Introduction

Soil (Pedosphere)

Soils are one of Earth's essential natural resources, yet they are often taken for granted. Most people do not realize that soils are a living, breathing world supporting nearly all terrestrial life. Soils and the functions they play within an ecosystem vary greatly from one location to another as a result of many factors, including differences in climate, the animal and plant life living on them, the soil's parent material, the position of the soil on the landscape, and the age of the soil.

Scientists, engineers, farmers, developers and other professionals consider a soil's physical and chemical characteristics, moisture content and temperature to make decisions such as:

- Where is the best place to build a building?
- What types of crops will grow best in a particular field?
- Will the basement of a house flood when it rains?
- How can the quality of the groundwater in the area be improved?

Using the data collected in the *GLOBE Soil (Pedosphere) Investigation*, students help scientists describe soils and understand how they function. They determine how soils change and the ways they affect other parts of the ecosystem, such as the climate, vegetation, and hydrology. Information about soils is integrated with data from the other GLOBE protocol investigations to gain a better view of Earth as a system.

Why Investigate Soils?

Soils develop on top of Earth's land surface as a thin layer, known as the *pedosphere.* This thin layer is a precious natural resource and so deeply affects every part of the ecosystem that it is often called the "great integrator." For example, soils hold nutrients and water for plants and animals. They filter and clean water that passes through them. They can change the chemistry of water and the amount that recharges the groundwater or 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. Soils play an important role in the amount and types of gases in the atmosphere. They store and transfer heat, affect the temperature of the atmosphere, and control the activities of plants and other organisms living in the soil. By studying these functions that soils play, students and scientists learn to interpret a site's climate, geology, vegetation, hydrology, and human history. They begin to understand soil as an important component of every land ecosystem on Earth and of the Earth System as a whole.

Scientists Need GLOBE Data

The data students collect through the GLOBE soil measurements are invaluable to scientists in many fields. For example, Soil scientists use the data to better understand how soils form, how they should be managed, and what their potential is for plant growth and other land use. Hydrologists use the data to determine water movement through a soil and a watershed and the effect of soils on water chemistry. They also examine the effects of different types of soil on the sedimentation in rivers and lakes. Meteorologists and climatologists use soil data in weather and climate prediction models. Atmospheric scientists want to know the effect of soils on humidity, temperature, reflected light, and fluxes of gases such as CO_2 and methane. Biologists examine the properties of soil to understand its potential for supporting plant and animal life. Anthropologists study the soil in order to reconstruct the human history of an area.

When data are available for many areas of the world, scientists study the spatial patterns of soil properties. When a full set of GLOBE atmosphere, hydrology, land cover and soils data exists at a specific site, scientists can use the information to run computer models to understand how the whole ecosystem functions and to make predictions about what the ecosystem will be like in the future.

The Big Picture

Soil Composition

Soils are composed of four main components:

- Mineral particles of different sizes.
- Organic materials from the remains of dead plants and animals.
- Water that fills open pore spaces.
- Air that fills open pore spaces.

The use and function of a soil depends on the amount of each component. For example, a good soil for growing agricultural plants has about 45% minerals, 5% *organic matter*, 25% air, and 25% water. Plants that live in wetlands require more water and less air. Soils used as raw material for bricks need to be completely free of organic matter.

The Five Soil Forming Factors

The properties of a soil are the result of the interaction between the *Five Soil Forming Factors*. These factors are:

1. *Parent Material:* The material from which the soil is formed determines many of its properties. The parent material of a soil may be bedrock, organic material, construction material, or loose soil material deposited by wind, water, glaciers, volcanoes, or moved down a slope by gravity.
2. *Climate:* Heat, rain, ice, snow, wind, sunshine, and other environmental forces break down parent material, move loose soil material, determine the animals and plants able to survive at a location, and affect the rates of soil forming processes and the resulting soil properties.
3. *Organisms:* The soil is home to large numbers of plants, animals, and microorganisms. The physical and chemical properties of a soil determine the type and number of organisms that can survive and thrive in that soil. Organisms also shape the soil they live in. For example, the growth of roots and the movement of animals and microorganisms shift materials and chemicals around in the soil profile. The dead remains of soil organisms become organic matter that enriches the soil with carbon and nutrients. Animals and microorganisms living in the soil control the rates of decomposition for organic and waste materials. Organisms in the soil contribute to the exchange of gases such as carbon dioxide, oxygen, and nitrogen between the soil and the atmosphere. They also help the soil filter impurities in water. Human actions transform the soil as well, as we farm, build, dam, dig, process, transport, and dispose of waste.
4. *Topography:* The location of a soil on a landscape also affects its formation and its resulting properties. For example, soils at the bottom of a hill will get more water than soils on the hillside, and soils on slopes that get direct sunlight will be drier than soils on slopes that do not.
5. *Time:* The amount of time that the other 4 factors listed above have been interacting with each other affects the properties of the soil. Some properties, such as temperature and moisture content, change quickly, often over minutes and hours. Others, such as mineral changes, occur very slowly over hundreds or thousands of years. Figure SOIL-I-1 lists different soil properties and the approximate time it takes for them to change.

