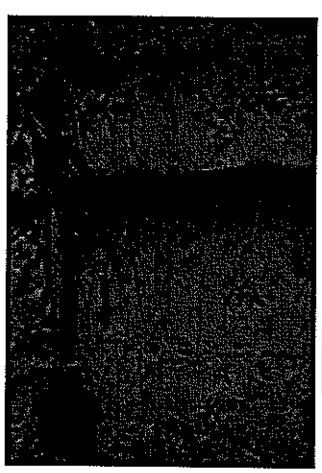


Figure SOIL-I-3: These soils are common in the midwestern USA, and also in the pampas of Argentina and in the Ukraine. They are usually deep and dark, and are among the best for growing crops. Their dark color is caused by many years of grass roots dying, decomposing, and building up a high organic matter content which allows the soil to hold water and nutrients for excellent plant growth.

Figure SOIL-I-4: Soil formed under a forest in far eastern Russia, near the city of Magadan.



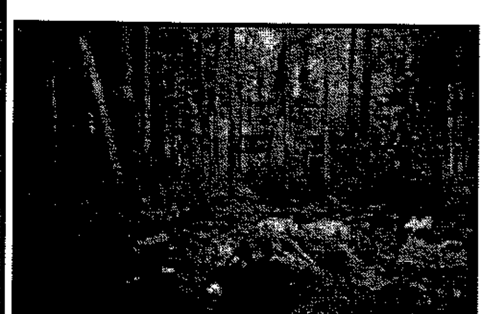
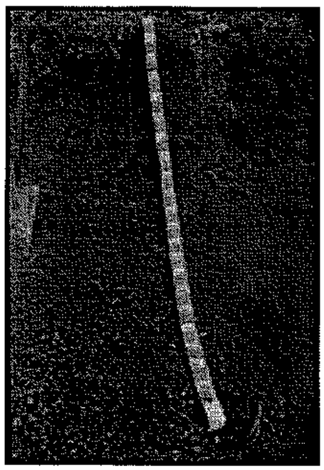


Figure SOIL-I-4: This soil is different from the grassland soil because most of its organic matter comes from leaves and roots of coniferous trees, which die and decompose near the surface or A horizon of the soil only. When this organic matter decomposes and mixes with rain, they form acids which "leach" or remove materials from the top horizons of the soil. Here you can see a white layer below the dark surface layer where the organic acids have leached nutrients, organics, clays, iron, and other materials and left bare minerals remaining. This horizon is called the E horizon, which stand for "eluvial" or "exit." The E horizon is the layer from which materials are removed or exit. Below the E horizon is the B horizon where materials from above are deposited. This B horizon has a dark color because organic matter has been deposited here. A second B horizon below this one is red due to iron oxide coatings brought in from the E horizon. A third B horizon is below this one which has fewer or different types of iron oxides coating the minerals which gives it a more yellow color. Below this is the C horizon which is the original parent material from which the soil formed. At one time, the whole soil looked like this C horizon, but over time, soil processes occurred which changed the way the soil looks. Soils that form under trees that are not coniferous will not usually have the same kind of soil profile that we see here.

Figure SOIL-I-5: A tropical environment in Northern Queensland, Australia



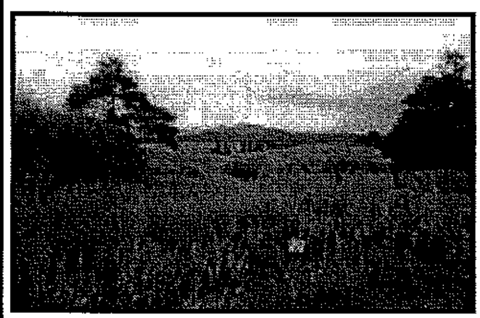
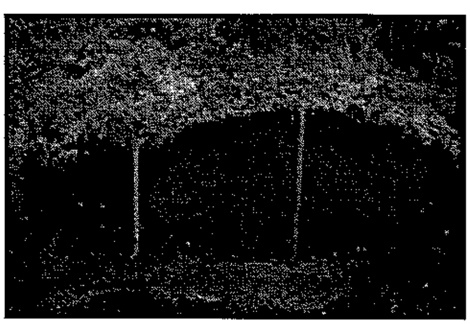


Figure SOIL-I-5: Notice how deep the soil is and how bright and red the colors are. Also, it is very difficult to distinguish different horizons from each other. This type of very weathered soil occurs when temperatures are hot and there are high amounts of rainfall. In this type of climate, the organic matter decomposes very quickly and transforms into an inactive material that binds with clay. Most of the nutrients have been leached from this soil leaving very weathered minerals that are coated by iron oxides. It is the iron oxides which give the soil its bright red color.

