Get the Dirt on Soil

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Lessons

What are Soils?

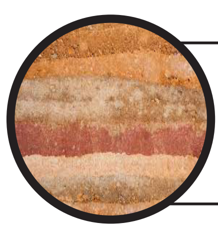
Soils serve as the foundation for life on land. Learn about how we define soils, where they come from, what properties they have, and why they are so important.

Soil Texture

Soil Texture is an important driver of many processes in soils. Learn about what texture is, how scientists identify it, and how it contributes to nutrient and water cycling, and organismal behavior.

What is Clay?

Clay is a special class of soil particle that has properties that can make or break the utility or fertility of a soil. Learn about what clay is and how it behaves in soils.



Soil Color

Ever notice that the earth presents a kaleidoscope of colors? Let's learn about what causes these different colors and how scientists use them to understand the life history of a soil.

Soils and Fossils

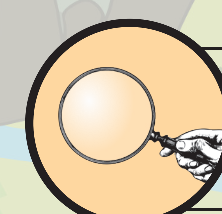
Not all soils are equal when it comes to fossils. Let's delve into what types of sediments are better for preserving fossils,. and how fossils are formed.

Life in Soils

Did you know that there is more life below ground than above it? Organisms that live in soils are vital to life as we know it. Learn about the roles these organisms play in the circle of life and our survival.

Soils and Plants

Plants need soils to grow and thrive, but did you know that soils need plants as well? Let's explore the dynamic relationship between soils and plants, and why they rely on each other to be healthy.



Other Resources

Applicable middle school content standards, additional suggestions to enhance lesson plans, and helpful links!

"There is no life on this earth without the soil and no soil without life "

The critical zone (CZ) is the thin veneer of the earth we inhabit and utilize. It encompasses everything between the top of the tree canopy to below our groundwater, including the air, the water, the organisms, the soil and the rock, and all of the interacrtions between them[1].

The CZ sustains life on earth and provides food, shelter, forage, and fuel and other services that are essential to human well-being. However, soils as building blocks and as integral components of this zone remain poorly appreciated, acknowledged, and understood.

This booklet contains a compilation of lesson plans that integrate CZ science, specifically emphasizing soils, with hands-on activities based in the arts and technology to make concepts and curricula more accessible to school-aged children. It is intended to help educators present aspects of the CZ to middle school students, but can be tailored to other age groups as well.

Each section covers a separate topic, with background information, questions to pose to students, interactive, hands-on moments, and larger activities meant to explore specific concepts in more detail. The last section provides a list of the applicable middle school content standards, suggestions for enhancing each section, and a list of additional resources educators can refer to for the activities and concepts presented, as well as ways to modify some activities for different grade levels.

[1]White et al. 2015. The Role of Critical Zone Observatories in Critical Zone Science. In *Developments in Earth Surface Processes*, Vol 19, pp 15-78. Elsevier.

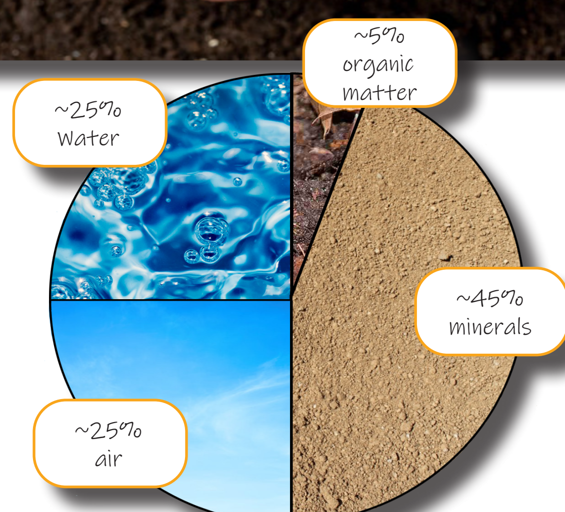
What is Soil?

What is soil?

What do you think soil is?

Soils — the 'skin of the earth' — are the major component of the critical zone. They are the loose layer of material that plants and animals (including humans!) interact with on a daily basis.

Soils are a mixture of minerals, soil organic matter, and varying amounts of water and air. The solid portion mostly consists of minerals (45%), which are inorganic particles derived from weathered rock. A smaller portion of the solid is organic matter (5%), consisting of decaying plants and animals. The rest, ~50%, is filled with varying amounts of water and/or air at any given point in time.



Soils are the product of both chemical and physcial weathering processes that occur on the surface over long periods of time, so are only able to form when the ground surface is stable. If the ground surface continuously changes- be it through natural processes such as landslides and floods, or through human activities such as agriculture and construction - soils cannot form or are reset to zero after each event.

Soils are vertically weathering profiles that develop in place and often result in gradients of colors moving from top to bottom.

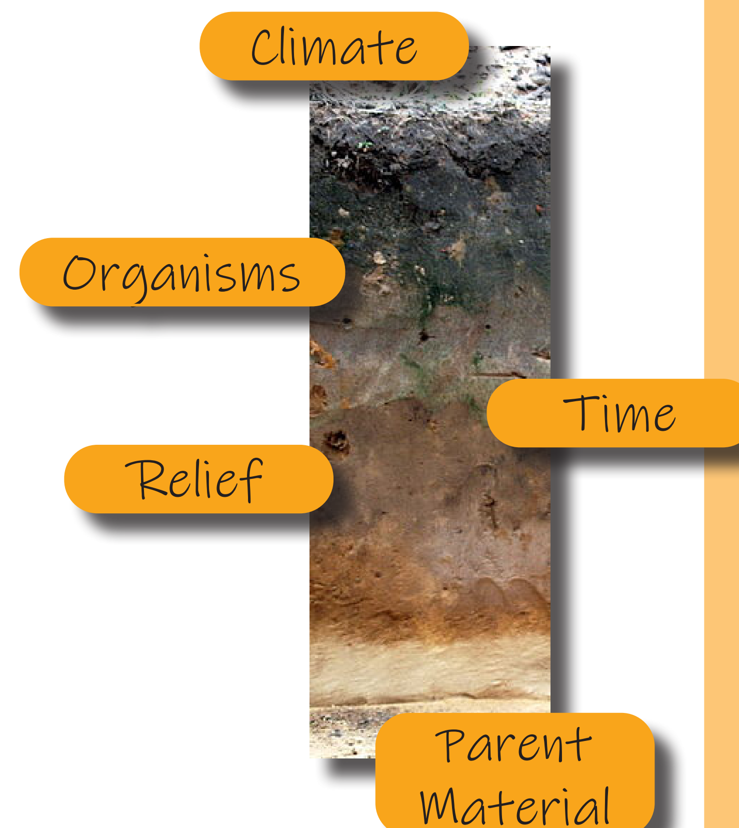
TAKE-HOME IDEA: Soils represent the result of chemical and physical processes acting on a deposit over a long period of time.

Learning Objectives:

1) Students will be able to define what soils are.

2) Students will be able to describe how soils are formed.

3) Students will be able to list some important properties of soils.



How are soils formed?

How do you think soil is formed? Where does it come from? How long does it take?

Soils take a very long time to form. By some estimates it takes at least 500 years to form 1 inch of soil!

There are 5 primary factors that direct soil formation[2]:

CLORPT

Climate, Organisms, Relief, Parent Material & Time

Why might these individual factors affect soil formation? Give some examples.

Climate: climatic variables such as temperature and moisture strongly affect weathering and leaching processes. Temperature affects the rate of chemical reactions and biological processes that alter or break down rocks and minerals (weathering). Moisture also influences these rates, but also how minerals and other substances are moved through the profile or lost from the system (leaching).

Organisms: plants and animals (including humans and microorganisms) chemically and physcially alter soils in many ways. For instance, burrowing animals and plant roots mix soils and alter their structures, and microorganisms help breakdown organic matter and secrete enzymes or other compounds that alter their chemical compositions.

Relief: slope and aspect (the direction a slope faces) affect the temperature and moisture of a soil and how much sun it receives, and slope is a primary control on patterns of erosion.

Parent Material: the material from which a soil forms determines the type of minerals and grains present. This affects the kinds of chemical and physical processes that can occur during soil development.

Time: soils are continuously altered by biological, chemical and physical processes over time. Soils can also be reset by natural or man-made forces, such as floods or landslides. Old soils can become buried. Additions, removals, and alterations are slow or rapid, depending on climate, landscape position, and biological activity.

[2]Jenny H (1941) Factors of soil formation a system of quantitative pedology. McGraw-Hill, New York.

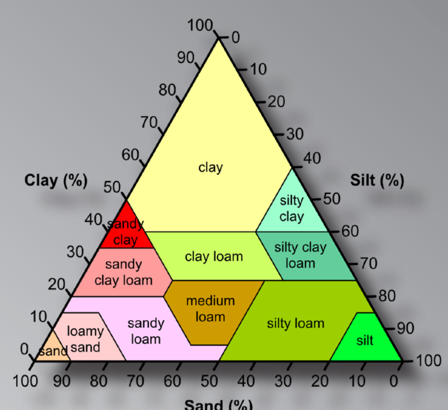
What is Soil?

Soils contain different layers called horizons.
All the horizons together make up a soil profile.

What are properties of soils?

Show students an example of a soil profile. When you look at a soil, what attributes or characteristics can you observe? Ask students to think about and discuss why these might be important.

In soil science, some of the most common properties examined are: texture, structure, porosity, and color.



Soil texture

Size of particles in the soil, specifically the proportion of sand, silt and clay. Sand is the largest with a gritty texture. Silt is fine and powdery, but not sticky when wet. Clay is the smallest, and is sticky when wet.

Soil structure

How the soil particles are clumped together (aggregates). Soil texture, organic matter and soil organisms influence aggregate formation. The amount and types of aggregates are important in determining how plants grow, how air and water move through the soil, and how nutrients are distributed. Good soils have a balance between the number, size and friability (how well they break apart) of aggregates, while poor soils have no aggregates, too large of aggregates, and/or very hard aggregates that don't break up easily.

Have examples of various soil profiles for students to examine. Now that you've reviewed these soil properties, have them describe what they see and discuss how the profiles are different from one another.

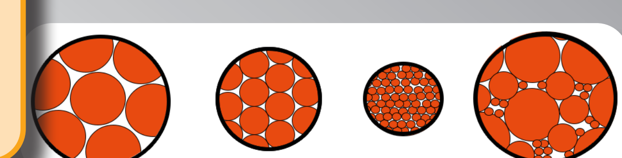
Soil color

A soil's color depends on its organic matter composition and mineral content, as well as drainage. Topsoil is often dark because of high amounts of organic matter. An even, single color indicates the soil is well drained. In contrast, rusty spots and grey patches indicate poor drainage.

Credit: Antonio Jordán (distributed via imaggeo.egu.eu)

Soil porosity

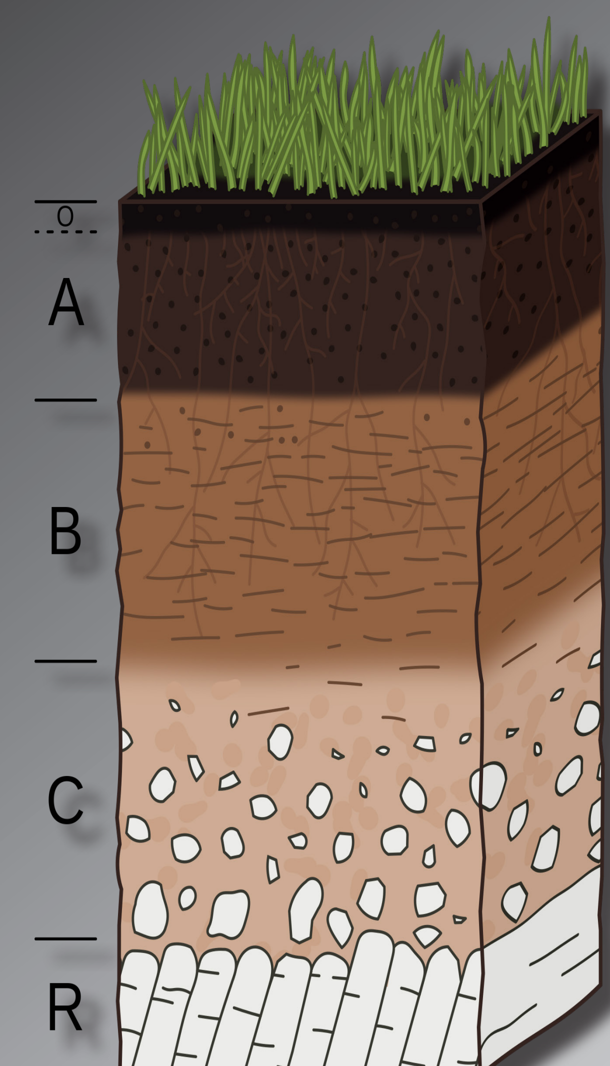
The number and size of spaces in the soil, which influences air and water movement. Too many or too large of pores and water can't be held for long, too few or too small and water cannot infiltrate and/or little oxygen is available for soil organisms to use.



Give students a printout of a soil profile. Have them draw boundaries for where they think different horizons begin and end. Laminate these to allow for redrawing boundaries as needed. Have them note what characteristics they used to make those

Soil Horizons

A well-developed soil is marked by distinct layers called horizons. These layers vary due to differences in properties like soil texture, color and structure. Scientists identify major horizons using capital layers O, A, B, C, E and R.



O is a layer of organic material on the surface of a soil. Not all soils contain this horizon.

A is the surface soil horizon, or topsoil, containing a mixture of mineral soil and organic matter. This is where most larger soil organisms live.

E consists of a lighter layer leached of minerals and organic matter. Not all soils contain this horizon.

B is the subsoil, containing abundant minerals and clays that have moved down from the horizons above.

C consists of weathered parent material, often with more rocky material.

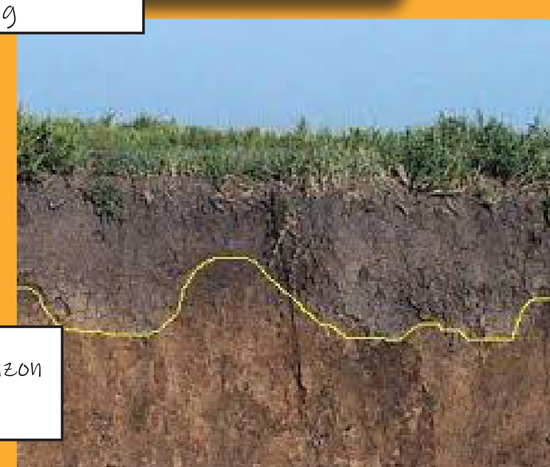
R consists of bedrock, or unweathered parent material.

HANDS-ON ACTIVITY
SOIL PROFILES

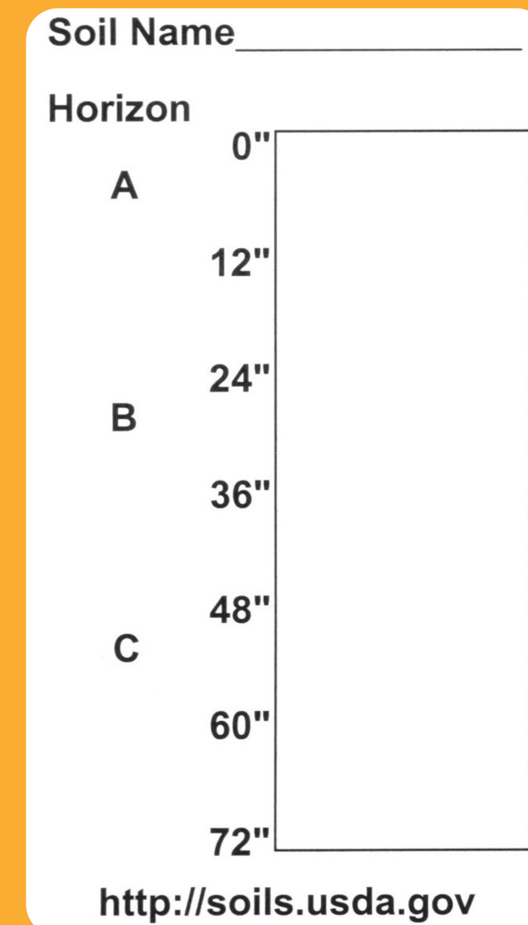
To understand soils in a particular location, scientists dig a hole and analyze its profile. They record visible properties in the field, such as color, texture, and structure. Other properties are measured and recorded in the laboratory, like pH, electrical conductivity, mineral content, particle size and chemical content. All of these inform on the quality of the soil as well as its developmental history.

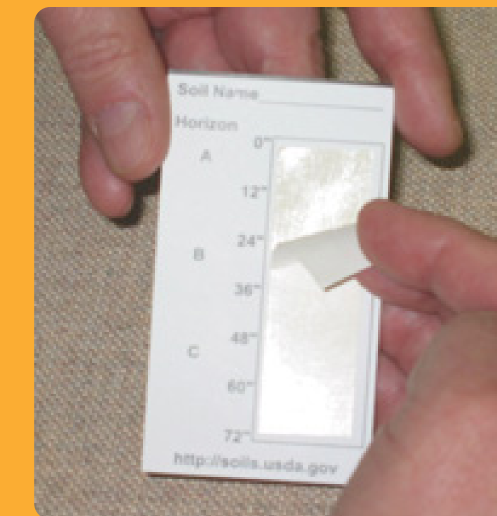
Activity: Find an exposed profile near you. If none are nearby, you can dig a hole as deep as you can go, wide enough so the students can see the profile clearly. The easiest place to do this is on the side of a hill or on the wall of a riverbed, but whatever you choose be sure to get permission before digging! Have the students examine the profile and determine where each horizon begins and ends. Discuss what visible attributes helped make this determination. Have the students make a soil profile card using the soils from the profile you examine.