Soil Profiles

The five soil-forming factors differ from place to place causing soil properties to vary from one location to another. Each area of soil on a landscape has unique characteristics. A vertical section at one location is called a *soil profile*. See Figure SOIL-I-2. When we look closely at the properties of a soil profile and consider the five soil forming factors, the story of the soil at that site and the formation of the area is revealed.

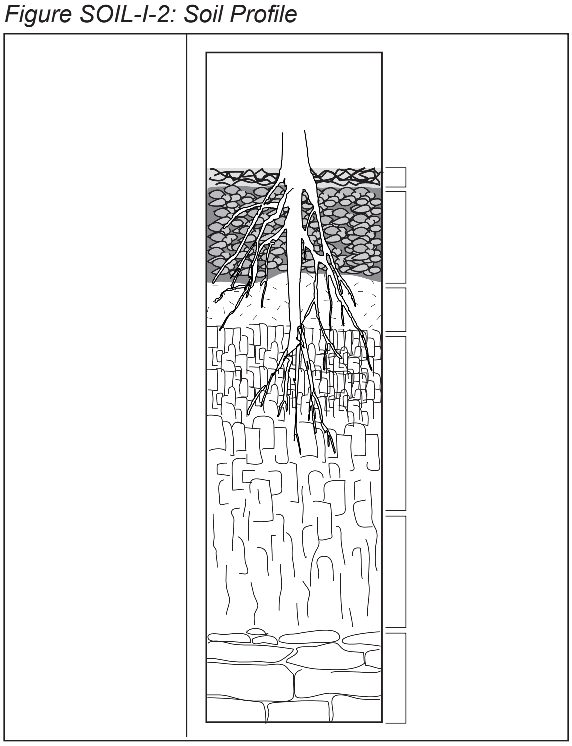
The chapters of the soil story at any location are read in the layers of the soil profile. These layers are known as *horizons*. Soil horizons can be as thin as a few millimeters or thicker than a meter. Individual horizons are identified by the properties they contain that are different from the horizons above and below them. Some soil horizons are formed as a result of the weathering of minerals and decomposition of organic materials that

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 Local composition of air	Soil pH Soil color Soil structure Bulk density Soil organic matter Soil fertility Microorganisms, animals, plants	Mineral content Particle size distribution Horizons Particle density

move down the soil profile over time. This movement, called *illuviation*, influences the horizon's composition and properties. Other horizons may be formed by the disturbance of the soil profile from erosion, deposition, or biological activity. Soils may also have been altered by human activity. For example, builders compact soil, change its composition, move soil from one location to another, or replace horizons in a different order from their original formation.

Figure SOIL-I-2: Soil Profile



Moisture in the Soil

Moisture plays a major role in the chemical, biological and physical activities that take place in the soil. Chemically, moisture transports substances through the profile. This affects soil properties such as color, texture, pH, and fertility. Biologically, moisture determines the types of plants that grow in the soil and affects the way the roots are distributed. For example, in desert areas where soils are dry, plants such as cacti must store water or send roots deep into the soil to tap water buried tens of meters below the surface. Plants in tropical regions have many of their roots near the surface where organic material stores much of the water and nutrients the plants need. Agricultural plants grow best in soils where water occupies approximately one-fourth of the soil volume as vapor or liquid. Physically, soil moisture is part of the hydrologic cycle. Water falls on the soil surface as precipitation. This water seeps down into the soil in a process called *infiltration*. After water infiltrates the soil, it is stored in the horizons, taken up by plants, moved upward by *evaporation*, or moved downward into the underlying bedrock to become *ground water*. The amount of moisture contained in a soil can change rapidly, sometimes increasing within minutes or hours. In contrast, it might take weeks or months for soils to dry out. If a soil horizon is compacted, has very small pore spaces, or is *saturated* with water, infiltration will occur slowly, increasing the potential for flooding in an area. If the water cannot move down into the soil fast enough, it will flow over the surface as *runoff* and may rapidly end up in streams or other water bodies. When the soil is not covered by vegetation and the slope of the land is steep, *water erosion* occurs. Deep scars are formed in the landscape as a result of the combined force of the runoff water and soil particles flowing over the surface. When a soil horizon is dry, or has large pore spaces that are similar in size to the horizon above, water will infiltrate the horizon quickly. If the soil gets too dry and is not covered by vegetation, *wind erosion* may occur.

The surface layer of soil is in direct content with the atmosphere and moisture entering or leaving the soil passes through this layer. Except in hyper arid conditions, the only soil property that can be measured from satellites is the moisture in the top 5 cm. NASA has flown the Soil Moisture Active Passive (SMAP) mission to measure this environmental property. Calibration and validation of SMAP data need in situ measurements of surface soil moisture, and GLOBE and SMAP have partnered to obtain these data from GLOBE participants.