Figure SOIL-I-6: Soil formed under a very cold climate near Inuvik in the Northwest Territory of Canada.



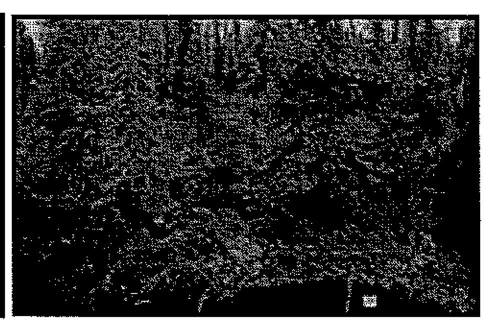


Figure SOIL-I-6: The "hummocky" or wavy surface of this soil is caused by the water stored in the soil freezing and then thawing year after year. The black zones indicate places where organic materials have fallen in to the soil profile with freezing and thawing cycles. This process of freezing and thawing and churning of the soil is called "cryoturbation." This soil is not very developed and has only faint indications of horizons as can be seen by very slight color differences. At the bottom of the profile is a layer called "permafrost" which can be made up of ice, soil, or a mixture of both, that stays below 0oc all year round.

Figure SOIL-I-7: Soil formed under very dry or arid conditions in New Mexico, USA.

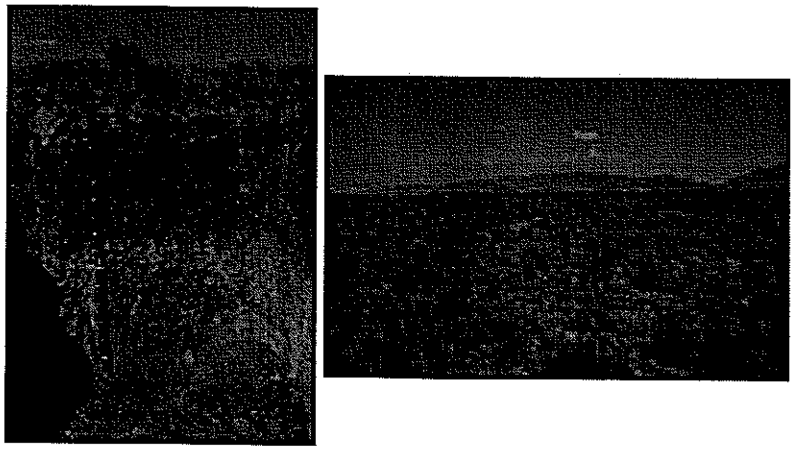


Figure SOIL-I-7: The light brown A horizon at the surface occurs because of the lack of organic matter or moisture which usually darken the soil. There is very little vegetation growing here, and so organic matter is not returned to the soil. When rainfall does occur in this environment, it carries materials downward into the profile to form B horizons. The white streaks near the bottom of this profile are formed from deposits of calcium carbonate which become very hard as they accumulate over time.

Figure SOIL-I-8: Wet soil sampled in Louisiana, USA.

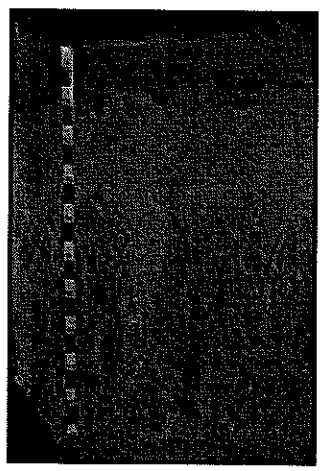


Figure SOIL-I-8: Wet soils are found in many parts of the world. The A horizon is usually dark because organic matter accumulates when the soil is saturated with water. When waterlogged (saturated) conditions occur, there is usually not enough oxygen for organisms to decompose this material. B horizon colors are usually grayish. Sometimes, as in this picture, the gray soil color has orange or brown streaks within it, which are called "mottles". The gray colors indicate that the soil was wet for a long period of time, while the mottles show us where some oxygen was present in the soil.Soil Investigation *Dr. John Kimble and Sharon Waltman of the USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska provided the photographs shown here.*

Overview of the Measurements

Soil Characterization

In the field, soil horizons can be distinguished from each other within a soil profile by differences in their structure, color, consistence, texture, and amount of free carbonates. When samples are taken back to the classroom or laboratory, measurements of soil characteristics such as bulk density, particle size distribution, pH, and soil fertility can also be different from one horizon to another.