Hillslopes and riverbeds are good places to find exposed profiles, and are easier to dig



Identify where each horizon begins and ends





Add a piece of double-sided tape to the card. Do not remove the cover on the exposed side of the tape until you are ready

Pull back the cover on the exposed side of the tape up to the depth of the base of the first horizon. Grab a sample of soil from the first horizon in your soil profile and place the soil sample on the profile card.

Repeat this step for each horizon in your soil profile.

Activity from USDA National Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/?cid=nrcs142p2_054308

Soil Texture

Soil Sensors: https://soilsensor.com/articles/soil-textures/

What is soil texture?

Soil texture refers to the size of particles in a soil; its proportion of sand, silt and clay.

Sand is the largest size, and is gritty

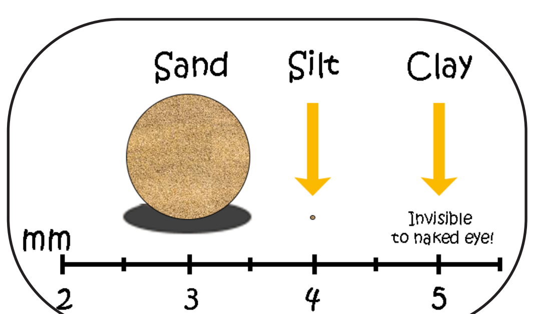
Silt is fine, smooth, and powdery, but not sticky when wet

Clay is the smallest and it's sticky when wet. (12,000 clay particles line up to make 1 inch!)

How do scientists describe soil texture?

Two common ways are the ribbon test and the sedimentation method.

Question: How does particle size and structure influence the retention of nutrients and water through the soil?



Ribbon Test: Provide balls of soil with different proportions of sand, silt and clay. Have the student use the flowchart on p. 14 to perform the ribbon test and come up with textures.

This method gives a more general description of the soil texture. It doesn't give precise amounts of each particle size, just the relative proportions that lead to certain properties that you can detect by feeling the soil.

Sedimentation Method: Add clean sand, silt and clay to different plastic bottles filled with water and shake them. Watch how particles settle. Note

TAKE-HOME IDEA:
The particle size and structure of soils affects how water moves through it.

Learning Objectives:

1) Students will be able to explain how soil texture influences water retention.

2) Students will be able to explain how soil texture influences water filtration.

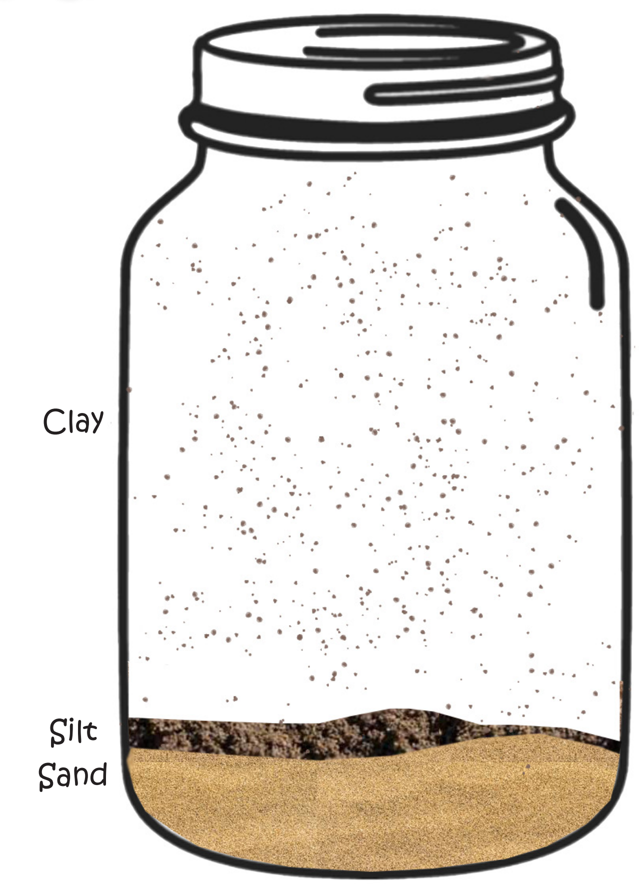
It's all about the grain size!

how fast the grains settle and the difference in clarity in the bottle with the sand, and the suspension of smaller particles in the other bottles. Add ~1/2 cup of soil representing a mixture of all particle sizes into a jar, fill with water until it is ~2/3 full, add a few drops of liquid detergent, cover and shake for about 5 minutes. Let the soil sit for 5 minutes and note how particles have settled. Observe again after 24 hours. Have layers formed? Which grain size is at the bottom and which is at the top? why?

This is a simplified version of the sedimentation method. We know particles of different sizes settle at different rates - the heavier the particle the faster it sinks, and the lighter it is the slower it sinks. Sand settles very quickly, silt follows, and clay takes the longest to settle. We know that sand settles within the first few seconds, often immediately. Silt can take hours, after which there is only clay left in suspension. If we measure how much material is in suspension once all the silt settles we can answer how much clay is present. If we take the material that has settled at the bottom, rinsed it until there is only sand left and weighed it, we'd know how much sand was present. Then, because we know how much soil we started with we can subtract the known sand and clay measures to get at how much silt there is. This gives us quantitative measures of soil texture.

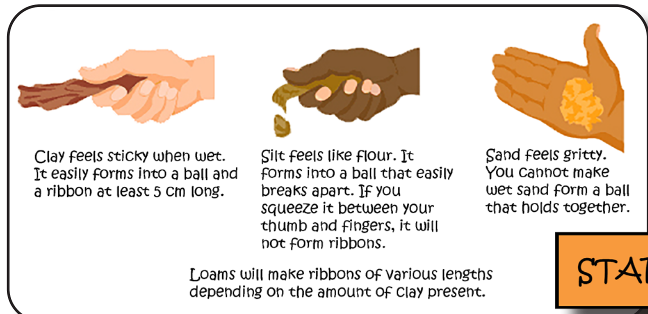
Why is texture important in soils?

Texture is important because it affects many properties of soils, such as water availability, air flow (gas exchange), nutrient cycling, pH, organismal activity, and so on. Here we will focus on its relationship with water.

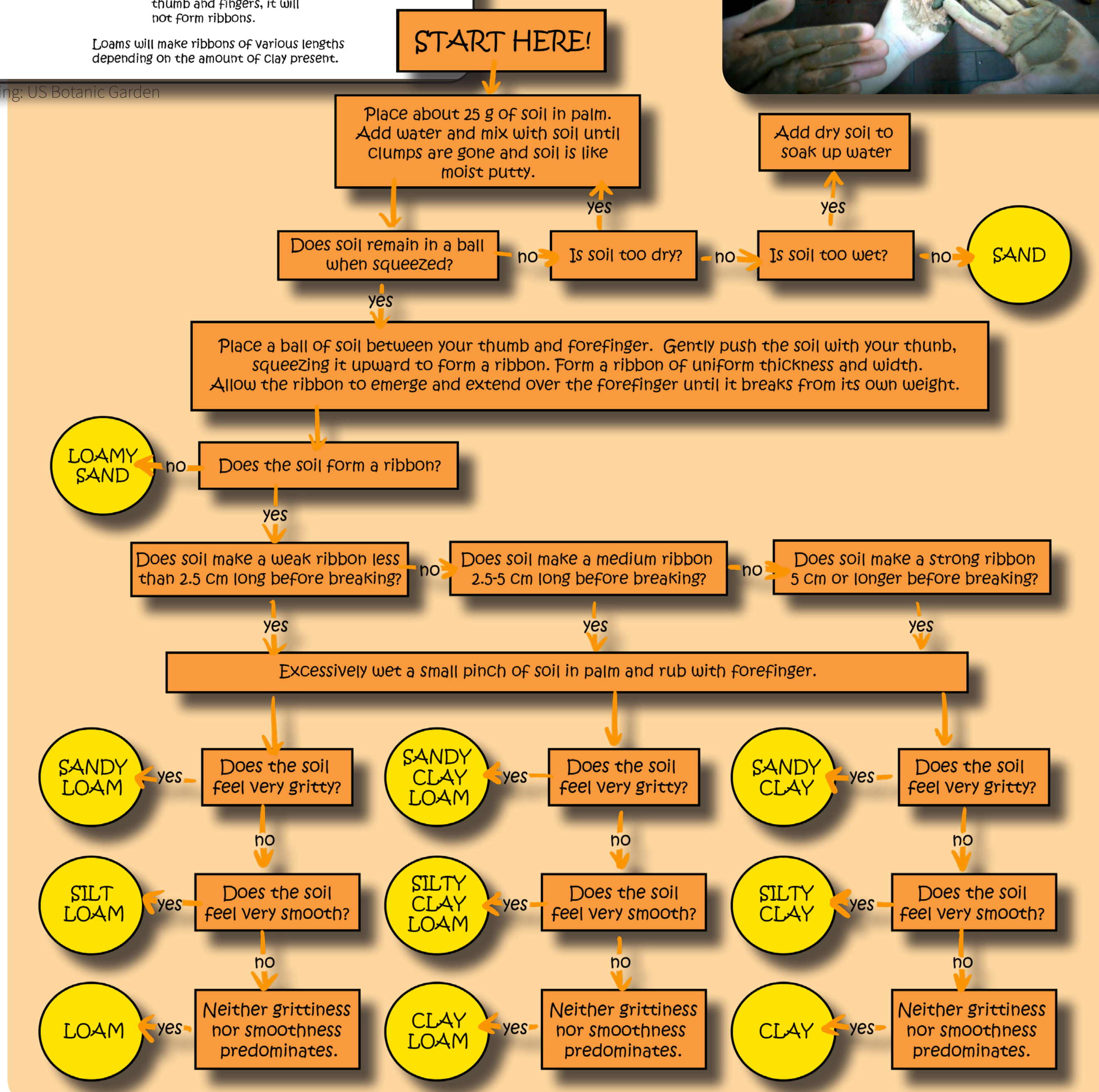


Have soils of different textures in containers, pour water in and observe how water moves through the different soils. Which does the water move through fastest? Does water immediately penetrate each sample? Why might that be? Why do you think this is important?

Soil Texture



Drawing: US Botanic Garden

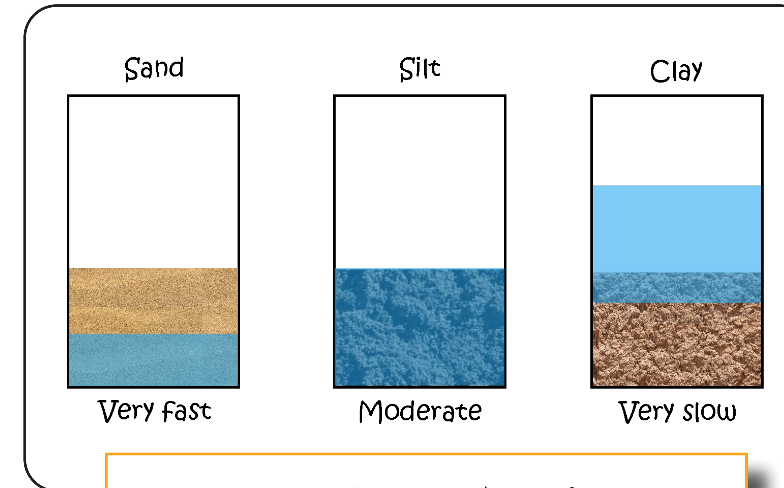


Modified from S.J. Thien. 1979. A flow diagram for teaching texture by feel analysis. Journal of Agronomic Education. 8:54-55.
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/kthru6/?cid=nrcs142p2_054311

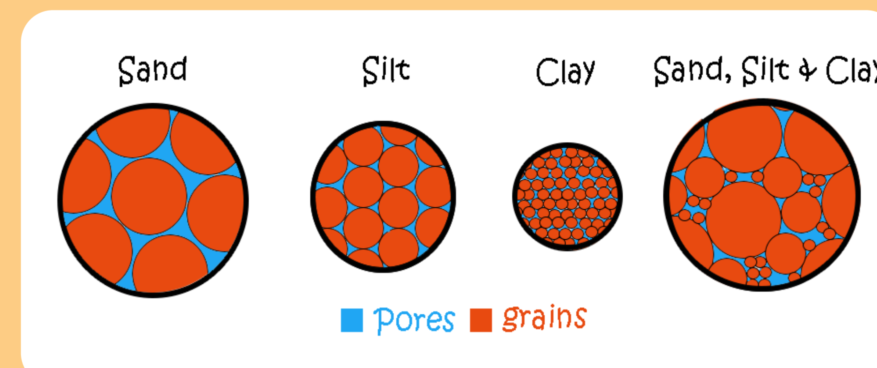
If you have a well-sorted soil, meaning all grains are the same size, then the amount of pore space will be equal across soils regardless of particle size. A sand, silt and clay of equal volume will have the same amount of pore space. However, particle size determines how large those pore spaces are. Large particles will have large pore spaces and small particles will have smaller ones. The larger the pores, the lower the water rentention as water moves more quickly through soils with larger pores than smaller ones.

Also, the smaller the particle, the greater the surface area to volume ratio. The greater the surface area, the greater the available area for bonding with water. The combination of very tiny pore spaces and much greater surface area means that clays, the smallest of particle sizes, hold onto, or retain, more water than any other type of soil.

While clays can retain the most water, the drawback is it is not easily accessible. Those same qualities of clay, small pore size and bonding capability, also means that the water is held very tightly by the clay particles themselves or water has to move through very, very small holes to be useful for plants and organisms. It will move very slowly through a soil. If the clays are very dense, water may pool up on the surface faster than it can seep into the soil, leading to more runoff and flooding.



Due to their particle sizes and size of pore spaces, water flows fastest through sand (and other large particle sizes) and slowest though clays.



A combination of grain sizes leads to better water movement and nutrient retention in soils.

On the opposite end, sand has a much larger particle size so larger pore spaces, and it has a lower surface area and does not hold onto water in the same way clay does. Here water tends to run through the sand and leave the system very quickly, with little left behind for plants and organisms to use.

Silt provides a good balance between the two. It has a smaller size, so a greater surface area relative to sand, but does not result in the same tiny, impenentrable pore spaces or have the same bonding qualities as clay. Silts have a good capacity to hold and store water for plants and organisms as water can move more freely than in clays, and are retained in the soils longer than in sands.

While you can find soils made up primarily of one particle size, it is more common to see combinations of particle sizes as seen in loams and other mixtures.

Loams can be made up of varying amounts of each particle size; if silt dominates it is called a silty loam, if clay dominates, it is a clay loam, and if sand dominates, it is a sandy loam. There are a number of possibilities, but you get the idea.

HANDS-ON ACTIVITY

NOT ALL SOILS ARE THE SAME!

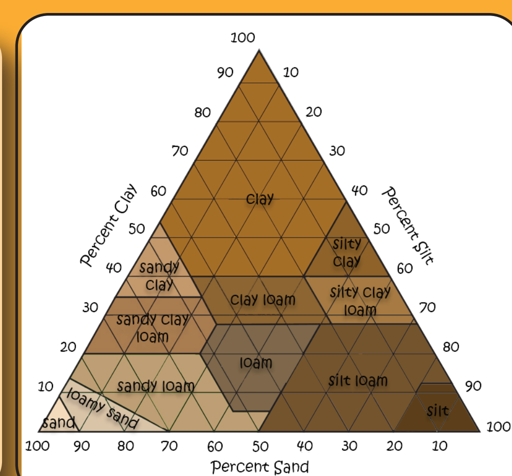
A soil's texture varies in different environments. For instance, soils from forests or swamplands will contain more organic matter and perhaps finer grained particles than soils from a beach, whose main grain size is sand. Lets explore this more in the lab.

Activity: Prior to this exercise, collect soils from several different environments. Try to pick environments that are obviously different from one another, such as a plot with native plants, an agricultural field, adjacent to a river, a construction site, a playground, a hillslope, or a forest.

Fill mason jars about 1/2 full with each sample (one per jar). Fill the jar to about 2/3 full with water and add a few drops of liquid detergent. The detergent acts as a surfactant, which separates the soil particles so they settle by grain size rather than in clumps. Cover and shake for about 5 minutes. Let the soils settle overnight (~24 hours). Observe the differences in the layers. Are they distinct or easily noted? Are they different colors? Can you see grain sizes in them? Is there material still floating in suspension? What do you think that is? Compare and contrast the different samples. Do all jars have the same layers? Why might they be similar or different?

Now let's calculate the proportion of sand, silt and clay in each sample. Measure the entire height of the soil sample, from base to top. This is the total amount of sample present. Now measure from the base of the jar to the top of the lowest layer. This is the total sand layer. Now measure from the top of the lowest layer to the top of the next layer. This is the total silt layer. Finally, measure from the top of this second layer to the top of the uppermost layer. This is the total clay layer. Now divide each of those values by the total value and multiply by 100 to get the percent sand, silt and clay in each sample. Determine the texture for each soil using the texture triangle below.