Soil Temperature

The temperature of a soil can change quickly. Near the surface, it changes almost as quickly as the air temperature changes, but because soil is denser than air, its temperature variations are less. Daily and annual cycles of soil temperature can be measured. During a typical day, the soil is cool in the morning, warms during the afternoon, and then cools down again at night. See Figure SOIL-I-3. Over the course of the year, the soil warms up or cools down with the seasons. Because soil temperature changes more slowly than air temperature, it acts as an insulator, protecting soil organisms and buried pipes from the extremes of air temperature variations. In temperate regions, the surface soil may freeze in winter and thaw in the spring, while in some colder climates, a permanent layer of ice, called *permafrost*, is found below the soil surface. In either case, the ground never freezes below a certain depth. The overlying soil acts as insulation so that the temperature of the deeper layers of soil is almost constant throughout the year. Temperature greatly affects the chemical and biological activity in the soil. Generally, the warmer the soil, the greater the biological activity of microorganisms living in the soil. Microorganisms in warm tropical soils break down organic materials much faster than microorganisms in cold climate soils. Near the surface, the temperature and moisture of the soil affect the atmosphere as heat and water vapor are exchanged between the land and the air. These effects are smaller than those at the surfaces of oceans, seas, and large lakes, but can significantly influence local weather conditions. Hurricanes have been found to intensify when they pass over soil that is saturated with water. Meteorologists have found that their forecasts can be improved if they factor soil temperature and moisture into their calculations.

Soils Around the World

Following are examples of six different soil profiles and landscapes. See Figures SOIL-I-4 through I-9.

Figure SOIL-I-3

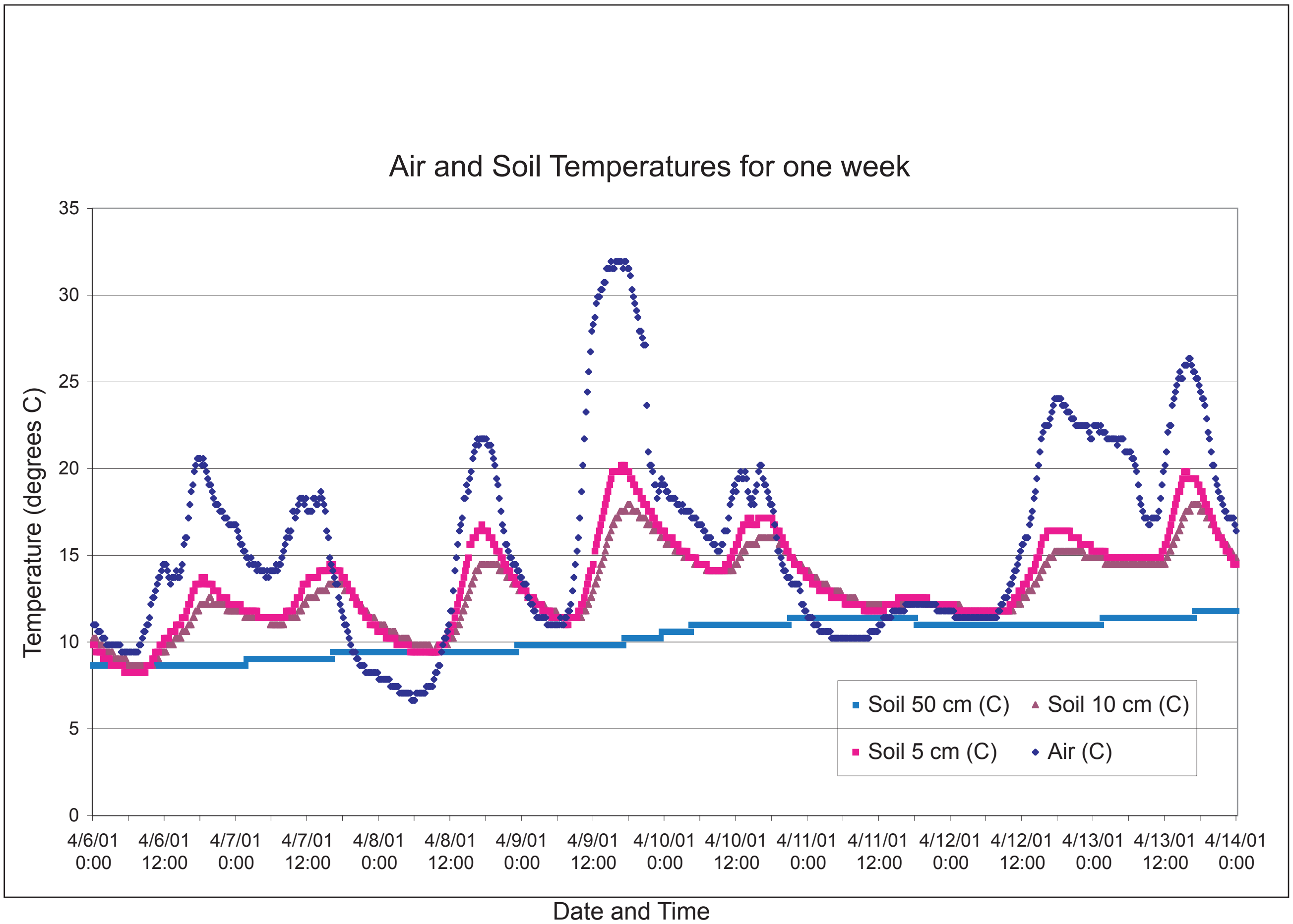


Figure SOIL-I-4: Grassland soils sampled in the southern part of Texas in the USA

These soils are common in the mid-western USA, and in the grasslands of Argentina and Ukraine. They are usually deep and dark in color, and are among the best soils for growing crops. Their dark color is caused by many years of grass roots dying, decomposing, and building up the organic matter content that allows the soil to hold the water and nutrients needed for excellent plant growth.