Structure:

Structure refers to the natural shape of groups of soil particles or aggregates (*peds*) in the soil. The structure affects how big the spaces will be in the soil through which roots, air, and water may move.

Color:

The color of the soil changes depending on how much organic matter is present and the kinds of minerals it contains (such as iron which usually creates a red color, or calcium carbonate which colors the soil white in dry areas). Soil color also differs depending upon how wet or dry the soil sample is and can indicate if the soil has been saturated with water.

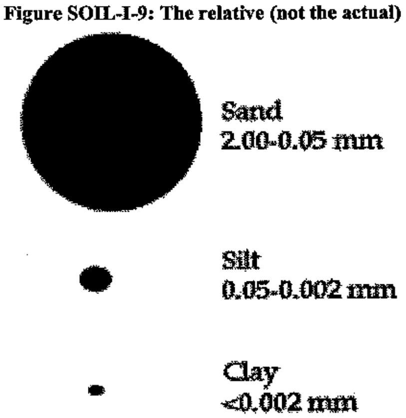
Consistence:

Consistence relates to the firmness of the individual *peds* and how easily they break apart. A soil with firm consistence will be harder for roots, shovels, or plows to move through than a soil with *friable* consistence.

Texture:

The texture is how the soil feels and is determined by the amount of sand, silt, and clay particles in the soil, each of which is a different size.

Figure SOIL-I-9: The relative (not the actual) size of sand, silt, and clay particles.



Human hands are sensitive to this difference in size of soil particles, so we are able to determine the texture or "feel" of the soil. Sand is the largest particle size group, and feels gritty to touch. Silt is the next size group, and feels smooth or *floury*. Clay is the smallest size group, and feels sticky and hard to squeeze. The actual amount of sand, silt, and clay size particles in a soil sample is called the *particle size distribution* and can be measured in the laboratory or classroom.

Carbonates:

Free carbonates are materials that coat soil particles in soils that are above pH 7, especially in arid or semi-arid climates. Carbonates usually have a white color, and can be scratched easily with a fingernail. They are salts of calcium or other elements that accumulate in areas where there is not extensive weathering from water. Also, carbonates can come from the parent material (e.g. limestone), can be caused by additions of carbonates to the soil, or can be the result of carbonate formation within the soil. Sometimes in dry climates, the carbonates can form a very hard and dense horizon which is similar to cement and will not allow plant roots to grow through it.

In GLOBE, this test is performed by squirting vinegar on the soil. If carbonates are present, there will be a chemical reaction between the vinegar, which is an acid, and the carbonates, which are bases, to produce carbon dioxide. When carbon dioxide is produced, it bubbles or *effervesces*. The more carbonates that are present, the more bubbles or *effervescence* you will observe.

Bulk Density:

Soil bulk density is a measurement of how tightly packed or dense the soil is. It is determined by measuring the weight of dry soil in a unit of volume (g/cm^3). How dense the soil sample is depends on the structure (shape) of the soil peds, how many spaces (pores) are in the sample, how tightly they are packed, and also the composition of the solid material. Soils made of minerals (sand, silt, and clay) will have a different bulk density than soils made of organic material. In general the bulk density of soils can range from 0.5 g/cm^3 in soils with many spaces, to as high as 2.0 g/cm^3 or greater in very compact horizons.

Knowing the bulk density of a soil is important for many reasons. Bulk density can give us information about the porosity (the proportion of the soil volume that is pore spaces) of a sample. This helps determine how much air or water can be stored or moved through the soil. Bulk density also indicates how tightly soil particles are packed together and if it will be difficult or easy for roots to grow or shovels to penetrate into and through a soil horizon. Bulk density is also used in converting between weight and volume for a soil sample. If we know the weight of a soil sample, we can calculate its volume by dividing the sample weight by the bulk density of the soil. If we know the volume of a soil sample, we can determine its weight by multiplying the sample volume by the bulk density of the soil.