Layer	Measurement	Height in jar	Percent of sample	Soil Texture
Sand	Bottom of jar to top of 1st layer			
Silt	Top of 1st layer to top of 2nd payer			
Clay	Top of 2nd level to top of 3rd level			
Total soil sample	Total height of soil			



WATER FILTRATION

As we saw, soil texture - the relative amount of sand, silt and clay present in a soil - influences the rate that water can run through it. This is important because it determines how much water is available to plants and organisms after a wetting event.

Another important role soil texture plays is in water filtration. The longer it takes water to move through the soil, the cleaner it gets. This is because the water has more time to interact with soil particles. Clays and organic matter in particular have important roles as they have charges that attract chemicals; they hold these chemicals and keep them from flowing through the soil into our groundwater or streams. This same interaction is what holds nutrients in soils for plants and animals to use.

Activity: Explore the effect of grain-size on water filtration using water with food coloring and stacks of bottles with soil for the water to move through. If the water runs through quickly, as with sand, the water will remain green when it comes out. If the water moves through slowly, the soil will capture the green and the water will run out clear.

Step 1:
- Remove bottoms from 4 plastic bottles.
- With 5th bottle, measure and mark where 1/4 to 1/2 cup of water reaches in the bottle. Cut off top of 5th bottle now.

Step 2
Cover lid end of all bottles with cheesecloth and attach with a rubber band.

Step 3
Fill 3 of the 4 bottles wihtout bottoms with 1/2 cup of sandy, clayey or loamy soil. Be sure to use only one type of soil in each stack of bottle filters.

Step 4
Mount bottles as follows (from top to bottom):
- bottle with no bottom and no soil
- bottom with no bottom with soil (x3)
- bottle with no top

Cut small vertical slits into the bottom of the bottles to improve fit.

Materials
- 5 empty plastic bottles (16-20 oz)
- Cheesecloth
- Rubber bands
- 1 and 1/2 cup of a type of soil (sandy, clayey or loamy)
- permanent marker

Adapted from USDA Natural Resources Conservation Service: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050949.pdf. Accessesd Aug 9, 2022.

What is Clay?

Learning Objectives:

1) **Students will be able to describe what clays are and where they come from.**

2) **Students will be able to describe some properties of clays.**

3) **Students will be able to explain why clays are plastic.**

What is clay?

What do you think clay is? Descriptors might include something **squeezable** *you can make a figurine with, something* **slimy** *that you bake to make pots/bowls, or mud or* **sticky** *dirt.*

'Clay' can be defined in multiple ways depending on who is defining it, whether it be a soil scientist, engineer, geologist, archaeologist, artist, and so on. The one we will focus on in this lesson is a definition based on particle or grain size, typically used in the earth sciences.

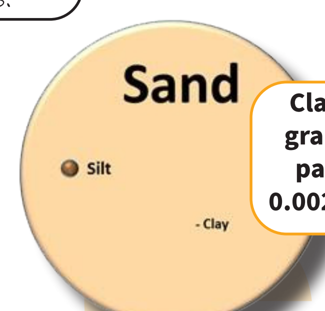
There are 3 primary grain sizes in soils: sands, silts and clays. Sand is the largest and is gritty; silt is in the middle, and is fine, smooth, and powdery, and not sticky when wet. Clay is the smallest grain size, less than 0.002 mm in diameter, and is sticky when wet and hardens when dried. Both silt and clay particles cannot be seen with the naked eye.

Have real examples of each grain size to touch. Have students feel/examine sand, silt and clay and come up with distinctions. Have grain size charts on hand to look at while they do this.

How is clay formed?

Clay is defined as having a very small grain size. Where does it come from and how does it get so small?

How do you think clay is formed? Where do you think it comes from? How do the grains get so very **very** *small?*



Clay is the smallest grain size, including particles less than 0.002 mm in diameter!

We can have clay-sized material from the breakdown of living things like tissues or tree bark and leaves, or non-living things like shells, but most of what is considered clay comes from the breakdown of rock.

TAKE-HOME IDEA: The extremely small size and the structure of clays allow them to be more sticky (hold water and nutrients) and moldable than other grain sizes.

What are rocks?

Rocks are the solid material that the earth's crust is made of. All rocks are made up of minerals. Some have only one kind, but most consist of several different minerals in a single rock. Rocks are classified based on how they were formed and what kinds of minerals they are made of.

How are rocks formed?

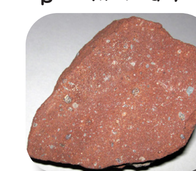
Rocks are formed in 3 different ways. Do you know what they are? *See insert on right for a review.*

How do rocks decompose?

Let's brainstorm about how rocks decompose. Possible answers should include both physical and chemical mechanisms as given below:

Igneous

Sedimentary



Metamorphic

Decomposition or *weathering* of rocks involves physical and chemical mechanisms:

Physical mechanisms include forces such as wind, water, or glacial ice that erode or abrade the surface of rocks. Rocks can also be broken down through repeating cycles of freezing and melting of water that penetrates cracks in rock - the water expands and contracts, thus weakening the rock and causing it to break; through temperature changes - rocks themselves expand and contract, weakening the rock and causing layers to break off; or when plant roots grow in cracks - roots make cracks bigger and lead to more breakdown. This form of decomposition does not alter the chemical composition of the rock, it simply breaks it into smaller and smaller pieces.

Chemical mechanisms occur in the presence of water and effectively dissolve rocks. For instance, reactions between compounds in water can produce acids that eat away at minerals, turning them into solutions that are often transported away. In this process, the chemical composition of the rock is changed, and new minerals can be formed.

Climate determines which process dominates. For instance, in areas with less water or large temperature differences fragmentation may be more important, and in areas with more water, chemical reactions may dominate.

What are the three rock types? Give examples of where they were formed. Answers should include something along the lines of the following:

Igneous: forms when hot, molten magma solidifies. They can be separated into intrusive and extrusive depending on where it solidifies.

Intrusive: hardens below the surface and cools over very long periods of time. This slow cooling allows minerals more time to form and grow larger, resulting in a more coarse-grained rock (rock with larger, observable grain sizes). e.g., granite.

Extrusive: magma hardens very quickly as it erupts at or above the surface, as it is exposed to the cooler atmospheric temperatures. This process is quick so minerals do not have time to grow, making the resulting rock very fine-grained or even glassy. e.g., basalt, obsidian.

Sedimentary: forms from materials eroded from other rocks or pieces of living organisms. These rocks usually have visible layers, formed as material is deposited in different events over time. These materials are typically transported by rivers and deposited in oceans and lakes. These get buried, lose water, and become cemented to form rock. Some forms come from accumulations of marine or lake organisms that die and sink to the bottom of the ocean, such as diatoms, radiolarians and sponges. These have glassy silica skeletons that sink, dissolve, recrystallize and cement to ultimately form rock. e.g., sandstone, mudstone, limestone, chert.

Metamorphic: igneous, sedimentary, or other metamorphic rock that has been substantially altered due to high heat, high pressure, or exposure to hot fluids, all found deep within the earth or where tectonic plates meet. These rocks don't melt, they are just transformed – if they melted they would become igneous rocks. e.g., schist, quartzite, marble, gneiss.

So ultimately, with time rocks are continuously broken down into smaller and smaller sizes. Some minerals in rock are very strong, so don't break down as easily. An example is the sand you see at the beach (or anything you think of as 'sand' for that matter) - most of that is made up of quartz grains that are very strong so they are difficult to break into smaller sizes. Others however, are more easily weathered, and are altered by physical and chemical processes until they are clay-sized minerals.

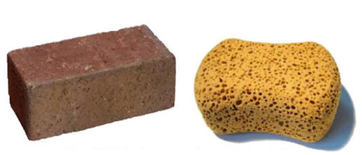
What is Clay?

What are the main properties of clay?

So now we know what clays are and how they are formed. What are some properties that set them apart from other grain types?

Compare and contrast clay and sand. What do you think of when you hear the term 'clay'? Possibly 'it's sticky', 'you can shape it', 'you can stretch it', 'it's wet', 'it's smooth', or 'it's hard when dried'? What do you think of when you hear 'sand'? Maybe it's 'gritty', 'sinks when it's stepped on', 'you can dig into it easily', 'you can build sand castles', or it's 'difficult to form into clumps'?

All of the potential answers given above are attributes that ultimately go back to the size of grains and their structures.

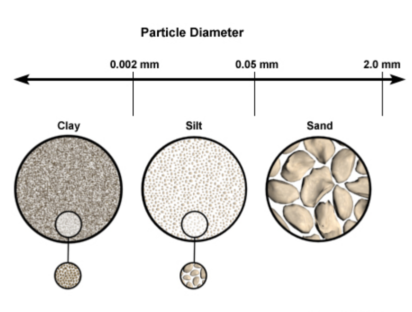


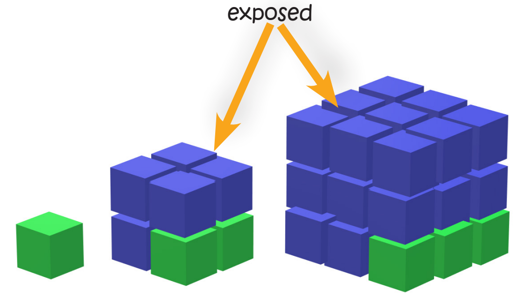
Brick = high bulk density, low pore space

Sponge = low bulk density, high pore space

Particle size: <0.002 mm (<2µm; 25,400 µm = 1 inch). Because of its small size, more clay particles can fit into a defined space than other particle types, with smaller to no gaps between them as the particles tend to bond together. This can make the matrix very dense and more difficult to penetrate than other mixtures of different sizes. Sand on the other hand is much larger, so fewer grains can fit into a defined space, there are larger air spaces between them, and the particles do not bond together so it is looser.

Have students explore porosity and density by comparing/contrasting a sponge and a brick, foam vs wood vs concrete, or fossil versus modern bone.





Surface area: the small size of clay particles gives it a high surface area. One gram of clay has roughly 1,000 times more surface area than one gram of sand; 1 gram of clay has nearly twice as much surface area as two basketball courts (>8000 sq ft). This surface area allows for more area for clays to react with other substances through chemical reactions and bonding. Sand sized grains don't have this same capacity. Again, this is why clays are sticky and sands are loose. In soils this results in a greater ability to hold on to water and nutrients in soil.

The particle size, surface area and structure of clays gives them their unique properties.

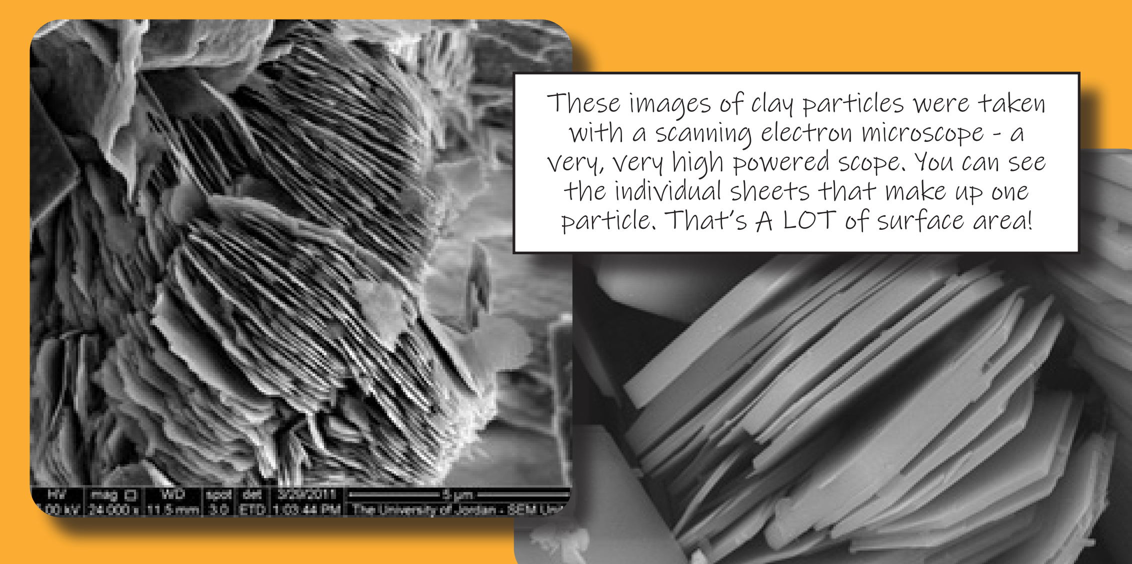
Have students explore surface area with sugar cubes. They can create a large cube by stacking and breaking them apart into smaller cubes to see how new faces are exposed and surface area increases (but the actual volume of material stays the same). 1 cm^3 of clay-sized particles has 1,000 times the surface area of an equal volume of coarse sand-sized particles. Have students calculate the surface area to volume ratio of different sized particles.

Particle structure: clays consist of flat sheets held together by a film of water molecules. Imagine a peanut butter and jelly sandwich. The 2 slices of bread are the clay sheets and the PB & J are the water holding it together. The PB & J make the bread slices stick together, but you can still move the slices around. The same goes for clay. The clay and water sandwich allows for the clay sheets to slip/slide across each other but the bonds between the water and clay are strong enough to keep them stuck to one another. This makes them more plastic. Bonds are weak enough to allow the sheets to slip when being molded into shape, but strong enough to keep them in place and allow the molded clay to retain its shape after being handled. Sands on the other hand are usually rounded particles representing the fraction of rock minerals that are very resistant to weathering. Because of the larger spaces between sand grains and its smaller surface area, it does not hold water and has no plasticity.

As a final note,

Why do clays harden when dried?

When heated, clay becomes permanently hard, like a rock. This is why it is a good medium for so many different things, like dishes, sculptures and buildings. When clay is dried, water molecules (the PB & J) between sheets (the bread!) are removed and the clay sheets bond directly to one another, making the clay rigid - you can't mold it, or when you apply pressure it doesn't bend - but still fragile - the bonds between the sheets are not permanent so they can still be easily broken. When clay is subjected to higher temperatures (as when it is put in an oven), more water loss and more intense reactions cause the sheets to stick to one another permanently. Different types of clay lose water at different rates - due to differences in their structure and mineral type – so require different temperatures and duration at that temperature for this permanent bonding to happen.

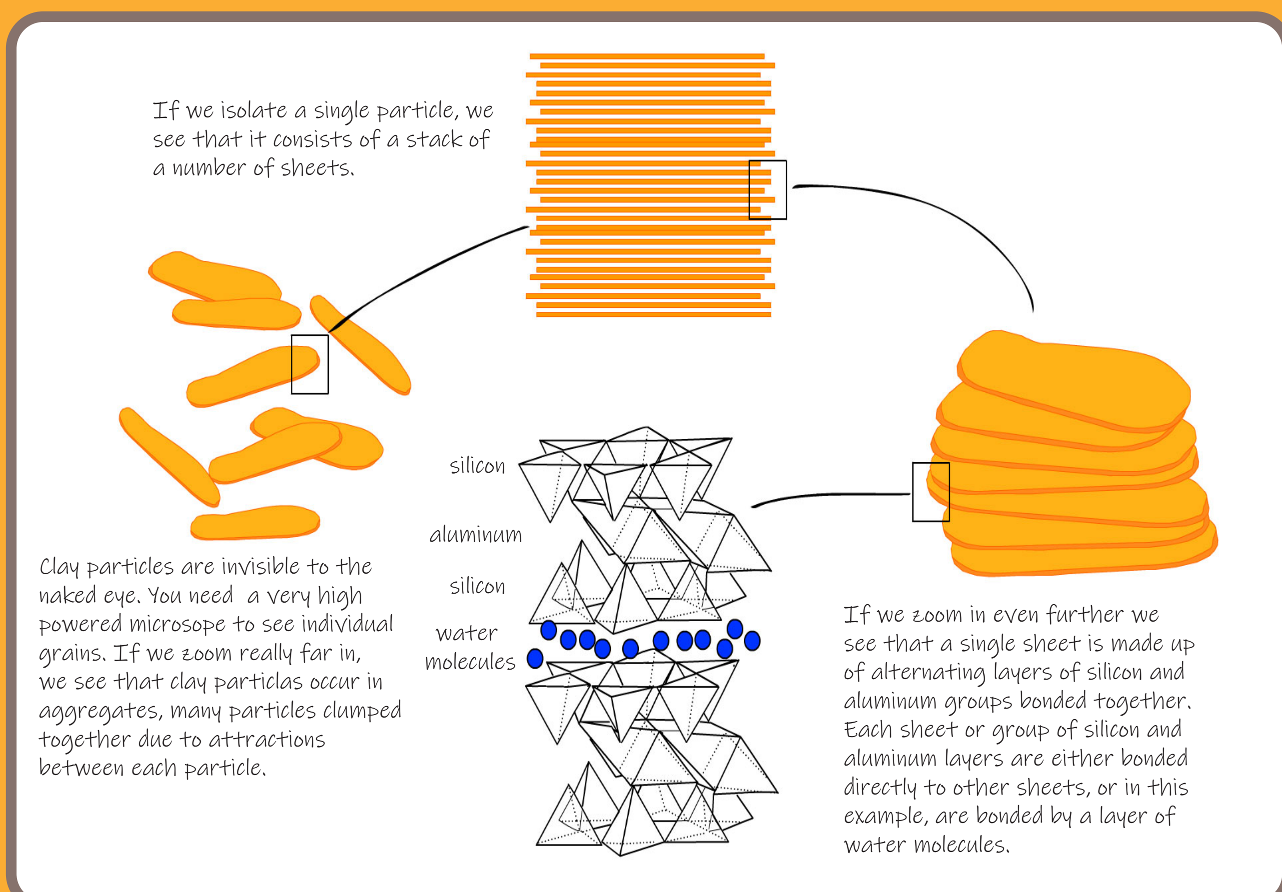


These images of clay particles were taken with a scanning electron microscope - a very, very high powered scope. You can see the individual sheets that make up one particle. That's A LOT of surface area!