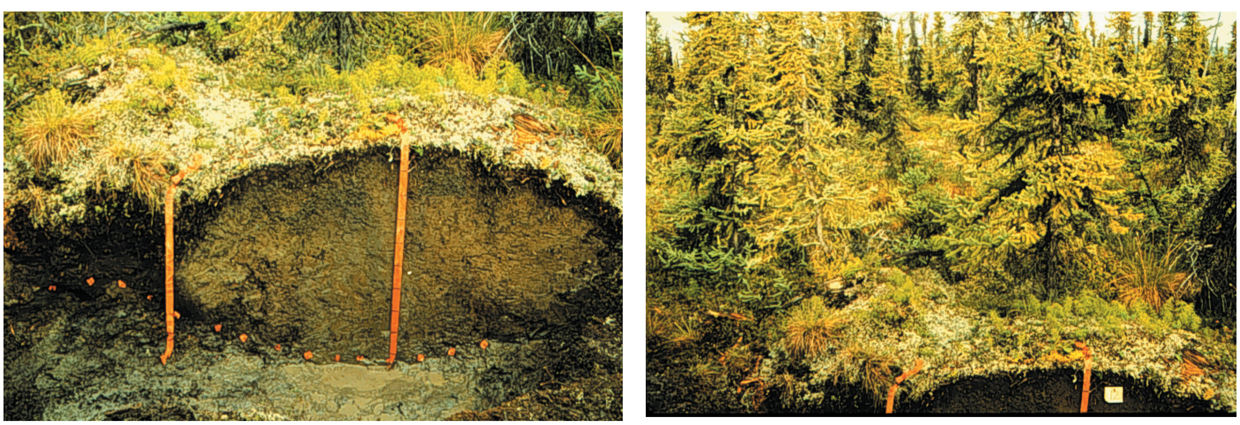
Figure SOIL-I-5: Soil formed under a forest in far eastern Russia, near the city of Magadan

Most of the organic matter in this soil comes from the leaves and roots of coniferous trees that die and decompose near the surface. When this decomposed organic matter mixes with rain, acids form that *leach*, or remove, materials from the top horizons of the soil. The white layer you see below the dark surface layer was caused by organic acids that removed the nutrients, organics, clays, iron, and other materials in the layer and left behind soil particles that are only mineral in composition. Below this horizon is a dark horizon that contains materials that were leached from the horizon above and deposited or illuviated. This horizon has a dark color because of the organic matter deposited there. The next horizon has a red color due to iron oxide brought in from the horizon above and coating the soil particles. The horizon below this one has fewer or different types of iron oxides coating the inorganic soil particles creating a yellow color. The lowest horizon in the profile is the original parent material from which the soil formed. At this site, the parent material is a sandy deposit from glaciers. At one time, the whole soil looked like this bottom horizon, but over time, soil-forming processes changed its properties.

Figure SOIL-I-6: A tropical environment in Northern Queensland, Australia

Notice the bright red colors and the depth to which the soil is uniform. It is very difficult to distinguish unique horizons. Hot temperatures and lots of rain help to form weathered soils like this. In tropical climates, organic matter decomposes very quickly and transforms into inactive material that binds with clay. Most of the nutrients have been leached from this soil by intense rainfall. Left behind are weathered minerals coated by iron oxides giving the soil its bright red color.

Figure SOIL-I-7: Soil formed under a very cold climate near Inuvik in the Northwest Territory of Canada



The "hummocky" or wavy surface of this soil is caused by freezing and thawing of water stored in the soil year after year. The black zones indicate places where organic materials have accumulated during freezing and thawing cycles. The process of freezing and thawing and churning of the soil is called *cryoturbation*. This soil is not very developed and has only slight indications of horizons that can be seen by faint color differences. At the bottom of the profile is a layer called *permafrost*, which consists of ice, soil, or a mixture of both. The permafrost layer stays below 0˚C throughout the year. The dark, thick organic material in this soil accumulates because decomposition is very slow in cold climates.

Figure SOIL-I-8: Soil formed under very dry or arid conditions in New Mexico, USA

A light brown horizon at the surface is often found in environments where organic matter is limited. High amounts of organic matter form dark soils. In dry places, organic matter is not returned to the soil because very little vegetation grows there. When rainfall does occur in this environment, the sandy texture of the soils allow materials to be carried downward into the lower horizons of the profile. The white streaks near the bottom of this profile are formed from deposits of calcium carbonate that can become very hard as they accumulate over time.

Figure SOIL-I-9: Wet soil sampled in Louisiana, USA

Wet soils are found in many parts of the world. The surface horizon is usually dark because organic matter accumulates when the soil is saturated with water. When these conditions occur, there is not enough oxygen for organisms to decompose the organic material. Colors of the lower horizon 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.

Dr. John Kimble and Sharon Waltman of the USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska provided the photographs shown here.

GLOBE Measurements

What measurements are taken?