Particle Size Distribution:

The amount of each particle size group (sand, silt, or clay) in the soil is called the soil particle-size distribution. Knowing the particle size distribution of a soil sample helps us understand many soil properties including how much water, heat, and nutrients the soil will hold, how fast water and heat will move through the soil, and what kind of structure and consistence will form.

The distribution of sand, silt, and clay in your sample will be determined by a settling measurement using an instrument called a *hydrometer*. The hydrometer is used to measure the amount of soil that stays in suspension after some of the soil has settled to the bottom of the cylinder.

Sand is the largest soil particle size group, silt is intermediate in size, and clay is the smallest. See Figure SOIL-I-9. There is disagreement in the scientific community about the exact size ranges used to distinguish sand from silt. For GLOBE, we will be measuring sand and silt based on 2 different size definitions:

1. The US Department of Agriculture (USDA) defines the size of sand as 2.0 - 0.05 mm, and the size of silt as 0.05 - 0.002 mm.

2. The International Soil Science Society (ISSS) defines the size of sand as 2.0 - 0.02 mm, and the size of silt as 0.02 - 0.002 mm.

GLOBE students will find the silt and sand amounts for both of these definitions so that our data can be used by scientists world wide.

Clays are the smallest particle size group and are defined by both organizations as being smaller than 0.002 mm. Particles greater than 2 mm are called stones or gravels and are not considered to be soil material.

Heavy, large particles settle first, so when a soil sample is stirred or shaken in a 500 mL cylinder, sand particles (according to the USDA definition) settle to the bottom of the cylinder after 2 minutes, while the clay and silt size particles stay in suspension. After 12 minutes, the sand (according to the ISSS definition) has settled, leaving the clay and silt particles in suspension. After 24 hours, the silt particles have settled, leaving only the clay in suspension.

pH:

The pH of a soil horizon (how acidic or basic the soil is) can be measured in the laboratory or classroom. The pH influences what can grow in the soil and is the product of the kind of parent material, the chemical nature of the rain and other water entering the soil, land management practices, and the activities of organisms (plants, animals, fungi, protists, and monera) living in the soil. For example, needles from pine trees are high in acids, and as they decay over time, they lower the pH of the soil. Soil pH is an indication of its chemistry and fertility. Just like the pH of water, the pH of soil is on the same logarithmic scale (see the *Introduction* of the *Hydrology Investigation* for a description of pH). It is important to know the pH of the soil because it affects the activity of the chemical elements in the soil, and so affects many soil properties. Different plants grow best at different pH values. Farmers will add *amendments* like calcium carbonate or calcium sulfate to change the pH of the soil depending on the kind of plants they want to grow. The pH of the soil also may affect the pH of ground water or of a nearby water body such as a stream or lake.

Fertility:

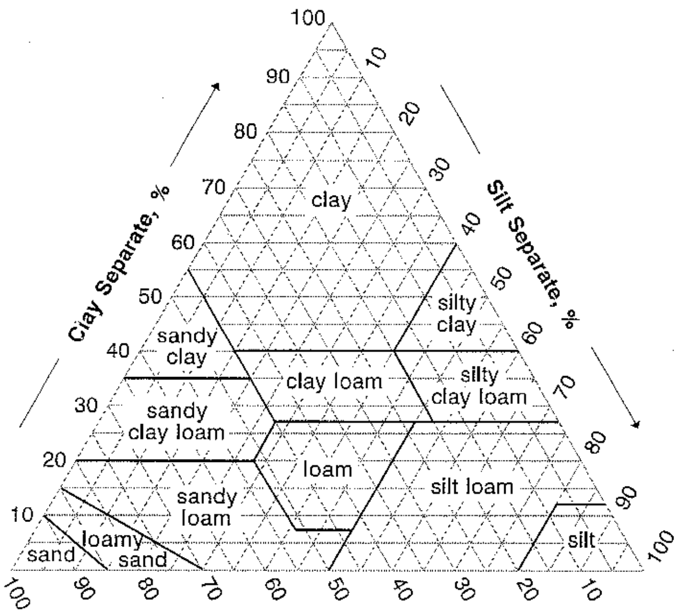
The fertility of a soil is determined by how many nutrients it has stored. Nitrogen (N) in the form of nitrate, phosphorus (P), and potassium (K) are three soil nutrients important for the growth of plants, and need to be maintained in the soil at a suitable level. Each also has the potential to leach from the soil into groundwater. By testing the soil for N, P, and K, we can determine how much of each is present in the soil horizons at your sample sites. Soil fertility information can help to explain why and how well certain plants grow at a Soil Characterization Sample Site, and also can be related to the water chemistry you will be measuring in the *Hydrology Investigation*.