HANDS-ON ACTIVITY
PLASTICITY/STRUCTURE

Plasticity allows a clay, upon addition of water, to be shaped and to retain that shape when left alone. Plasticity is lost when the water is removed from the clay in drying, but the shape you created will be retained. If you re-wet the dried clay it will become plastic again, but the shaped form will disappear. That is because the bonds between the clay sheets are not permanent. Upon heating or burning however, clays become hard and durable, and above certain temperatures the bonds between the clay sheets become permanent. No amount of water will make the clay plastic or moldable again. The final shape the clay is in cannot be changed. Think of cups or bowls...they are made of clay but their shape is permanent, which is why you can wash and reuse them for a very long time.

ACTIVITY 1: each student will get samples of dry clay and they will add increasing amounts of water to it to see how it changes the plasticity from dry to over wet.



The most important factors for plasticity are clay particle size and clay structure. Clay particles are very small with a flat, sheet-like shape with a very large surface area (relative to other particle sizes).

When water is mixed with clay, a thin film of adsorbed water surrounds clay particles, acting as a lubricant that allows the platelets to slide over one another - think back to the PB & J example. The finer the particle size of a given volume of clay, the greater its plasticity, in part because a larger number of clay grains, and hence a large surface area, is present. However, due to these same factors, the finer the clay the larger amount of water needed to optimize plasticity.

The thin film of adsorbed water serves as a lubricant to allow clay particles to slide against one another in molding of the clay, but at the same time its surface tension forces are strong enough to make it harder to pull the clay apart.

Surface tension: when the surface of a liquid is strong due to molecules in the liquid being attracted to each other. You see this every day, such as when small objects float on water, insects can walk across water, and in how water droplets hold their shape.

The finer the particles, the greater the amount of surrounding water, the greater the surface tension, and thus the greater the plasticity.

ACTIVITY 2: each student gets multiple lumps of clay with different amounts of coarser grained material in it. They can add specific amounts of water to each one and note which combination needed more or less water to become sufficiently plastic to mold into a shape.

ACTIVITY 3: each student gets a clump of clay to create a work of art that they can take home and let dry. They can explore combining pieces, which gets at the ability of clays to adhere to one another due to their plasticity – particle size, structure and interaction with water (surface tension).

Soil Color

Soils

TAKE-HOME IDEA:
A soil's color tells a story about the development of a particular soil.

Seven Coloured Earths in Chamarel, Mauritius: https://www.flickr.com/photos/shankaronline/7637242672

Learning Objectives:

1) Students will be able to explain why scientists care about soil color.

2) Students will be able to list several factors that cause soils to have different colors.

3) Students will be able to explain and show how scientists record soil color.

Questions:
Why are soils different colors?
What do these colors mean?

Why are soils different colors?

Do you ever notice different colors of earth as you move across a landscape? Maybe while taking a hike, or as you drive through deserts or mountains? Some can be very vibrant colors, like a rainbow of reds, oranges, yellows, greens and blues, while others are darker and more subdued, with varying shades of blacks, brown and greys.

Where do these colors come from? What causes one soil to be a different color than another?

Let's brainstorm! What might be some reasons for soils to change color? What are soils made of? What are soils exposed to on a daily basis?

There are four primary causes: 1) the type of mineral present, 2) the amount of iron, 3) the amount of organic matter, and 4) moisture content.

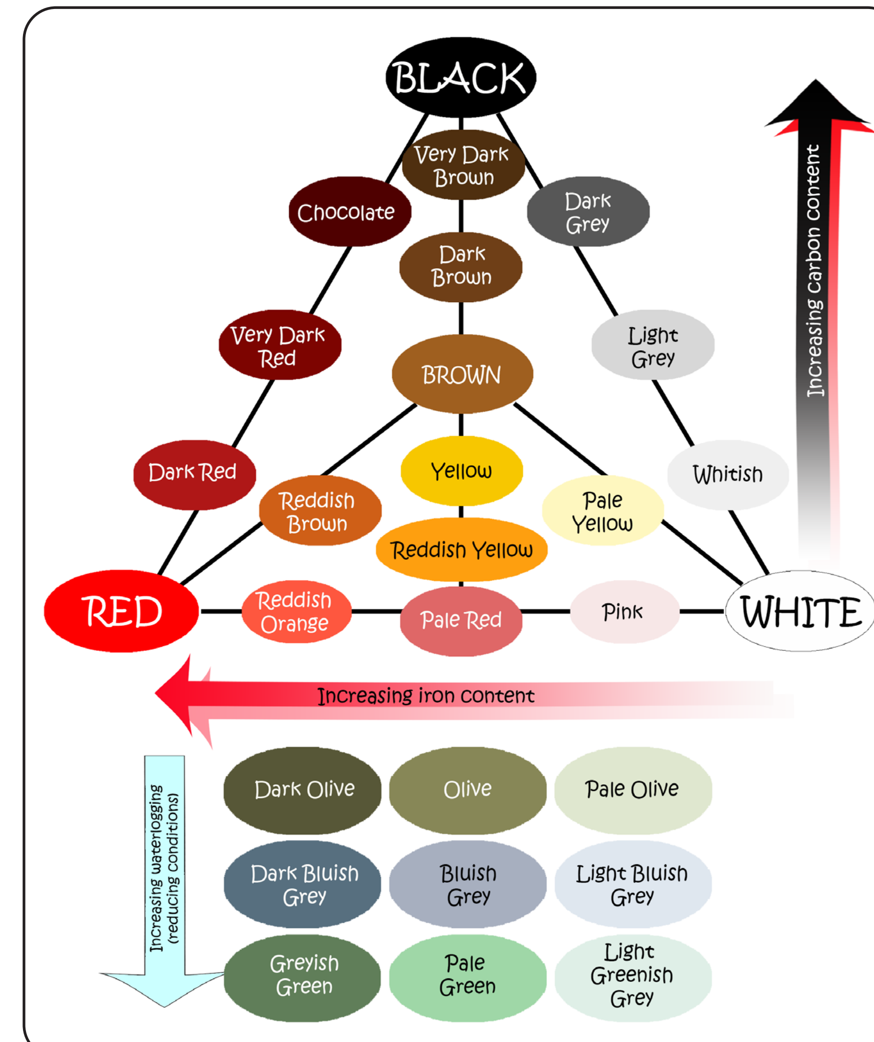
Most soils fall in the range of black, brown, red, gray and white. The raw material for soils - the individual grains - come from the breakdown of rock; the type of rock largely determines the types of minerals present. These minerals govern the initial coloration of sediments. For instance, unaltered sediments with a lot of quartz can be white - though with time, weathering and soil development this can change. In dry regions, this original color might dominate until more water or cooler temperatures allow for plant growth and the development of organic matter.

Organic matter contributes browns to blacks depending on the amount and level of decomposition with the most highly decomposed organic matter being jet black. Calcium carbonates, gypsum and other dissolvable salts make soils white.

Why is soil color important? What does it mean?

Soil color gives information on how a soil formed. Darker colors usually signify the presence of a lot of organic matter, suggesting conditions were good for lots of plant growth within those soils. Bright reds suggest lots of iron minerals in the soil that were exposed to high oxygen content with good water drainage and warmer temperatures, allowing for chemical reactions that oxidize the iron. Yellows are from similar conditions as reds, though with slightly wetter conditions. Greys indicate the soil was submerged in water with little to no air in pore spaces - leading to less oxygen - promoting reactions that reduce the iron. White can signify a dry climate, where salt precipitates and accumulates in layers.

Colors can change as you move deeper into a soil through differences in any of the 4 primary causes of soil color. Through time, minerals, organic matter, salts/carbonates, and so on also move deeper into the soil, which can lead to gradients of darker to lighter colors as organic matter moves downward, or development of stark layers of white - due to salt or carbonate accumulation - below the surface.



Redrawn from image produced by State of Victoria (Agriculture Victoria)

Soil Color

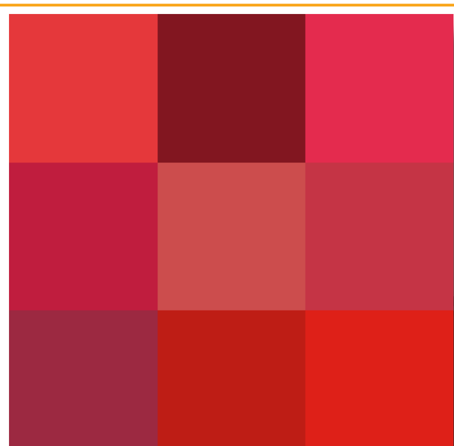
How do scientists record soil color?

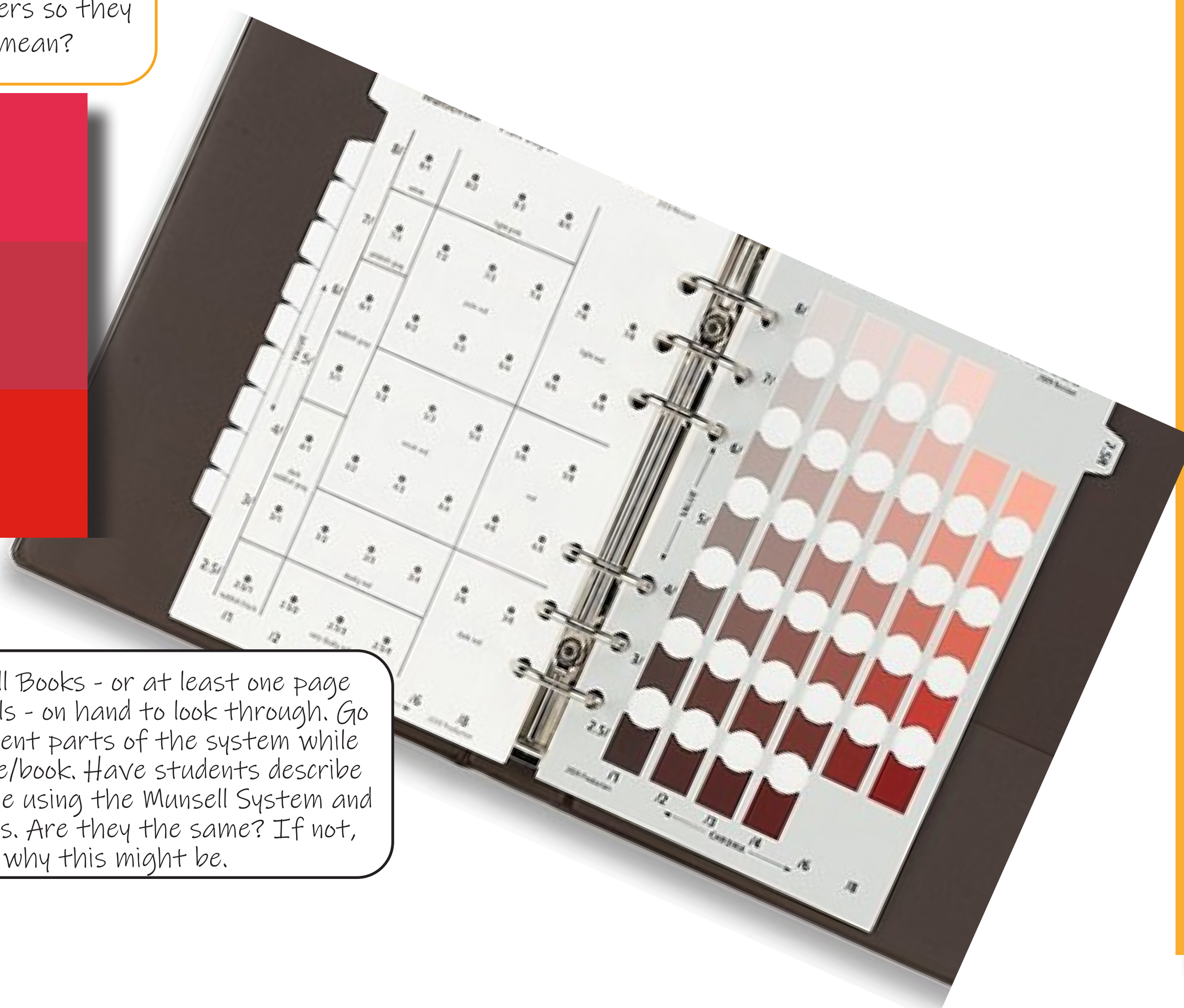
What do you think of when someone says something is 'red'? An apple? A tomato? Blood? A ladybug? Are they all the same red? Or is one deeper or lighter than another? Or perhaps with a more orange or brownish tone?

Colors can be pretty subjective, meaning, everyone might have a slightly different perception of what is considered 'red'. It gets even more difficult when trying to be more specific. This is especially important in describing soils, as soil color infers different conditions and processes of soil formation. Is it 'reddish-gray', 'pale red', 'light red', 'dusky red', 'very dusky red' or just plain old 'red'?

In science it is critical that people describe things in the same way so that our communication is clear and observations are repeatable. What is 'reddish brown' in one part of the world should also be 'reddish brown' in another, allowing us to directly compare them in analyses. To reliably and consistently describe soil color, soil scientists have adopted the Munsell System. The Munsell system is an international standard for describing color. It divides color into 3 parts: hue, value and chroma. Hue is the color category, such as red, yellow, or blue. Value is the lightness or darkness of a color in a range of 0 to 10. Chroma is the intensity/strength of a color or its degree of difference from a neutral color. There are over 1,400 possible colors in this system, available in a book of color chips. Each page within this book represents a color hue, with a number of chips representing value and chroma variation within that hue. To make it easier to navigate, they have filtered the color choices based on a specific need. For example, soil scientists can obtain a book specifically designed to describe soils, which includes only about 10 of the 40 available pages.

How would you describe these colors? Are they all 'red'? How would you communicate their 'color' to others so they know exactly what you mean?





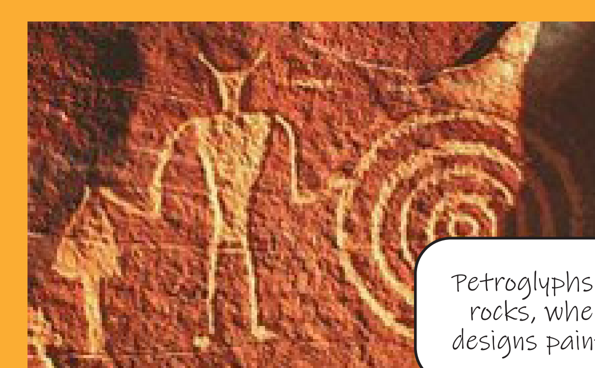
Have Munsell Books - or at least one page relevant to soils - on hand to look through. Go over the different parts of the system while reviewing the page/book. Have students describe the same soil sample using the Munsell System and share their results. Are they the same? If not, discuss why this might be.

Hands-on Activity
Painting with Soil

Pictographs are a form of ancient art where paint is applied on the surface of a rock. This is opposed to a petroglyph, which is when the design is engraved or carved into the rock. Paints, or pigments, derived from rocks and soils have been used for at least 40,000 years. Rocks or clays of desired colors - usually reds, yellows, whites, browns and blacks - and/or charcoal (black) were ground to fine powders and mixed with some sort of 'glue', such as plant sap, animal fat, blood, or water, to bind it to the surface they are painting. Painters experimented with pigments by combining colors or heating them (which causes chemical reactions that alter its color) to create new colors or different shades to enhance the realism in their art. Pigments were also often filtered to extract the smallest particles - the clays or other specific chemical components that provide the color - to make them better suited for painting and easier to apply to a surface. Pigments were then applied using bone implements, animal hair, fingers, stamps, sticks or other tools. The raw materials to make pigments were often found locally, though certain colors were highly prized and traded for or obtained through long-distance travel to the specific source.

It is difficult to identify the meaning behind ancient art. Are they images of day-to-day observations? Do they depict specific events? Are they created for ceremonial purposes? Are they informational, such as records of animal sightings or migration patterns? Or are they purely decorative? As we cannot go back in time to question the artists we may never know. What we do know is that people have been expressing themselves through art for a very long time!

Activity: Have soil samples of different colors available. If these can be collected locally even better, as you can talk about where they were obtained and what they might mean. Have some mortars and pestles so students can play with grinding soils to get them finer-grained. Take samples of soils and mix them with clear Elmer's glue and water (~1:1:1). You can experiment with mixing soils to create new colors. Have the students paint a picture.



Petroglyphs (left) are designs carved into rocks, whereas pictographs (right) are designs painted onto the surface of rocks.

Soils and Fossils

Questions: What conditions are required for remains to be preserved? When and where are these conditions met? Based on these, where are you likely to find fossils? What are differences in fossil preservation among the sediment types?

What is a fossil?

What is a fossil? Some familiar thoughts might be 'bones', 'dinosaurs', 'remains of plants or animals', 'rocks', 'shell', 'what's left behind when something dies', or 'footprints and tracks'.

Fossils are the geologically preserved remains of once-living organisms and/or their activities.

We say 'geologically preserved', as they are created and preserved naturally through geological processes, such as sediment deposition or rock formation. 'Remains' include actual body parts in the form of bone, shell, or exoskeletons, imprints of these, such as casts or molds of body parts, as well as traces of activities of these organisms, such as tracks, burrows, and bite marks.