In the GLOBE Soil Investigation, two sets of soil measurements are made. The first set, known as Soil Characterization, describes the physical and chemical characteristics of each horizon in a soil profile. Some Soil Characterization measurements are carried out in the field, while others are done in a laboratory or classroom. Soil Characterization measurements are carried out one time for an identified site. The second set of measurements are Soil Moisture and Temperature, which determine the water and temperature properties of soil at specified depths. Soil moisture and temperature measurements are carried out repeatedly and can be directly compared with the air temperature and precipitation measurements that are described in the *Atmosphere Investigation*. Although these two sets of soil measurements are different, having both soil characterization and soil moisture at a given location provides the most amount of meaningful information. For example, differences in soil temperature and moisture between one site and another that have the same air temperature and precipitation may be due to differences in the soil characterization properties. Understanding the physical and chemical properties of the soil will help to interpret patterns in soil moisture and temperature.

Soil Characterization Measurements

Carried Out in the Field

- Site Description
- Horizon Depths
- Soil Structure
- Soil Color
- Soil Consistence
- Soil Texture
- Roots
- Rocks
- Carbonates

* Lab measurements use samples collected in the field.

*Carried out in the Classroom or Lab**

- Bulk Density
- Particle Density
- Particle Size Distribution
- pH
- Soil Fertility (N, P, K)

Soil Moisture and Temperature Measurements

Carried out in the Field

- Soil Temperature
- Soil Moisture Monitoring

*Carried out in the Classroom or Lab**

- Gravimetric and Volumetric Soil Moisture

Individual Measurements

Soil Characterization

At a soil site, horizons in a soil profile are distinguished from one another by differences in their structure, color, consistence, texture, and the amount of roots, rocks, and free carbonates they contain. Laboratory or classroom analyses of bulk density, particle density, particle size distribution, pH, and soil fertility also reveal differences among horizons.

Structure

Structure refers to the natural shape of aggregates of soil particles, called peds, in the soil. The soil structure provides information about the size and shape of pore spaces in the soil through which water, heat, and air flow, and in which plant roots grow. Soil ped structure is described as *granular, blocky, prismatic, columnar,* or *platy*. If the soil lacks structure, it is described as either *single grained* or *massive*.

Color

The color of soil is determined by the chemical coatings on soil particles, the amount of organic matter in the soil, and the moisture content of the soil. For example, soil color tends to be darker when organic matter is present. Minerals, such as iron, can create shades of red and yellow on the surface of soil particles. Soil in dry areas may appear white due to coatings of calcium carbonate on the soil particles. Soil color is also affected by moisture content. The amount of moisture contained in the soil depends on how long the soil has been freely draining or whether it is saturated with water. Typically, the greater the moisture content of a soil, the darker its color.

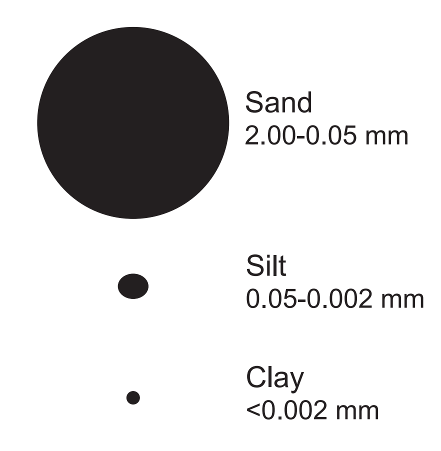
Consistence

Consistence describes the firmness of the individual peds and the degree to which they break apart. The terms used to describe soil consistence are *loose, friable, firm,* and *extremely firm*. A soil with friable consistence will be easier for roots, shovels, or plows to move through than a soil with a firm consistence.

Texture

The *texture* describes how a soil feels and is determined by the amounts of *sand, silt,* and *clay* particles present in the soil sample. The soil texture influences how much water, heat, and nutrients will be stored in the soil profile. Human hands are sensitive to the difference in size of soil particles. Sand is the largest particle size group, and feels gritty. Silt is the next particle size group, and feels smooth or *floury*. Clay is the smallest particle size group and feels sticky and is hard to squeeze. See Figure SOIL-I-10. The actual amount of sand, silt, and clay size particles in a soil sample is called the *particle size distribution* and is measured in a laboratory or classroom.

Figure SOIL-I-10: Particle Size Groups



Relative (not actual) size of sand, silt, and clay particles.

Roots

An estimate of the roots in each horizon in a soil profile illustrates the depth to which roots go to obtain nutrients and water. The more roots found in a horizon, the more water and nutrients being removed from the soil, and the more organic matter being returned. Knowing the amount of roots in each horizon allows scientists to estimate the soil's fertility, bulk density, water holding capacity, and its depth. For example, a very compact horizon will inhibit root development whereas a porous horizon will not.

Rocks

An estimate of the number of rocks in each horizon helps to understand the movement of water, heat, and air through the soil, root growth, and the amount of soil material involved in chemical and physical reactions.

Soil particles greater than 2 mm in size are considered to be rocks.

Carbonates

Carbonates of calcium or other elements accumulate in areas where there is little weathering from water. The presence of carbonates in soil may indicate a dry climate or a particular type of parent material rich in calcium, such as limestone. Free carbonates often coat soil particles in soils that are basic (i.e., pH greater than 7). These soils are common in arid or semi-arid climates. Carbonates are usually white in color and can be scratched easily with a fingernail. Sometimes in dry climates, carbonates form a hard and dense horizon similar to cement, and plant roots cannot grow through it. To test for carbonates, an acid, such as vinegar, is squirted on the soil. If carbonates are present, there will be a chemical reaction between the vinegar (an acid) and the carbonates (a base) to produce carbon dioxide. When carbon dioxide is produced, the vinegar bubbles or *effervesces*. The more carbonates present, the more bubbles or effervescence occurs.