Sampling Strategy

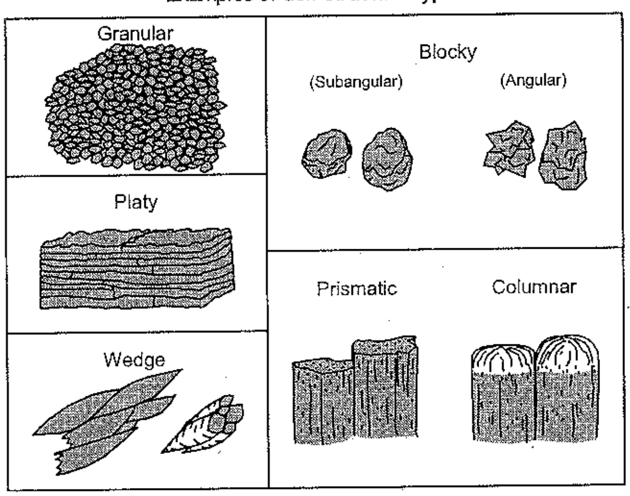
The protocols for Soil Characterization should be done once at each site where soil affects another GLOBE measurement. The two highest priority sites are within the Biology Study Site and the Soil Moisture Study Site. The protocols are divided between field and classroom activities. In the field, students describe and sample soil. For this, a hole is dug either with a shovel or an auger. Obtaining a soil profile one meter deep is desired, but an option is provided to sample the top 10 cm of soil when obtaining a 1 m profile is not possible. All students will describe the soil, take samples back to the classroom, dry and sieve the samples, determine the bulk density, and measure them for pH, nitrate, phosphorus, and potassium (N, P, K), and soil particle-size distribution. A measurement of surface infiltration rate should be taken as well.

Soil Moisture

Texture Triangle:
Fine Earth Texture Classes (——)



Examples of Soil Structure Types



(SOIL) STRUCTURE

(Soil) Structure is the naturally occurring arrangement of soil particles into aggregates that results from pedogenic processes. Record Grade, Size, and Type. For compound structure, list each Size and Type; e.g., medium and coarse SBK parting to fine GR. Up to ten entries (per horizon) are permitted in PDP. (For PDP only, estimate the percent of each type.) Lack of structure (structureless) has two end members: massive (MA) or single grain (SG). A complete example is: weak, fine, subangular blocky or 1, f, sbk.

(SOIL) STRUCTURE - TYPE (formerly Shape) -

Type	Code Conv	Code NASIS	Criteria: (definition)
NATURAL SOIL STRUCTURAL UNITS (pedogenic structure)			
Granular	gr	GR	Small polyhedrals, with curved or very irregular faces.
Angular Blocky	abk	ABK	Polyhedrals with faces that intersect at sharp angles (planes).
Subangular Blocky	sbk	SBK	Polyhedrals with sub-rounded and planar faces, lack sharp angles.
Platy	pl	PL	Flat and tabular-like units.
Wedge	—	WEG	Elliptical, interlocking lenses that terminate in acute angles, bounded by slickensides; not limited to vertic materials.
Prismatic	pr	PR	Vertically elongated units with flat tops.
Columnar	cpr	COL	Vertically elongated units with rounded tops which commonly are "bleached".
STRUCTURELESS			
Single Grain	sg	SGR	No structural units; entirely noncoherent; e.g., loose sand.
Massive	m	MA	No structural units; material is a coherent mass (not necessarily cemented).
ARTIFICIAL EARTHY FRAGMENTS OR CLODS[1] (non-pedogenic structure)			
Cloddy[1]	—	CDY	Irregular blocks created by artificial disturbance; e.g., tillage or compaction.

[1] Used only to describe oversized, "artificial" earthy units that are not pedogenically derived soil structural units; e.g., the direct result of mechanical alteration; use Blocky Structure Size criteria.