Have students look at different examples of these broad classes of fossils.

TAKE-HOME IDEA: The characteristics of the surrounding environment determine if and how well fossils are preserved.

Learning Objectives:

1) Students will be able to describe where and in what kinds of sediments fossils form.

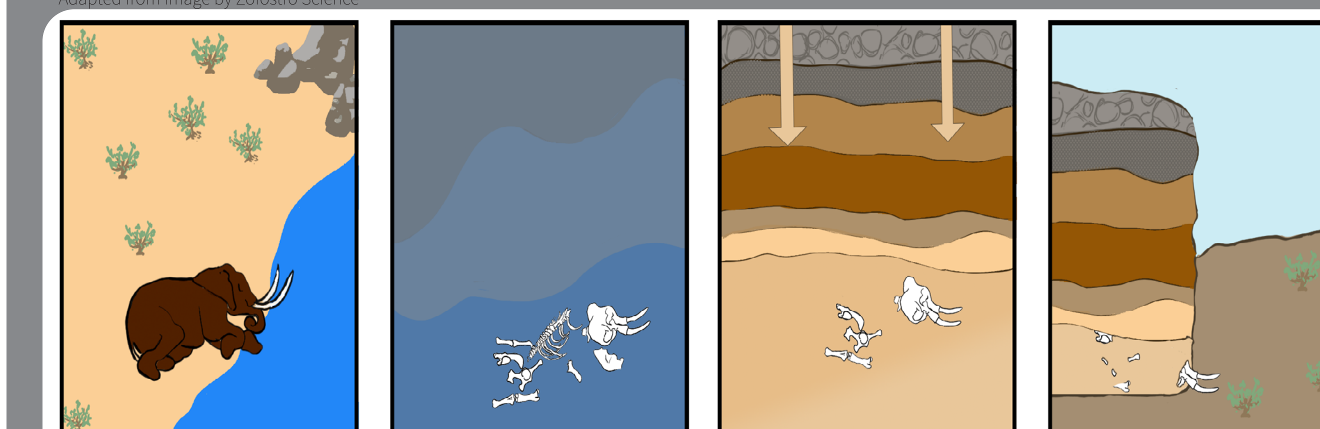
2) Students will be able to explain how the texture of the sediment affects fossil development and preservation.

What conditions are required for fossil formation?

How are fossils formed? If you say 'things die', 'they get buried', or 'they turn into rock', you are right!

When plants and animals die their bodies are typically broken down, or decomposed, into their base elements due to weathering and/or microbial and other animal activity. These components are then recycled in the surrounding environment. For fossilization to occur we need to isolate the remains from this process and incorporate them into the rock record. This is done through burial. When buried, bodies are protected from further breakdown by both physical processes - such as being moved, broken or eroded through natural mechanisms - and animal scavenging activity. Decomposition is also slowed considerably if burial is in an environment with low oxygen, as decomposing organisms (e.g., fungi, bacteria) need oxygen to function. While burial may be all that is needed to preserve hard (mineralized) parts of an organism, such as shell or bone, reducing decomposition rates allows time for soft parts to be converted to a stable form that can stand the test of time. The most common locations for burial and low oxygen environments are areas near water, especially basins like lakes and oceans, as sediment is constantly being deposited and can accumulate over long periods. Over time, remains buried in these sediments are modified by various processes to form the fossils we see today.

Adapted from image by Zofostro Science



Animal dies near a waterbed. | While soft tissue decomposes, the skeleton remains and is eventually buried. Over time, the bone is replaced by minerals and effectively turns into stone. | Over longer periods of time layers of sediment build, and pressue compresses them to form rock. | If we are lucky, the fossil becomes exposed again through geological uplift or other natural or man-made processes.

Soils and Fossils

Fossils are usually only found in sedimentary rocks, as both igneous and metamorphic rock formation most often result in the destruction of fossil material through extreme heat and pressure levels.

What conditions determine the type of fossil formed?

The type of fossil created depends on where an organism died and what it was made of. For instance, mollusks contain an outer mineral shell that surrounds soft tissues. The mineral shell is much more durable and resistant to decomposition than the softer, organic tissues. While the soft tissue disappears, the hard shell can stay intact for long periods of time, ultimately undergoing recrystallization to make it even more stable over vast geological time scales.

In other situations, the hard part can dissolve leaving an impression of its outer walls in the surrounding sediment (mold), or it can be filled with sediment leaving behind evidence of its internal structure (cast).

Bone can be permineralized, during which minerals precipitating out of groundwater in the burial environment fill pore spaces, effectively turning bone into stone.

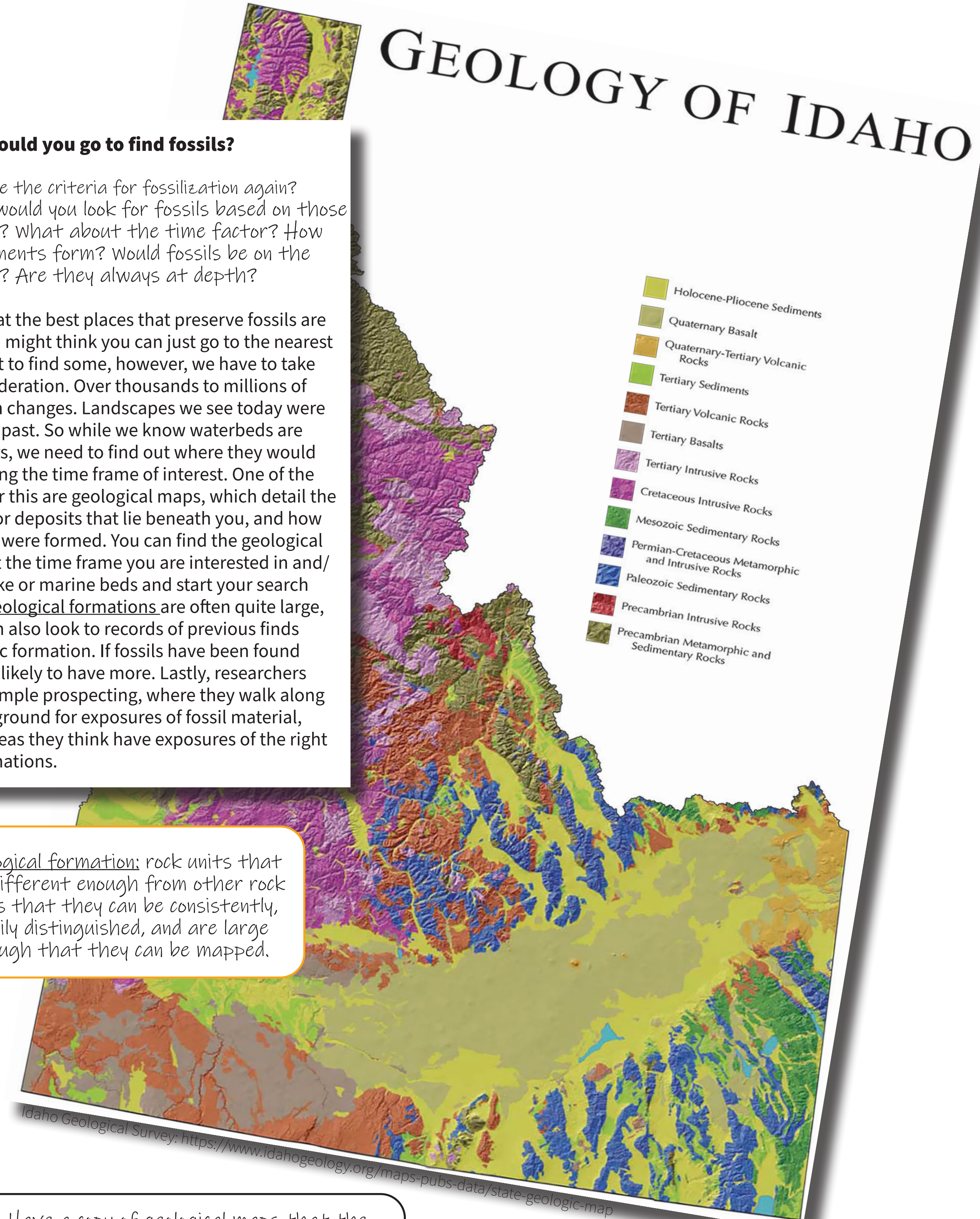
Plants on the other hand do not have hard, mineralized tissues. To be preserved, these need to be buried before they are decomposed in the external environment, and the internal environment also needs to have little to no oxygen to reduce decomposition by microbial activity after burial. If these conditions are met, the soft tissues of plants are compressed through heat and pressure during rock formation and converted into carbon (carbonization), leaving a thin black residue in place of the original organism.

So...where would you go to find fossils?

What are the criteria for fossilization again? Where would you look for fossils based on those criteria? What about the time factor? How do sediments form? Would fossils be on the surface? Are they always at depth?

So we know that the best places that preserve fossils are near water. You might think you can just go to the nearest lake and expect to find some, however, we have to take time into consideration. Over thousands to millions of years, the earth changes. Landscapes we see today were different in the past. So while we know waterbeds are good preservers, we need to find out where they would have been during the time frame of interest. One of the best sources for this are geological maps, which detail the types of rocks or deposits that lie beneath you, and how and when they were formed. You can find the geological features that fit the time frame you are interested in and/or represent lake or marine beds and start your search there. As the geological formations are often quite large, researchers can also look to records of previous finds within a specific formation. If fossils have been found in it before it is likely to have more. Lastly, researchers also conduct simple prospecting, where they walk along looking at the ground for exposures of fossil material, especially in areas they think have exposures of the right geological formations.

Geological formation: rock units that are different enough from other rock units that they can be consistently, easily distinguished, and are large enough that they can be mapped.



Idaho Geological Survey: https://www.idahogeology.org/maps-pubs-data/state-geologic-map

Have a copy of geological maps that the students can take a close look at and explore.

HANDS-ON ACTIVITY

WHAT ROLE DOES GRAIN SIZE HAVE IN FOSSIL FORMATION?

Why does the size of the grains surrounding a potential fossil matter? What might be the difference in the result of fossilization if grains are large versus small?

Grain size plays a crucial role in 1) decomposition rate of the original material and thus how much of it is preserved, and 2) the resolution of the preserved fossil. Finer grained deposits (i.e. those with more clay) can both reduce the flow of oxygen through a deposit - creating a low oxygen environment - and block the ability of decomposers to break down organic material directly by coating the surface. This allows for greater preservation of the original form. Due to its extremely small size, the coating of clay also preserves very fine detail of the original material. Imagine pressing your hand into sand versus clay. Sand might retain the general form of your hand but clay preserves all of the fine lines and ridges as well.

Grain size also informs on the depositional environment. Smaller grain size, such as clays, indicates more slowly moving water whereas more force is required to move larger grains, such as sand. More complete preservation is likely in areas with slower movement.

Activity: Have different mixtures of grain sizes: 100% clay, 50/50 sand/clay, and 100% sand. Have different types of materials to create imprints within those different mixtures, such as plant leaves, model fish, skeletons, shell, etc. Slightly wet the mixtures and press the object into it. Use the same object on all three mixtures. Have the student examine each and note similarities/differences between them. What parts show up clearly? What parts do not? Are there differences in how clear the representation is between the different mixtures? Which one has the most detail? Have the students go around and look at other student's imprints. Have them start with the 100% sand mixture and try to determine what the object was. Do this for the 50/50 next and lastly with the 100% clay mixture. How easy was it to interpret the imprint for each mixture? What does that imply for our understanding of the past?

THINKING ABOUT PRESERVATION AND THE FOSSIL RECORD

Adapted from Idaho Public Television's Fun with Fossils lesson plan: https://idahoptv.pbs-learningmedia.org/resource/ess05.sci.ess.earthsys.lp_funfossils/fun-with-fossils/

Activity: Divide the class into groups. Assign one organism to each group and have them discuss and be prepared to share their thoughts on the following questions:

•Worm •Fish •Bird •Elephant •Snail •Tree •Spider

1) Under what conditions would these organisms fossilize?

2) What type of fossil would they form?

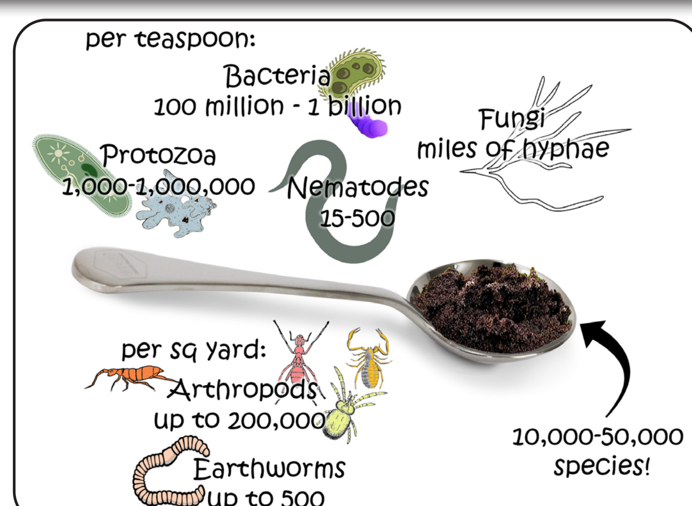
3) What parts would be fossilized?

4) Would the potential for fossilization or the types of fossils formed be different between a) a rainforest, b) the cold arctic, c) the desert, d) a lake or e) a swamp?

"For my part, following out Lyell's metaphor, I look at the natural geological record, as a history of the world imperfectly kept, and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved; and of each page, only here and there a few lines." (Darwin, 1859, p. 310-311).

Life in Soils

There is more life underground than there is above it. One teaspoon of soil can contain billions of organisms! Most are invisible to the naked eye, but they play such important roles in the circle of life. Without them life as we know it would cease to exist.



TAKE-HOME IDEA:
Soils are alive. They are teeming with life that are vital to our survival.

Learning Objectives:

1) Students will be able to discuss why soil organisms are essential for maintaining soil quality.

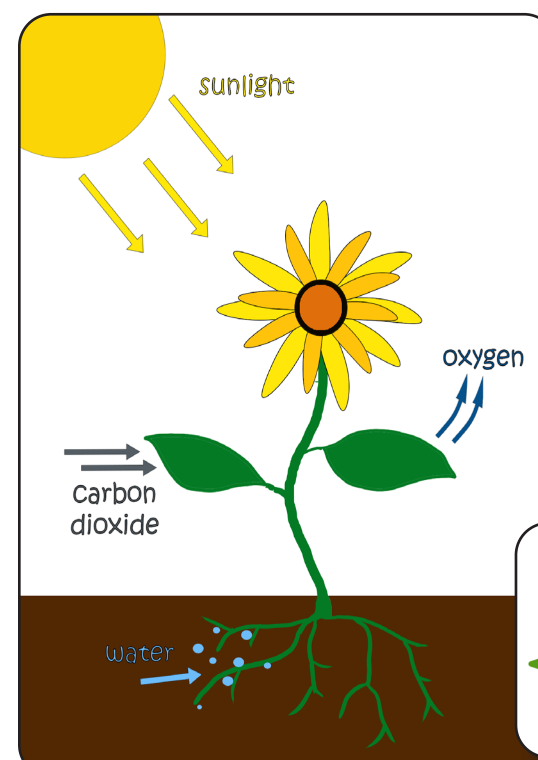
2) Students will be able discuss why soil organisms serve as the foundation for life aboveground

What kinds of organisms live in our soils?

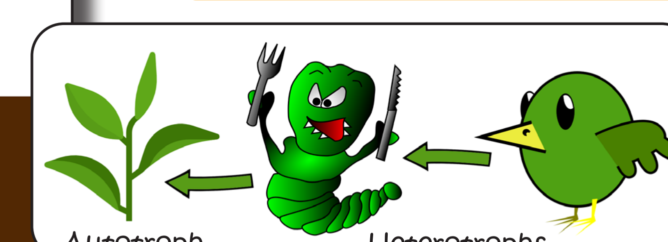
Let's give examples of soil organisms! What do you think lives in your soil? Can you see them easily? What do they eat? How do they move?

We can group soil organisms into two general types, autotrophic and heterotrophic.