Bulk Density

Soil bulk density is a measure of how tightly packed or dense the soil is and is measured by the mass of dry soil in a unit of volume (g/cm^3). See Figure SOIL-I-11. Soil bulk density depends on the composition of the soil, structure of the soil peds, the distribution of the sand, silt, and clay particles, the volume of pore space, and how tightly the particles are packed. 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 ranges 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 mineral horizons.

Knowing the bulk density of a soil is important for many reasons. Bulk density indicates how tightly soil particles are packed and the ease with which roots can grow through soil horizons. Bulk density is also used when converting between mass and volume for a soil sample. If the mass of a soil sample is known, its volume is calculated by dividing the sample mass by the bulk density of the soil. If the volume of a soil sample is known, the mass is calculated by multiplying the sample volume by the bulk density of the soil.

Particle Density

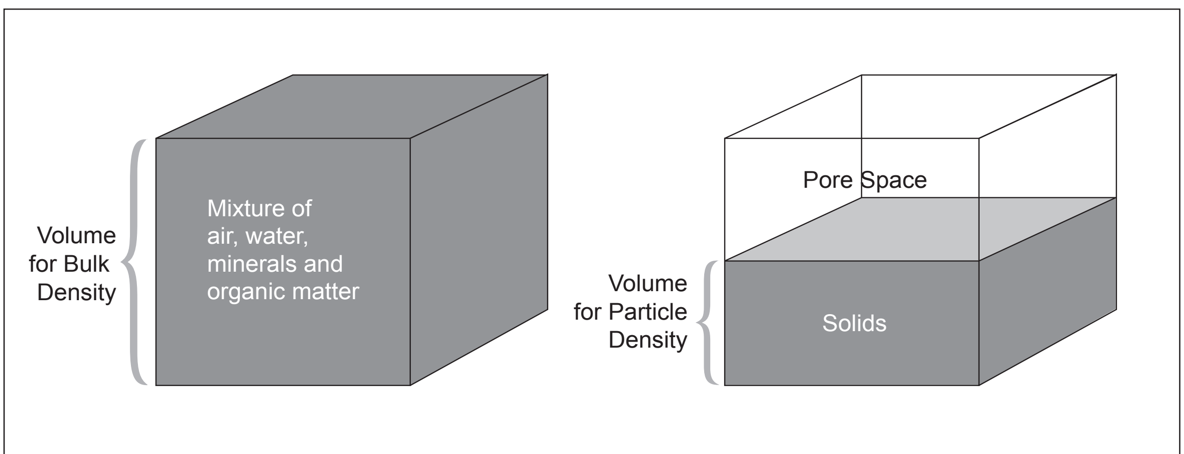
The *particle density* of a soil sample is the mass of dry soil in a particular volume of the soil when all of the air spaces have been removed. See Figure SOIL-I-11. The type of minerals the soil particles are made of affects the particle density. Soils consisting of pure quartz particles generally have a particle density of 2.65 g/cm^3. Soils consisting of particles made of minerals other than quartz will have a different mass for the same volume of particles. By knowing both the particle density and the bulk density, the *porosity* (the proportion of the soil volume that is pore space) can be calculated. Porosity establishes the amount of air or water that can be stored or moved through the soil.

Particle Size Distribution

The proportion of each particle size group (sand, silt, or clay) in the soil is called the soil *particle-size distribution*. Sand is the largest soil particle, silt is intermediate in size, and clay is the smallest. The particle-size distribution of a soil sample determines its exact textural class (which is "estimated" in the field by doing the Soil Texture Protocol). It also helps determine how much water, heat, and nutrients the soil will hold, how fast water and heat will move through the soil, and the structure and consistence of the soil.

The amount of sand, silt, and clay in a soil sample is determined by a settling method using an instrument called a *hydrometer*. A dried sample of soil is first dispersed so that none of the particles stick together, and then it is suspended in water and allowed to settle. The largest particles (sand) settle out in minutes while the smallest particles (clay) stay suspended for days. A hydrometer is used to measure the specific gravity of the soil suspension after settling has proceeded for specific amounts of time.

Figure SOIL-I-11: A Comparison of Bulk Density and Particle Density



Bulk density is a measure of the mass of all the solids in a unit volume of soil including all the pore space filled by air and water. If the volume were compressed so that there were no pore spaces left for air or water, the mass of the particles divided by the volume they occupy would be the particle density.

Soil pH

The *pH* of a soil horizon (how *acidic* or *basic* the soil is) is determined by the parent material from which the soil is formed, the chemical nature of the rain or other water entering the soil, land management practices, and the activities of organisms (plants, animals, and microorganisms) living in the soil. Just like the pH of water, the pH of soil is measured on a logarithmic scale (see the *Introduction* of the Hydrology Investigation for a description of pH). Soil pH is an indication of the soil's chemistry and fertility. The activity of the chemical substances in the soil affects the pH levels. Different plants grow at different pH values. Farmers sometimes add materials to the soil to change its pH depending on the types of plants they want to grow. The pH of the soil also affects the pH of ground water or nearby water bodies such as streams or lakes. Soil pH can be related to the water pH measured in the *Hydrology Investigation* and the precipitation pH measured in the *Atmosphere Investigation*.

Soil Fertility

The *fertility* of a soil is determined by the amount of nutrients it contains. Nitrogen (N), phosphorus (P), and potassium (K) are three of the most important nutrients needed by plants for optimum plant growth. Each horizon in a soil profile can be tested for the presence of these nutrients. The results of these measurements help to determine the suitability of a soil for growing plants. Soil fertility can be related to water chemistry measurements carried out in the *Hydrology Investigation*.

Soil Moisture

Soil moisture, also known as *Soil Water Content* (SWC), can be calculated by mass (gravimetric) or by volume (volumetric) and is presented as a ratio of water to soil. When measuring for gravimetric soil moisture, the ratio is of the mass of water contained in a soil sample to the mass of dry matter in that sample. This ratio typically ranges from 0.05 g/g to 0.50 g/g. When measuring volumetric soil moisture, the ratio is the volume of water contained in a volume of soil. The volumetric content of the soil can be as great as 0.5 cc/cc; the volume ratio typically ranges from 0.05 cc/cc to 0.50 cc/cc. Only extremely dry soils that retain a small amount of water, such as those in a desert, have values below 0.05 g/g (gravimetric) or 0.05 mL/mL (volumetric). Only organic-rich soils, peat or some clays absorb large amounts of water and have values above 0.50 g/g (gravimetric) or 0.05 mL/mL (volumetric). The soil moisture measurement helps to define the role of the soil storage in the dynamics of the ecosystem. For example, soil moisture measurements reveal the ability of the soil to hold or transmit water affecting groundwater recharge, surface runoff, and *transpiration* and evaporation of water into the atmosphere. It also describes the ability of the soil to provide nutrients and water to plants, affecting their growth and survival.

Soil Temperature

Soil acts as an insulator for heat flowing between the solid earth below the soil and the atmosphere. Thus, soil temperatures can be relatively cool in the summer or relatively warm in the winter. These soil temperature variations affect plant growth, the timing of bud-burst or leaf fall, and the rate of decomposition of organic materials.

Soil temperatures typically have a smaller daily range than air temperatures and deeper soil temperatures usually vary less. Soil temperature extremes range from 50° C for near-surface summer desert soils (warmer than the maximum air temperature!) to values below freezing in high latitude or high elevation soils in the winter.

Soil Study Site Selection

Soil study sites for carrying out soil characterization measurements and soil moisture and temperature measurements should be carefully selected.

For soil characterization measurements, a site should be considered that allows students to dig a hole with either a shovel or an auger. The purpose is to expose a soil profile that is one meter deep. If this is not possible, students have the option to sample the top 10 cm of the soil profile. It is important to check with local utility companies to be sure there are no pipes or wires buried at the site chosen for digging. A site that is chosen close to the site where soil moisture and temperature measurements are being made will help to understand these measurements better. A soil characterization site chosen near or in the Land Cover study site will help interpret the role that the soil properties play in controlling the type and amount of plant growth.

For soil moisture measurements, a site that is open should be considered. The site must not be irrigated, should have *uniform* soil characteristics, be relatively undisturbed, and be safe for digging. Soil moisture samples are collected from the surface (0-5 cm) and 10 cm depths. Samples may also be collected at depths of 30 cm, 60 cm, and 90 cm to obtain a depth profile. If possible, the site should be within 100 m of a GLOBE Atmosphere Study Site or other location where precipitation measurements are being collected.

For soil temperature measurements, a site should be selected that is adjacent to a GLOBE Atmosphere Study site, or some other location where air temperature measurements are taken. Alternatively, soil temperature can be measured at a soil moisture study site. The site should be in the open and representative of the soils in the area. Soil temperature measurements are made at depths of 5 and 10 cm with all protocols and also at 50 cm with monitoring protocols.

Site Description

After students have selected a site for their soil measurements, they use the following identifying factors to define and describe the location they plan to study: latitude and longitude (using GPS receivers), elevation, slope, aspect (the direction of the steepest slope), type of vegetation covering the soil, parent material, current land use practices, and the position of the soil on the landscape. The students determine some of these properties at the site, while other properties are established using local resources such as maps, soil survey reports, and local experts.

Frequency of Measurements

Soil characterization measurements should be carried out one time for each Soil Characterization Study Site. More than one study site can be used in order to identify soil properties at different locations (such as at the soil moisture and temperature sites, land cover site, or along different parts of the landscape for example).

To help understand the global picture of soil moisture, GLOBE has partnered with the NASA SMAP Mission. The priority is to build a time series of surface soil moisture data. Ideally samples are collected on mornings when SMAP flies over a site – 3 times every 8 days for most locations. Periodic data from 5 cm and 10 cm is useful in characterizing the seasonal and annual patterns of a site. If observations are taken for a limited time period, try to choose a time when soil is drying out or becoming wet.

Daily and continuous soil moisture data from sensors are broadly useful and not generally available.