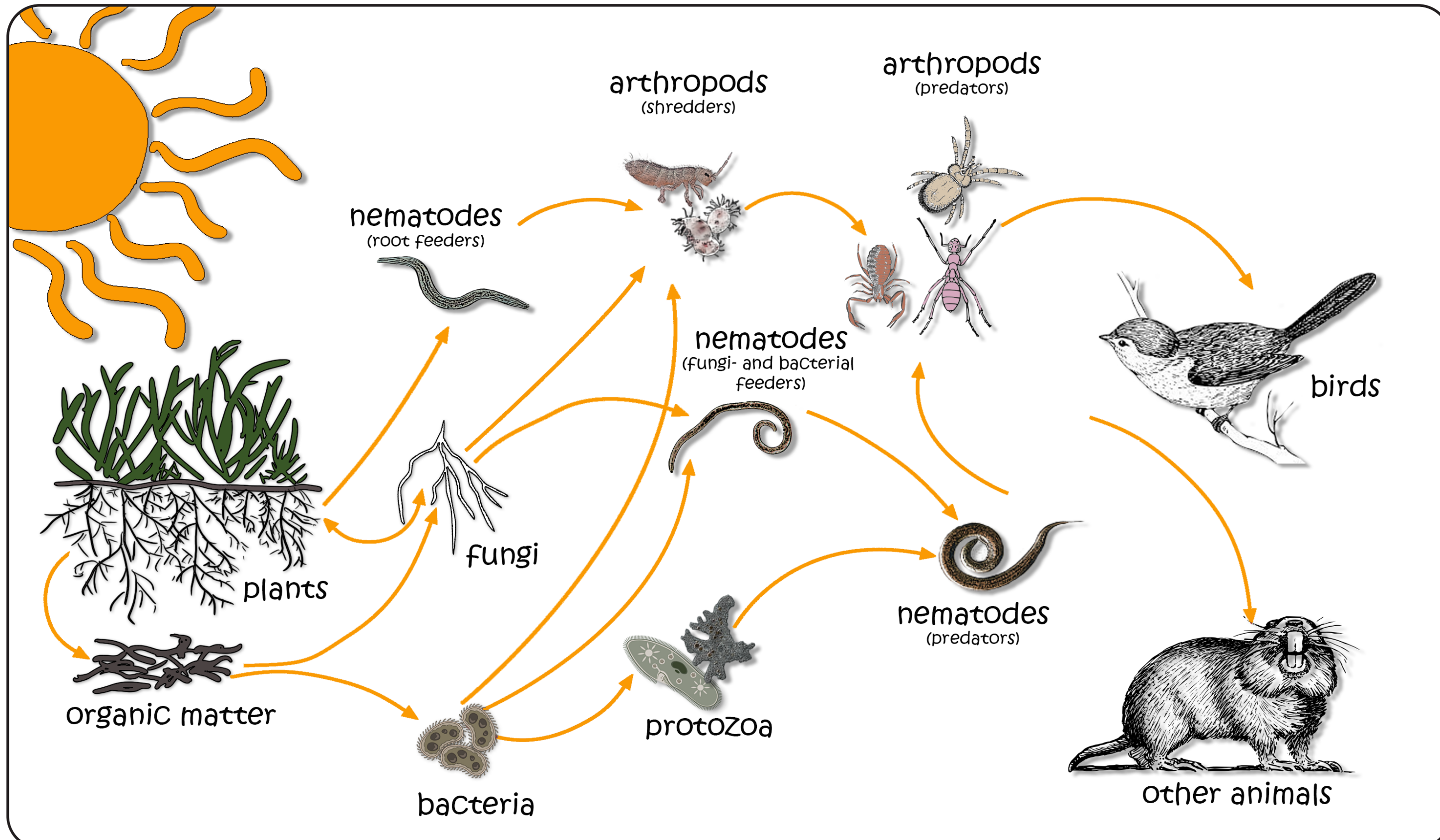
- Autotrophic organisms are primary producers. They can make their own food from materials in their environment using light or energy. The most well-known examples are plants, but algae, phytoplankton and select bacteria are also autotrophs.
- Heterotrophic organisms on the other hand cannot produce their own food. These organisms feed on organic matter made by autotrophs, or by eating other organisms. All animals are heterotrophs.



Organic matter: any carbon-based compounds in nature, which are produced originally by living organisms -- usually via photosynthesis -- and returned to the soil and recycled through decomposition. This includes the bodies of all living organisms e.g., plants, microbes, animals) and their remnants and waste products in all stages of decomposition.



The Soil Food Web

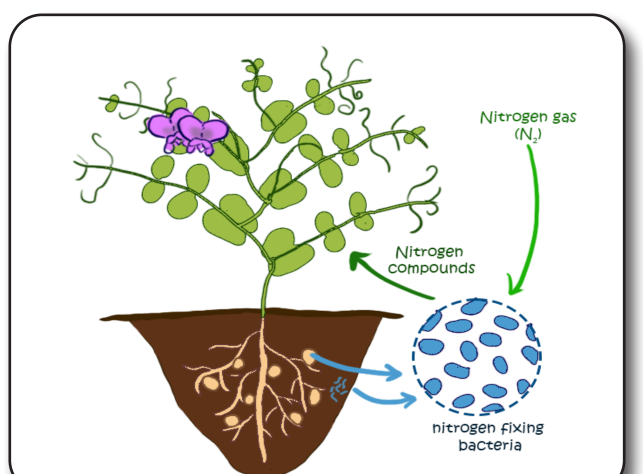


Adapted from USDA Natural Resources Conservatoin Service: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/health/?cid=nrcs142p2_053868

Many types of organisms exist in soils. The soil food web illustrates how these organisms interact with each other and their environment. At the base of this web we have plants, algae and some bacteria that fix carbon into organic matter, usually through photosynthesis. Above this are other bacteria and fungi that break down organic matter into forms usable by other organisms and plants. Protozoa and nematodes feed on these bacteria and fungi, who are in turn eaten by a host of different arthropods. The arthropods serve as a food source for larger organisms, including birds and other animals that live below and aboveground, which in turn are eaten by even larger organisms, such as humans. As you can see, soil organisms are the foundation for all life on land!

How do these organisms contribute to soil quality?

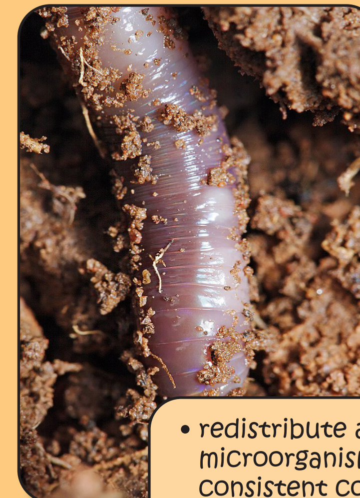
Soil organisms are essential in nutrient cycling. Nitrogen is a critical component in the building blocks for all life - e.g., amino acids, proteins, DNA, chlorophyll. Though most of our atmosphere is made of nitrogen (78%!) it isn't available in a form that can be used by living things. Nitrogen-fixing bacteria convert this atmospheric nitrogen into ammonium, introducing it into the life cycle and allowing plants and other organisms to take hold and grow. Autotrophs (plants, algae and some bacteria) similarly bring carbon into the cycle, which is a critical source of energy for most organisms. Once these are introduced and organic matter is produced, heterotrophs break down dead or decomposing organic matter into forms re-usable by plants and other organisms, ensuring the continuous cycling of these essential nutrients. This transformation and decomposition process serves as the source for energy and for many of the essential nutrients required by all living things.



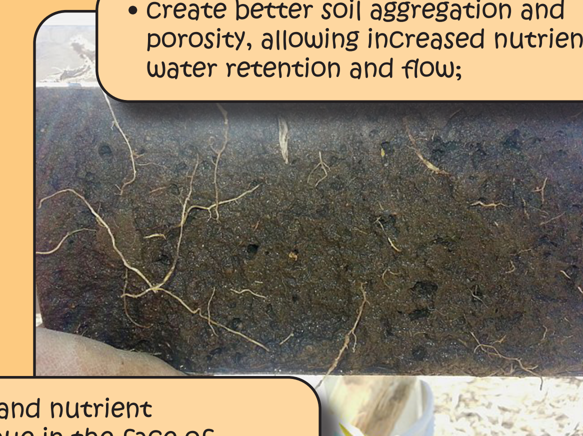
Adapted from https://commons.wikimedia.org/wiki/File:Nitrogen_fixation_Fabaceae_en.svg

Diversity is a key to success!

The more organisms there are, and the greater variety of these organisms, results in healthier soils, as they also:



- hold nutrients in their bodies, preventing their loss from the soils;
- redistribute and mix soils and microorganisms, enabling more consistent contact between organisms and food sources;



- create better soil aggregation and porosity, allowing increased nutrient and water retention and flow;

- ensure that soil and nutrient processes continue in the face of disturbance, as more than one organism can serve the same function;

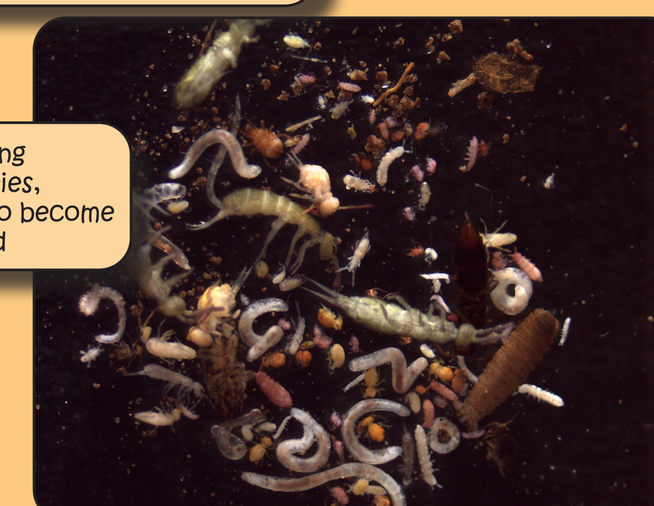


Photo by Dr. Rob Griffiths, © UK Centre for Ecology and Hydrology

- keep populations in check by having balanced predator-prey communities, meaning organisms are less likely to become overly harmful or destructive; and

- reduce pollutants in our soils through conversion into non-threatening compounds.

HANDS-ON ACTIVITIES

FIELD WORK

Collecting soil samples

The abundance and diversity of soil organisms depends on the soil environment. The amount of water, soil temperature, amount of organic matter, soil texture and structure, amount of sunlight, amount of plant cover, plant types, farming practices, and so on are just some of the factors that determine the kinds and amounts of organisms in a soil. To explore this, take it to the field!

Collect several samples of soil from different environments and take a look at what kinds of organisms are found in them, and learn about field work in the process.

Create a map of the area you are taking samples from. Clearly place each sample location on this map, and make notes about each sampling site:

- What kinds of plants are present? How much plant cover is there?
- Is the soil wet or dry? Is there an irrigation system in place?
- Is the sample location in the sun or shade?
- Is the sample location walked on regularly?
- What can you say about the soils? Texture?
- Take measurements of soil moisture, temperature and pH using a soil probe
- Place samples in bags clearly marked with sample location, date and time of collection.

Pitfall traps

To explore the variability in larger soil organism distributions you can set up pitfall traps at each sample location. This can be done prior to sample collection so it is ready at the same time, or can be done during sample collection and analyzed afterwards. To do this, dig a hole into the soil and place a container in it. Keep the top of the container level with the surrounding soil so soil organisms will drop into it as they roam. If traps are to be in place for a longer span, you can place alcohol in the container to prevent the organisms from eating one another. After a period of hours to days, depending on the quality of the soil or duration of the lesson, collect the sample and examine the variety and amounts of organisms in it.

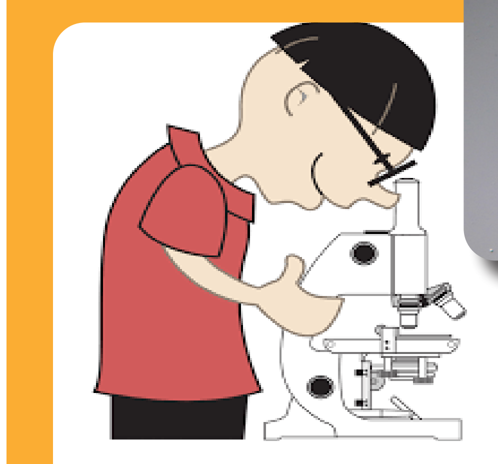
IN THE LAB

Soil Nutrients

Back in the lab, we can get more details about the soil. We can do ribbon tests for texture, and we can use rapid test kits designed to explore nutrient status. These are available mostly for nitrogen, phosphorus and potassium as they are key nutrients required for plant growth. While these are very low resolution, they allow students to think about nutrient status and how it might differ from soil to soil. This nutrient status also relates to the abundance and diversity of soil organisms in a particular location. Compare and contrast results between sample environments.

Berlese funnel

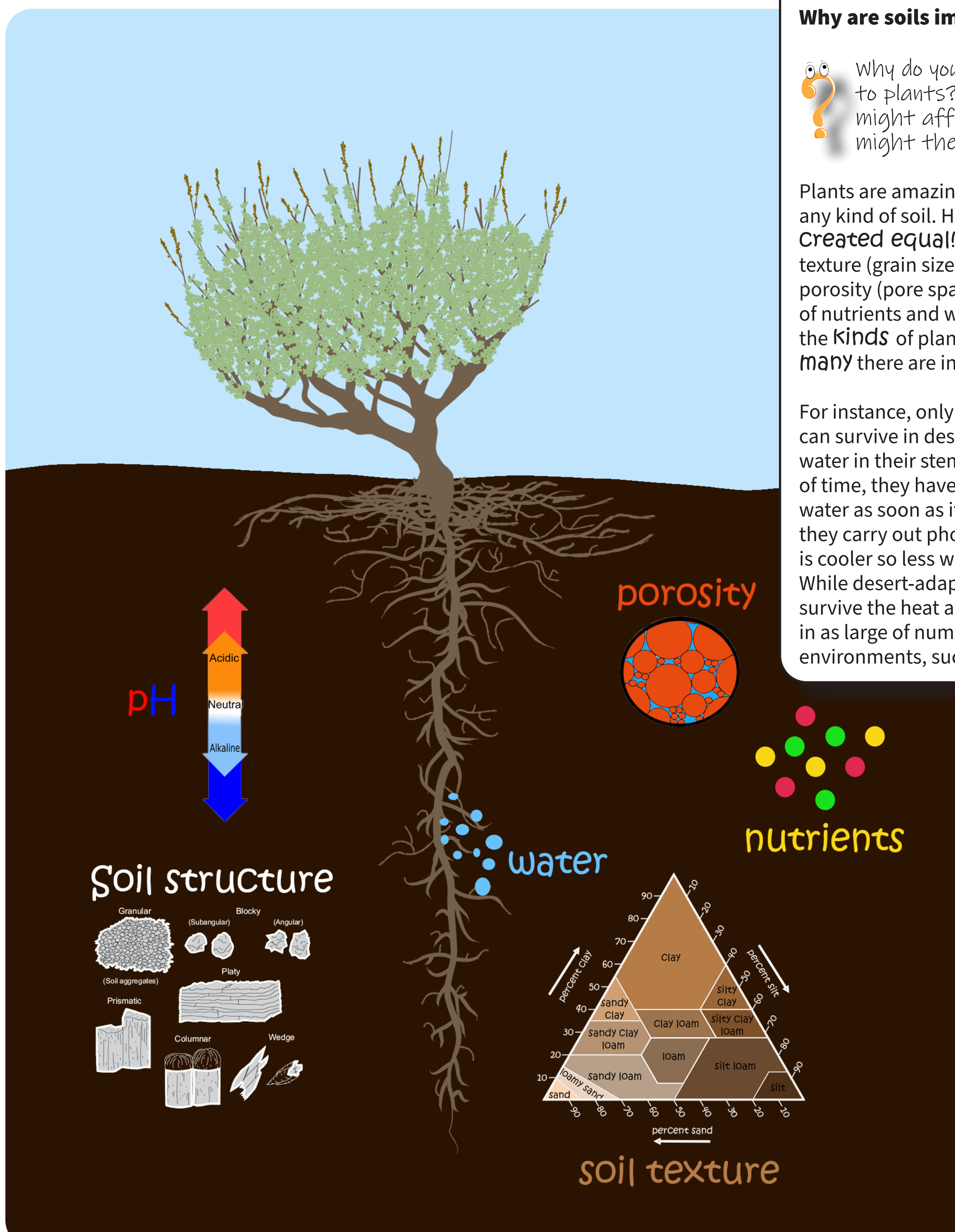
Another option to examine larger soil organisms is a Berlese funnel. Place a funnel over a jar with a small amount of alcohol at the bottom. Place a wire mesh piece in the funnel, and add a clump of soil on top. Place a light source over it, and let the soil dry slowly. Any organisms in the soil will move towards the base of the funnel as the soil dries from top to bottom, and will eventually fall into the jar.



Microscopic views

Take a small sample of soil and mix it with distilled water using a ~1:9 ratio (9 parts water to 1 part soil). Shake the mixture gently for 30 seconds. Let the soil sit so larger particles can settle. Using an eye dropper, take a small sample and place it on a microscope slide and place a slide cover over it. Look at the sample under a compound microscope and note the variety of organisms in the sample. What sizes are they? Do they all look the same? Do they move the same? Where are they on the slide, next to soil particles or organic matter? How many are there?

Plants and Soils



Why are soils important to plants?

Why do you think soils are important to plants? What soil properties might affect plant growth? How might they affect plant growth?

Plants are amazing in that they will grow in any kind of soil. However, **not all soils are created equal!** Characteristics like soil texture (grain sizes), structure (agrregate type), porosity (pore space) and pH, and the amount of nutrients and water available all determine the **kinds** of plants that can grow and **how many** there are in a specific area.

For instance, only plants adapted to low water can survive in deserts. Cacti can store tons of water in their stems for a relatively long period of time, they have shallow roots to absorb water as soon as it falls, and unlike most plants they carry out photosynthesis at night when it is cooler so less water is lost in the process. While desert-adapted plants like these can survive the heat and dryness, they do not occur in as large of numbers as you see in wetter environments, such as rainforests.

Plant drawings by: Jeremy Maestas, Maja Smith, Sage Grouse Initiative.

Take Home:
The interaction between plants and soils is dynamic, they influence each other in a myriad of ways and contribute to each other's health and endurance.

Learning objectives:

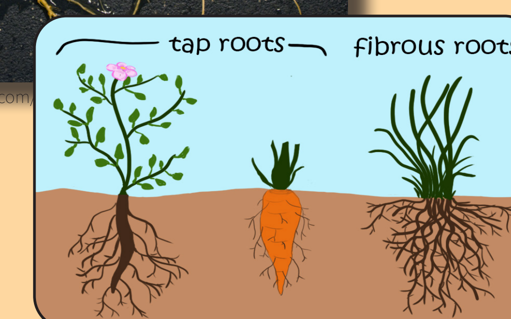
1) Students will be able to discuss how soils affect plant growth and survival.

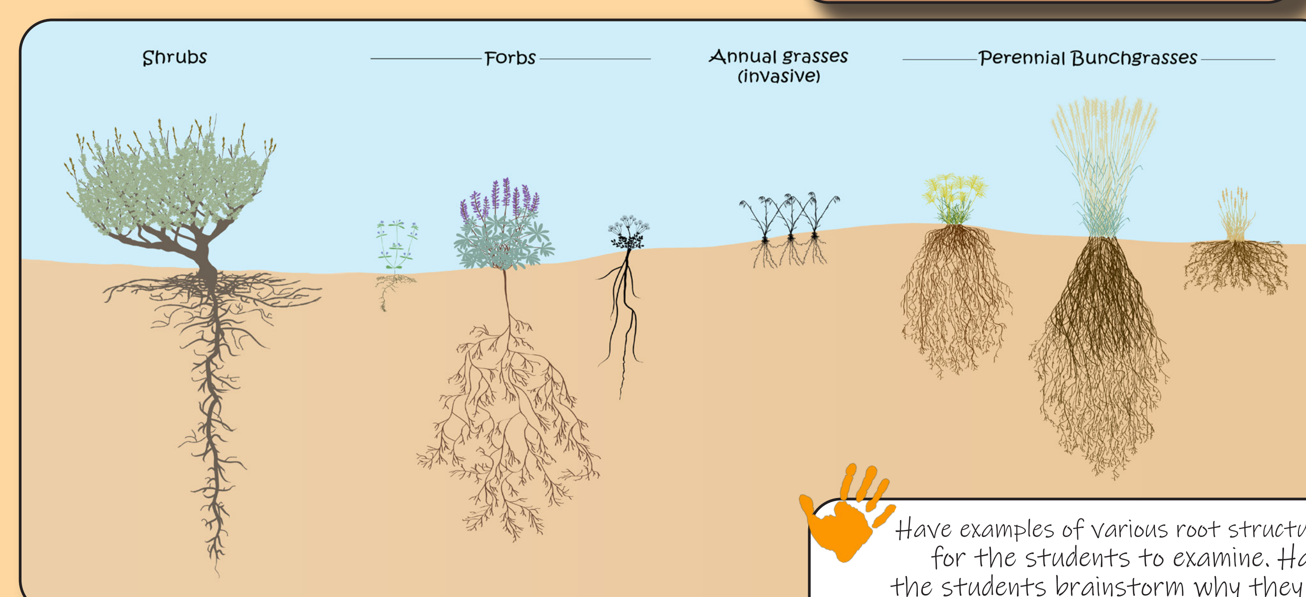
2) Students will be able to discuss how plants affect soil properties.

How do plants adapt to different soils belowground?

Different plants have different types of root systems, from long, singular deep taproots, to hairy or fibrous mats near the surface. The types of roots depend on a number of factors, such as how long the plant lives, how big it gets and how much support it needs to remain upright, and where in the soil profile it gets its water and nutrients from. While many of these are a function of plant type, characteristics of the soil itself also influence how a plant's roots grow. For instance, if a soil is healthy, with good porosity and texture, roots can penetrate easily and grow where they need to. If a soil has too much clay or is too compact, roots cannot move through the soil and can become stunted.

https://www.flickr.com/ N00/5995961553





Plant drawings by: Jeremy Maestas, Maja Smith, Sage Grouse Initiative.

Have examples of various root structures for the students to examine. Have the students brainstorm why they fit the plant type and environment.

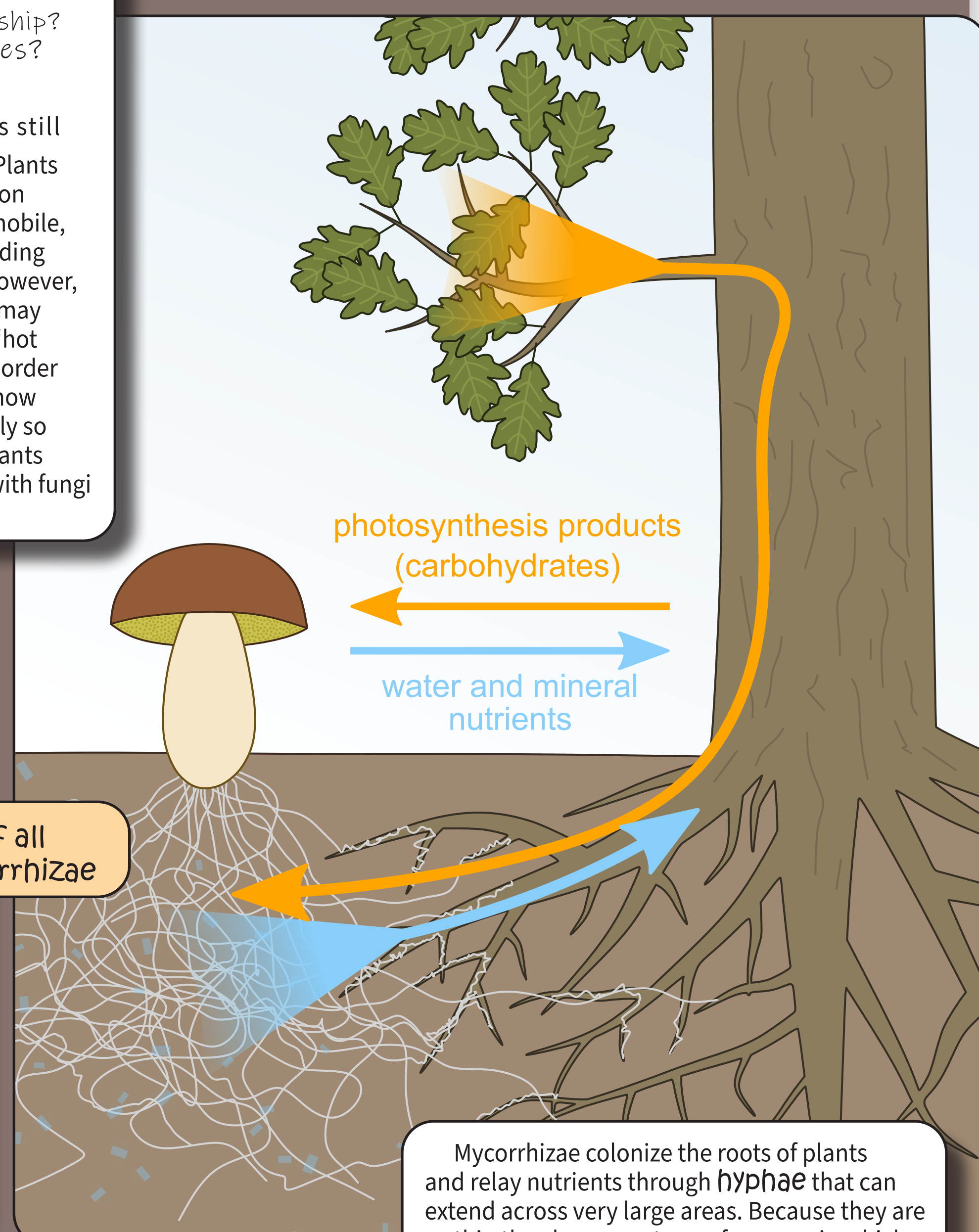
Plant artwork by: Jeremy Maestas, Maja Smith, Sage Grouse Initiative.

Plants and Soils

A symbiotic relationship

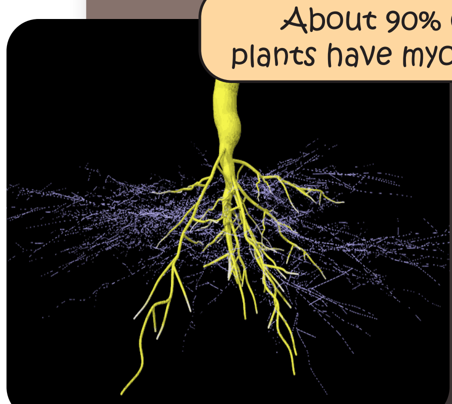
What is a symbiotic relationship? Can you give some examples?

Even when soils are healthy, plants still struggle to obtain sufficient nutrients. Plants incorporate nutrients through absorption through their roots; since roots are immobile, nutrients need to be in the soil surrounding roots in order for plants to use them. However, soils are very unpredictable. Nutrients may exist in high amounts in one area (i.e., "hot spots") but may be absent in others. In order to maximize their reach while limiting how much energy is expended (there are only so many roots a plant can make), many plants have formed a symbiotic relationship with fungi called mycorrhizae.



https://commons.wikimedia.org/wiki/File:-Mutualistic_mycorrhiza_en.svg

About 90% of all plants have mycorrhizae



Mycorrhizae colonize the roots of plants and relay nutrients through hyphae that can extend across very large areas. Because they are so thin they have greater surface area in which to absorb more nutrients. The hyphae can tap into high nutrient (and water) zones, collect nutrients and send them back to the plant roots. In return plants provide them with carbon.

Have examples of plant roots colonized by mycrrhizae, with emphasis on how they attach to the roots and what the hyphae look like. Compare this to plants without these associations.

How do plants affect soils?

Do you think plants can influence soils? Can they alter soil properties like porosity or structure? Do they contrbute nutrients to the soil? If so, how?

We have seen how soils are important to plants, but can plants be just as important to soils? Hint: Yes! Plants contribute greatly to soil quality in a number of ways:

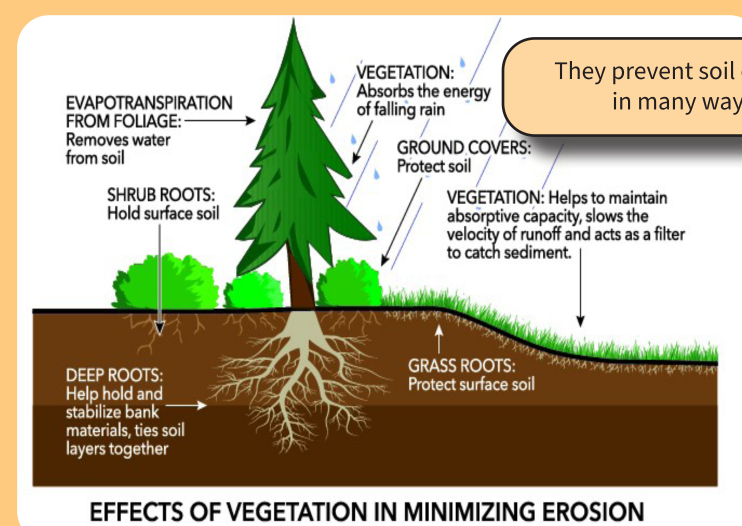
They help to increase soil aggregation, allowing for more stability and pore space.

They help to increase soil porosity, allowing better air, water and nutrient flow.

Dead plant material is returned to the soil as organic matter which is decomposed and used by microorganisms and other plants.

They excrete nutrients from their roots that can be used by soil microorganisms.

They prevent soil erosion in many ways!



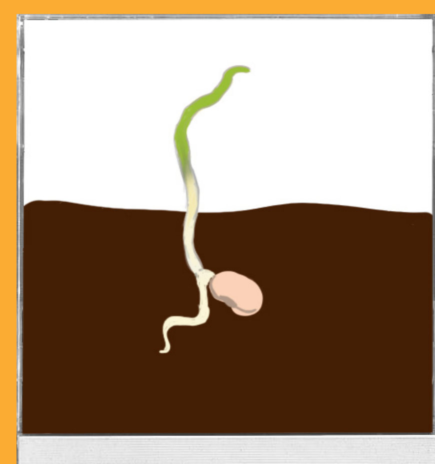
Washington State University Extension: https://shorestewards.cw.wsu.edu/faq/using-plants-trees-for-stability/

HANDS-ON ACTIVITIES

HOW DOES IT GROW?

We are surrounded by plants yet often we do not get the chance to watch them germinate and grow. What are the essential requirements for this to happen? What do plants need to thrive and survive? Light? Water? Nutrients? Where do they get these from?

Activity 1: Let's watch seeds grow by planting them in a CD case. Open a clear CD case and remove the inner tray that holds the CD. Put a thin layer of wet potting soil at the bottom of the case, starting at the end opposite of the hinge and filling halfway. Place a bean in the middle of the soil with the concave side facing down. Water the bean using an eyedropper. Close the case and stand it upright, tape the sides and bottom, leaving only the top (with the hinge) open. Keep the case in a sunny spot, adding water each day through the slit in the top. Once it sprouts, map the growth of the bean with a different colored pen each day to see how it changes as it grows. (Maryland Science Center: https://www.mdsci.org/wp-content/uploads/2018/05/CD-Greenhouse.pdf)



Activity 2: Let's explore the effect of different soil textures on plant growth. Here we will use an egg carton. Cut the lid off the egg carton and use it as a tray beneath the base that holds the eggs. Poke holes in the bottom of each egg cup and fill each with a different mixture of soil textures. One can be potting soil, another 100% sand, another 100% clay, or some other known mixture of grain sizes. If possible have multiples of each type represented so you have redundancy. Place seeds in at the appropriate depth and water the soil until it is moist but not soaked. Use the same seed type for all containers so differences in growth are due to soil type only. Put the container in a sunny spot and water daily. Observe daily and note which samples grow, and if there are any differences in appearance or growth rate between soil types. Hypothesize why this would be. (Get step-by-step instructions here: https://www.instructables.com/easy-seed-starter./)

Helpful Resources

Lesson: What is Soil?

Soil Science Society of America: K-12 Soil Science Teacher Resources:
https://www.soils4teachers.org/

USDA Natural Resources Conservation Service: Soil Education:
https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/edu/

For examples of soil profiles to print:
Michigan State University Soil Profiles: https://project.geo.msu.edu/soilprofiles/

Soil profile card activity (cards also available on next page for printing):
USDA National Resources Conservation Service:
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/?cid=nrcs142p2_054308

Fun resource full of information and activities for youth:
Food and Agriculture Organization of the United Nations: Soils Challenge Badge:
https://www.fao.org/3/i3855e/i3855e.pdf

Simple video using an apple as the earth which puts the importance and finite nature of soils into perspective: https://www.youtube.com/watch?v=mA78nPn41F4

Soil Science Society of America: How much soil is there? Enhanced apple as the earth activity that can be modified for different age ranges:
https://www.soils.org/files/s4t/lessons/lesson-plan-how-much-soil-is-there.pdf

More advanced version of 'apple as the earth' concept:
https://utah.agclassroom.org/matrix/lesson/551/

Short video explaining the different horizons using real examples:
Purdue Extension: Soil Basics - Soil Profiles: https://www.youtube.com/watch?v=xoTd7ctj-eO

Video briefly reviewing aspects of soil formation and soil properties:
Bozeman Science: Soil and Soil Dynamics:
https://www.youtube.com/watch?v=mg7XSjcnZQM&t=459s

Video reviewing the 5 factors of soil formation:
Jerry Delsol: https://www.youtube.com/watch?v=US9rSigOLHE

Video reviewing 4 processes that contribute to soil formation:
https://www.youtube.com/watch?v=3Dnf2e1i9Ag

Soil Science Society of America: Basic Soil Processes Lesson Plan
https://www.soils.org/files/sssa/iys/basic-soil-processes.pdf

Soil Name ______________

Horizon

0"
A
12"
24"
B
36"
48"
C
60"
72"

http://soils.usda.gov

Soil Name ______________

Horizon

0"
A
12"
24"
B
36"
48"
C
60"
72"

http://soils.usda.gov

Soil Name ______________

Horizon

0"
A
12"
24"
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36"
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60"
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Soil Name ______________

Horizon

0"
A
12"
24"
B
36"
48"
C
60"
72"

http://soils.usda.gov

Lesson: Soil Texture

Soil Science Society of America: Soil Moisture activity:
https://www.soils4teachers.org/files/s4t/soil-moisture-learning-activity-2015-16.pdf

Video explaining the Soil Texture Triangle:
Cindy Byron: https://www.youtube.com/watch?v=JQhEihSVX2A

More in-depth lessons and activities looking at soil texute and its role in how soils function:
Science Friday - Soil Engineering: The Relationship Between Soil Texture and Function
https://www.sciencefriday.com/educational-resources/soil-texture/

Simple video (no words) showing the different rates that water flows through and is retained in soils dominatd by different particle sizes:
Maria Rebelo, Soil Permeability: https://www.youtube.com/watch?v=7PISyM1Na6g

Another video that clearly explains how pore sizes in a soil affects the ability of water to move through it.
Seth Horowitz, Permeability and Water Retention:
https://www.youtube.com/watch?v=TfaLqSOsqLc

Video showing you how to perform the ribbon test: UC DAvis International Programs Office:
https://www.youtube.com/watch?v=GWZwbVJCNec

Lesson: What is Clay?