Soil temperature measurements are carried out at least once each week. The *Digital Multi-Day Max/Min/Current Air and Soil Temperature Protocol* provides for daily measurement of the maximum and minimum soil temperatures from a depth of 10 cm. Optional protocols are available for measuring daily maximum and minimum soil temperatures at 5 cm and 50 cm depths and for collecting soil and air temperature every 15 minutes using a data logger.

Field Considerations

Many teachers find that their students take great pride and satisfaction in digging a soil pit to expose a soil profile. Occasionally, adult volunteers are needed to assist, or someone in the area with a backhoe can be asked to help out. When digging, all necessary precautions should be taken to avoid buried utilities. To keep the hole from being a hazard to both people and animals, the pit should be open only while students are conducting their observations. It should be kept well covered when the class is not working in it.

Managing Students

Depending on the size of the soil pit and the number of students, it might be possible to work on the pit as a class. In other cases, it is better to allow groups of 3-5 students into the pit at a time. There are many strategies for using multiple groups of students to collect data from different horizons or to collect duplicate samples. Teachers should expect the soil characterization measurements and sampling procedures to take several hours. Some teachers choose to carry out the measurements on repeated visits. Experts in Soil Science from local Universities, the USDA Natural Resources Conservation Service,

Figure SOIL-I-12

National Science Education Standards	Basic Protocols					Advanced Protocols			Learning Activities	
	Charac-terization	Temperature	Soil Moisture	Bulk Density	Soil pH	Particle Size Distribution	Particle Density	Soil Fertility	Just Passing Through	Just Passing Through-Beg.
Earth and Space Science Concepts										
Earth materials are solid rocks, soil, water, biota, and the gases of the atmosphere.			■	■		■	■			
Soils have properties of color, texture, structure, consistence, density, pH, fertility; they support the growth of many types of plants.	■	■	■	■	■	■	■	■	■	■
The surface of Earth changes.	■	■	■		■			■		
Soils are often found in layers, with each having a different chemical composition and texture.	■				■			■	■	■
Soils consist of minerals (less than 2 mm), organic material, air and water.	■		■	■		■	■	■	■	■
Water circulates through soil changing the properties of both the soil and the water.	■	■	■	■	■			■	■	■
Physical Science Concepts										
Objects have observable properties.	■	■	■	■	■	■	■	■		
Energy is conserved.		■								
Heat moves from warmer to colder objects.		■								
Chemical reactions take place in every part of the environment.					■			■		
Life Science Concepts										
Atoms and molecules cycle among the living and nonliving components of the ecosystem.								■		
Scientific Inquiry Abilities										
Identify answerable questions.	■	■	■	■	■	■	■	■	■	■
Design and conduct an investigation.	■	■	■	■	■	■	■	■	■	■
Use appropriate tools and techniques including mathematics to gather, analyze, and interpret data.	■	■	■	■	■	■	■	■	■	■
Develop descriptions and explanations, predictions and models using evidence.	■	■	■	■	■	■	■	■	■	■
Communicate procedures and explanations.	■	■	■	■	■	■	■	■	■	■

and other agricultural agencies can provide assistance with digging, describing the site, and characterizing the soil.

Soil moisture samples should be collected from as large an area around a school as possible. For comparison to SMAP data 10+ sites within a 20 km radius is ideal. This allows all students (and parents) to participate. Teams of students and parents can work together to collect site descriptions, GPS coordinates, near-surface gravimetric samples, and any other GLOBE data that interests the class. Other groups of students can be responsible for weighing the wet soil as soon after sample collection as possible and then beginning the drying process. It might be useful to contact and work with soil scientists from local colleges, the USDA Natural Resource Conservation Service and other agencies to help dry samples. Generally, a team of two or three students is appropriate for taking soil moisture samples or manually reading soil moisture sensors.

Soil temperature readings from the digital max/min thermometer are taken along with air temperature readings at least once every 7 days. Temperature probe measurements are best made by small teams (2-3 students) on a daily or weekly schedule. One successful strategy is to have one experienced student helping a less experienced student, who later becomes the mentor to new team members. Data collection takes 10-20 minutes.

Combining the Measurements

In the *GLOBE Soil Investigation*, students study both the soil properties that change very slowly (soil characterization), and those that change rapidly (soil temperature and moisture). Without knowing the slowly changing properties of the soil profile, it is difficult to understand the dynamic moisture and temperature changes that occur. In the same way, the patterns in moisture and temperature in the soil over time, affect the formation of the soil. Teachers are encouraged to combine soil characterization measurements with soil temperature and moisture measurements so that students gain a true understanding of the way the pedosphere functions and affects the rest of the ecosystem.

Educational Objectives

Students participating in the activities presented in this chapter should gain scientific inquiry abilities and understanding of a number of scientific concepts. See Figure SOIL-I-12. These abilities include the use of a variety of specific instruments and techniques to take measurements and analyze the resulting data along with general approaches to inquiry. The Scientific Inquiry Abilities listed in Figure SOIL-I-12 and in the grey boxes at the beginning of each protocol are based on the assumption that the teacher has completed the protocol including the Looking at the Data section. If this section is not used, not all of the inquiry abilities will be covered. The Science Concepts included in the figure and grey boxes are outlined in the United States National Science Education Standards as recommended by the US National Research Council and include those for Earth and Space Science and Physical Science. Figure SOIL-I-12 provides a summary indicating which concepts and abilities are covered in which protocols or learning activities.