UNC-TV Science: The Real Dirt About Clay: https://www.youtube.com/watch?v=6h12dvkruHQ

Tinker & Think: What is Clay? Science for Pottery:
https://www.youtube.com/watch?v=fvJYpWFgVWO

Simple, fun art project using clay:
That Art Teacher: Textured Tiles Clay Lesson Plan & Video Tutorials:
https://thatartteacher.com/2019/11/09/how-to-make-textured-tiles-slab-clay-lesson-plan-art-teacher-diy/

Lesson: Soil Color

USDA Natural Resources Conservation Service: The Color of Soil
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054286

Gilson Company Inc, How to Identify the Color of Soil Using the Munsell Soil Color Book:
https://www.youtube.com/watch?v=6RSd2y7cDvs

State of Victoria (Agriculture Victoria), Practical Note: Soil Colour
https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_prac_soil_colour_pdf/$FILE/PracNote_Colour.pdf

USDA Natural Resources Conservation Service: Exploring Soil Colors
https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd1418242&ext=pdf

Missouri Center for Career Education, Soil Color:
https://www.missouricareereducation.org/doc/soilsci/SRLesson3.pdf

Lesson: Soils and Fossils

USGS: The National Geologic Map Database: https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

Idaho Geological Survey: https://www.idahogeology.org/

Paleontological Research Institution: Digital Encyclopedia of Ancient Life
https://www.digitalatlasofancientlife.org/learn/

Brief video reviewing the process of fossilization:
National Geographic, Fossils 101: https://www.youtube.com/watch?v=bRuSmxJo_iA

American Geosciences Institute: Fossils
https://www.americangeosciences.org/education/k5geosource/content/fossils

Lesson plans with activities: National Park Service, A Fossil's Journey
https://www.nps.gov/teachers/classrooms/a-fossil-s-journey.htm

Idaho Public Television, PBS Learning Media. Search for 'Fossils' for a number of lesson plans, videos and activities: https://idahoptv.pbslearningmedia.org/search/?q=fossil

Video showing the recovery of a mammoth fossil at American Falls Reservoir in Idaho:
Bureau of Reclamation: Fossil Find at American Falls:
https://www.youtube.com/watch?v=E5MhI68Zu7c

Hagerman Fossil Beds National Monument, Idaho: https://www.nps.gov/hafo/index.htm

Lesson: Life In Soils

Soil Science Society of America: The Berlese Funnel
https://www.soils4teachers.org/files/s4t/lessons/berlese-funnel.pdf

Kids Gardening.org: Soil is Alive!: https://kidsgardening.org/resources/lesson-plan-soil-is-alive/

Soil Science Society of America: Teacher's Guide - Soil Biology
https://www.soils4teachers.org/lessons-and-activities/teachers-guide/soil-biology/

National Agriculture in the Classroom - Search for 'Soils' under Teacher Resources for a host of lesson plans, resources and activities for all age groups: https://agclassroom.org/matrix/

California Academy of Sciences - The Living Soil Beneath Our Feet:
https://www.calacademy.org/educators/the-living-soil-beneath-our-feet

USDA Natural Resources Conservation Service: Soil Biology
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/soils/health/?cid=nrcs142p2_053860

Hour-long video on life in soils: Economics of Soil Health Systems - Living Soil Film
https://www.youtube.com/watch?v=ntJouJhLM48

More advanced lessons about soil properties and biology: UC Santa Cruz, Center for Agroecology: Teaching Organic Farming & Gardening: Resources for Instructors, Part 2: Applied Soil Sciences: https://agroecology.ucsc.edu/about/publications/Teaching-Organic-Farming/part-2.html

Lesson: Soils and Plants

Curriculum aimed at 3rd graders, but adjustable for different age groups:
Nova Scotia, Department of Education: Let's explore plants and soils: a curriculum resource: https://www.ednet.ns.ca/files/curriculum/LetsExplorePlantsandSoils.pdf

Soil Science Society America - Tea4Science, activity exploring organic matter decomposition: https://www.soils4teachers.org/files/s4t/lessons/lesson-plan--tea4science.pdf

Iowa Agriculture Literacy Foundation, Biology of Soil - Lesson 5 - Plant and Soil Interactions: https://www.iowaagliteracy.org/Article/Biology-of-Soil-Lesson-5-Plant-and-Soil-Interactions#:~:text=Soil%20is%20a%20substrate%20for,their%20roots%2C%20and%20ample%20nutrients.

Lessons around soil properties and their influence on plants:
North Carolina Extension Gardener Handbook - 1. Soils and Plant Nutrients:
https://content.ces.ncsu.edu/extension-gardener-handbook/1-soils-and-plant-nutrients

Crash Course Kids: Great source for short videos on a variety of science topics geared towards 5th graders: https://www.youtube.com/c/crashcoursekids/videos

SciShow Kids: Great source for short videos on a variety of science topics geared towards 1st-3rd graders: https://www.youtube.com/c/scishowkids/videos

Learn Bright: Another great source for short videos on a variety of science topics geared towards K-6 grade: https://www.youtube.com/c/LearnBright/videos
Lesson plans are also available here: https://learnbright.org/lessons/

Nature Lab, Educator Resources: Garden Lesson Plant - Soil: Leasson plan aimed at middle school students: https://www.nature.org/content/dam/tnc/nature/en/documents/nature-lab-lesson-plans/NLGardens-Soil.pdf

Relevant Idaho State Content Standards

Science Domain + Unit	Science Domain + Unit + Grade Level + Standard#	Performance Standard	Further Explanation	Supporting Content	Crosscutting Concepts	Applicable Modules
ESS: EARTH AND SYSTEMS SCIENCES						
Earth's Systems	ESS2-MS-1	Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.	Emphasis is on the processes of melting, crystallization, weathering, deformation, and sedimentation, which act together to form minerals and rocks through the cycling of Earth's materials.	ESS2.A: Earth's Materials and Systems: All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.	*Stability and Change*: Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and processes at different scales, including the atomic scale.	Primary: *What is Soil?* *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils* Secondary: *Life in Soils* *Soils and Plants*
Earth's Systems	ESS2-MS-2	Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.	Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.	ESS2.A: Earth's Materials and Systems: The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future. ESS2.C: The Roles of Water in Earth's Surface Processes: Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations.	*Scale Proportion and Quantity*: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.	Primary: *What is Soil?* *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils*
Earth's Systems	ESS2-MS-4	Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.	Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.	ESS2.C: The Roles of Water in Earth's Surface Processes: Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land.	*Energy and Matter*: Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter.	Secondary: *What is Soil?* *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils* *Life in Soils* *Soils and Plants*
Earth and Human Activity	ESS3-MS-1	Construct a scientific explanation based on evidence for how the uneven distributions of Earth's mineral, energy, and groundwater resources are the result of past and current geoscience processes.	Emphasis is on how these resources are limited and typically non-renewable, and how their distributions are changing as a result of removal by humans. Examples of uneven distributions of resources as a result of past processes include but are not limited to petroleum (locations of the burial of organic marine sediments and subsequent geologic traps), metal ores	ESS3.A: Natural Resources: Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes.	*Cause and Effect*: Cause and effect relationships may be used to predict phenomena in natural or designed systems. *Influence of Science, Engineering, and Technology on Society and the Natural World*: All human activity draws on natural resources and has both short and long-term consequences, positive as well as	Primary: *What is Soil?* *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils* *Life in Soils* *Soils and Plants*

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			(locations of past volcanic and hydrothermal activity associated with subduction zones), and soil (locations of active weathering and/or deposition of rock).		negative, for the health of people and the natural environment.	
Earth and Human Activity	ESS3-MS-3	Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.	Examples of the design process include examining human environmental impacts, assessing the kinds of solutions that are feasible, and designing and evaluating solutions that could reduce that impact. Examples of human impacts can include water usage (such as the withdrawal of water from streams and aquifers or the construction of dams and levees), land usage (such as urban development, agriculture, or the removal of wetlands), and pollution (such as of the air, water, or land).	ESS3.C: Human Impacts on Earth Systems: Human activities can have consequences (positive and negative) on the biosphere, sometimes altering natural habitats and causing the extinction of other species. Technology and engineering can potentially mitigate impacts on Earth's systems as both human populations and per-capita consumption of natural resources increase.	*Influence of Science, Engineering, and Technology on Society and the Natural World*: The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time.	Secondary: *What is Soil?* *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils* *Life in Soils* *Soils and Plants*
Earth and Human Activity	ESS3-MS-4	Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.	Examples of evidence include grade-appropriate databases on human populations and the rates of consumption of food and natural resources (such as freshwater, mineral, and energy). Examples of impacts can include changes to the appearance, composition, and structure of Earth's systems as well as the rates at which they change. The consequences of increases in human populations and consumption of natural resources are described by science, but science does not make the decisions for the actions society takes.	ESS3.C: Human Impacts on Earth Systems: Technology and engineering can potentially mitigate impacts on Earth's systems as both human populations and per-capita consumption of natural resources increase.	*Cause and Effect*: Cause and effect relationships may be used to predict phenomena in natural or designed systems. *Influence of Science, Engineering, and Technology on Society and the Natural World*: All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. *Science Addresses Questions About the Natural and Material World*: Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes.	Secondary: *What is Soil?* *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils* *Life in Soils* *Soils and Plants*
LS: LIFE SCIENCES						
Molecules to Organisms: Structure and Processes	LS1-MS-1	Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.	Emphasis is on developing evidence that living things are made of cells, distinguishing between living and non-living cells, and understanding that living things may be made of one cell or many and varied cells.	LS1.A: Structure and Function: All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular).	*Scale, Proportion, and Quantity*: Phenomena that can be observed at one scale may not be observable at another scale. *Interdependence of Science, Engineering, and Technology*: Engineering advances have led to important discoveries in virtually every field of science, and scientific	Secondary: *Life in Soils*

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					discoveries have led to the development of entire industries and engineered systems.	
Molecules to Organisms: Structure and Processes	LS1-MS-5	Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.	Emphasis is on tracing movement of matter and flow of energy.	LS1.C: Organization for Matter and Energy Flow in Organisms: Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use	*Energy and Matter*: Within a natural system, the transfer of energy drives the motion and/or cycling of matter.	Primary: *Life in Soils* *Soils and Plants*
Molecules to Organisms: Structure and Processes	LS1-MS-6	Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.	Emphasis is on describing that molecules are broken apart and put back together and that in this process, energy is released. Also understanding that the elements in the products are the same as the elements in the reactants.	LS1.C: Organization for Matter and Energy Flow in Organisms: Within individual organisms, food moves through a series of chemical reactions (cellular respiration) in which it is broken down and rearranged to form new molecules, to support growth, or to release energy.	*Energy and Matter*: Matter is conserved because atoms are conserved in physical and chemical processes.	Secondary: *Life in Soils* *Soils and Plants*
Ecosystems: Interactions, Energy, and Dynamics	LS2-MS-1	Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.	Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.	LS2.A: Interdependent Relationships in Ecosystems: Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction Growth of organisms and population increases are limited by access to resources.	*Cause and Effect*: Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Primary: *Life in Soils* *Soils and Plants* Secondary: *What is Soil?* *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils*
Ecosystems: Interactions, Energy, and Dynamics	LS2-MS-2	Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.	Emphasis is on predicting consistent patterns of interactions in different ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems. Examples of types of interactions could include competitive, predatory, and mutually beneficial.	LS2.A: Interdependent Relationships in Ecosystems: Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.	*Patterns*: Patterns can be used to identify cause and effect relationships.	Primary: *Life in Soils* *Soils and Plants*
Ecosystems: Interactions, Energy, and Dynamics	LS2-MS-3	Develop a model to describe the cycling of matter and flow of energy among living and	Emphasis is on describing the conservation of matter and flow of energy into and out of various	LS2.B: Cycle of Matter and Energy Transfer in Ecosystems: Food webs are models that demonstrate how matter and energy is transferred between producers, consumers,	*Energy and Matter*: The transfer of energy can be tracked as energy flows through a natural system.	Primary: *What is Soil?* *Life in Soils* *Soils and Plants*

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		nonliving parts of an ecosystem.	ecosystems, and on defining the boundaries of the system.	and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.	*Scientific Knowledge Assumes an Order and Consistency in Natural Systems*: Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.	Secondary: *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils*
Ecosystems: Interactions, Energy, and Dynamics	LS2-MS-4	Develop a model to describe the flow of energy through the trophic levels of an ecosystem.	Emphasis is on describing the transfer of mass and energy beginning with producers, moving to primary and secondary consumers, and ending with decomposers.	LS2.B: Cycle of Matter and Energy Transfer in Ecosystems: Food webs can be broken down into multiple energy pyramids. Concepts should include the 10% rule of energy and biomass transfer between trophic levels and the environment.		Primary: *What is Soil?* *Life in Soils* *Soils and Plants*
Ecosystems: Interactions, Energy, and Dynamics	LS2-MS-5	Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.	Emphasis is on recognizing patterns in data and making warranted inferences about changes in populations, and on evaluating empirical evidence supporting arguments about changes to ecosystems.	LS2.C: Ecosystem Dynamics, Functioning, and Resilience: Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.	Stability and Change: Small changes in one part of a system might cause large changes in another part.	Primary: *What is Soil?* *Life in Soils* *Soils and Plants* Secondary: *Soil Texture* *What is Clay?* *Soil Color*
Ecosystems: Interactions, Energy, and Dynamics	LS2-MS-6	Evaluate competing design solutions for maintaining biodiversity and ecosystem services.	Examples of ecosystem services could include water purification, nutrient recycling, and prevention of soil erosion. Examples of design solution constraints could include scientific, economic, and social considerations.	LS2.C: Ecosystem Dynamics, Functioning, and Resilience: Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health. LS4.D: Biodiversity and Human: Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling.	*Stability and Change*: Small changes in one part of a system might cause large changes in another part. *Influence of Science, Engineering, and Technology on Society and the Natural World*: The use of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time. *Science Addresses Questions About the Natural and Material World*: Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes.	Primary: *What is Soil?* *Soil Texture* *What is Clay?* *Soil Color* *Soils and Fossils* *Life in Soils* *Soils and Plants*

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Biological Adaptation: Unity and Diversity	LS4-MS-1	Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past.	Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.	LS4.A: Classification of Organisms: The collection of fossils and their placement in chronological order is known as the fossil record and documents the change of many life forms throughout the history of the Earth. Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record enable the classification of living things.	*Patterns:* Graphs, charts, and images can be used to identify patterns in data. *Scientific Knowledge Assumes an Order and Consistency in Natural Systems*: Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.	Primary: *Soil Texture* *What is Clay?* *Soils and Fossils*
PS: PHYSICAL SCIENCES						
Matter and It's Interactions	PS1-MS-1.	Develop models to describe the atomic composition of simple molecules and extended structures.	Emphasis is on developing models of molecules that vary in complexity. Examples of simple molecules could include ammonia and methanol. Examples of extended structures could include sodium chloride or diamonds. Examples of molecular-level models could include drawings, 3D ball and stick structures, or computer representations showing different molecules with different types of atoms.	PS1.A: Structure and Properties of Matter: Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals). PS1.B: Chemical Reactions: Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.	*Scale, Proportion, and Quantity*: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.	Primary: *What is Clay?*
Matter and It's Interactions	PS1-MS-3.	Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.	Emphasis is on natural resources that undergo a chemical process to form the synthetic material. Examples of new materials could include new medicine, foods, and alternative fuels.	PS1.A: Structure and Properties of Matter: Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. PS1.B: Chemical Reactions: Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.	*Structure and Function*: Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used. *Interdependence of Science, Engineering, and Technology*: Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. *Influence of Science, Engineering and Technology on Society and the Natural World*: The uses of technologies and any limitation on	Primary: *What is Clay?*

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					their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time.	
MATHEMATICS						
Geometry: Solve real-world and mathematical problems involving area, surface area, and volume	6.G.A.2	Find the volume of a right rectangular prism with fractional edge lengths by packing it with unit cubes of the appropriate unit fraction edge lengths and show that the volume is the same as would be found by multiplying the edge lengths of the prism. Apply the formulas $V = lwh$ and $VV= Bh$ to find volumes of right rectangular prisms with fractional edge lengths in the context of solving real-world and mathematical problems.				Primary: *What is Clay?*
Geometry: Solve real-world and mathematical problems involving area, surface area, and volume	6.G.A.3	Draw polygons in the coordinate plane given coordinates for the vertices; use coordinates to find the length of a side and area by joining points with the same first coordinate or the same second coordinate. Apply these techniques in the context of solving real-world and mathematical problems.				Primary: *What is Clay?*
Geometry: Solve real-world and mathematical problems involving area, surface area, and volume	6.G.A.4	Represent three-dimensional figures using nets made up of rectangles and triangles and use the nets to find the surface area of these figures. Apply these techniques in the context of solving real-world and mathematical problems. Example: Explain how you could find the surface area of a rectangular prism given a three dimensional representation or a net.				Primary: *What is Clay?*
Ratios and Proportional Relationships: Understand ratio and rate concepts and use ratio and rate reasoning to solve problems	6.RP.A.1	Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. Examples: 1) The ratio of wings to beaks in the bird house at the zoo was 2: 1, because for every two wings there was one beak. 2) For every vote candidate A received, candidate C received nearly three votes, meaning that candidate C received approximately three times the number of votes as candidate A, or candidate A received approximately 1 3 of the number of votes that candidate C received.				Primary: *Soil Texture*
Ratios and Proportional Relationships: Understand ratio and rate concepts and use ratio and rate reasoning to solve problems	6.RP.A.3.c	3. Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations. c. Find a percent of a quantity as a rate per 100; solve problems involving finding the whole, given a part and the percent. Example: 30% of a quantity means 30/100 times the quantity.				Primary: *Soil Texture*