United States Department of Agriculture

Natural Resources Conservation Service

Elementary Soils Concepts for the NM Envirothon

Logan Peterson—Soil Scientist
Natural Resources Conservation Service
logan.peterson@usda.gov[1]

Figure 1. A pit at the Soils Station during a previous NM Envirothon.

[1]Yes, you can email me with questions about any of the study materials. This is good practice for college.

Introduction

If you're only going to study one guide for the Soils Section of the competition, this should be it. Here, we'll cover the most basic soils concepts. The other guides go into more detail, and I suggest you **read** them, too. Like it or not, you'll have to **read a lot** if you hope to ace my exam, but this is good practice for college. Notice a theme here? As you go through this guide, you'll probably come across a number of strange new terms like *parent material* and *alluvium*. You can find many simple definitions in this text, and others in the Soils Glossary on the Soils Page of the NM Envirothon site.

If you can't define *soil*, you're not alone. Ask a random person on the street what soil is, and she's most likely to tell you "Dirt." She might also describe what it looks like, what it's good for, and where it is found, but very few people can *define* soil. Believe it or not, the following definition is pretty simple…that is, in terms of soil science.[2]

soil – The unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants.

Don't worry, we'll *break it down below*. Puns intended.

When we say that soil is **unconsolidated**, we mean that it has broken-down (decomposed or weathered) from the stuff it formed out of (*parent materials*). Soil is not hard bedrock, nor is it fresh plant or animal parts. With a little effort (and maybe a blister or two), we can dig through most soils with hand tools.

[2]Almost nothing is simple in the world of soils. But hey, the same is true for society.

Figure 2. A pit in a typical forest soil. On the right are samples from different *horizons* of this soil.

It's also very important that we understand the difference between **mineral** and **organic** materials. In simple terms, organic matter is stuff that was once living tissue of organisms. Common organic parent materials that break down into soil are roots, leaves, manure, and soil organisms (fungus, bacteria, insects, centipedes, etc.). Decomposed (broken-down) organic matter is dark in color, so soil layers that are rich in organic matter are generally dark.[3] Mineral materials are everything else—they come from non-living stuff—mostly rocks. If you're wondering whether a substance is organic or not, consider whether it will burn. Wood, flesh, fungus, leaves, pine needles, gasoline, coal—all will burn, and all come from living tissues. Granite, limestone, basalt, iron, water, table salt—none of these come from living tissues, and none of them will burn.

[3]One example of how organic matter becomes dark as it decomposes is a compost pile—where your food waste and yard clippings are transformed into rich, dark compost. Even closer to home is your own digestive system. Poop is a fact of life, and it is very important to soil scientists. A small concentration (1 or 2 percent by mass) of decomposed organic matter will make a soil layer dark brown.

When organic matter decomposes, CO_2—a greenhouse gas—is released. Since there's roughly twice as much carbon in soil organic matter as there is in the atmosphere, soil has a tremendous effect on the global climate. Tillage (plowing), overgrazing, and drainage of wetlands can cause soils to release CO_2 as organic matter breaks down. On the other hand, practices like cover cropping, no-till farming, and prescribed grazing can add organic matter to the soil—thereby removing CO_2 from the atmosphere.

Figure 3. On the left, we see a pile of rocks that fell from the cliffs above. These rocks are mineral materials. If they stay in-place for a few thousand years, they will break down into a soil like the one to the right. This soil contains very little organic matter, so it is pretty light in color.

Figure 4. On the left, we see a forest floor covered with organic materials (wood, leaves, and fir needles). As critters chew these materials, they become unconsolidated. At the very surface, there is a thin layer of duff (an "O horizon)—made up of unconsolidated organic material. The second layer down (nearly black) is mostly mineral material, but it is darkened by organic matter. We call this an "A horizon." For more info on soil horizons, see "From the Surface Down."

Also, soil is found on the **immediate surface of the Earth** (think of the uppermost 2 or 3 meters). If it's buried far underground, or at the bottom of the ocean, or under your fingernails, then it isn't soil (although it may have once been).

Lastly, soil **serves as a natural medium for the growth of land plants**. This means that plants have sent roots into the soil. If land plants haven't grown in it, then it isn't soil. Many aquatic plants can float in deep waters, and many seeds will sprout in a wet paper towel (which is not a "natural medium"), but neither a body of water nor a paper towel are soil (although all soils contain water, and a paper towel can decompose and become soil).

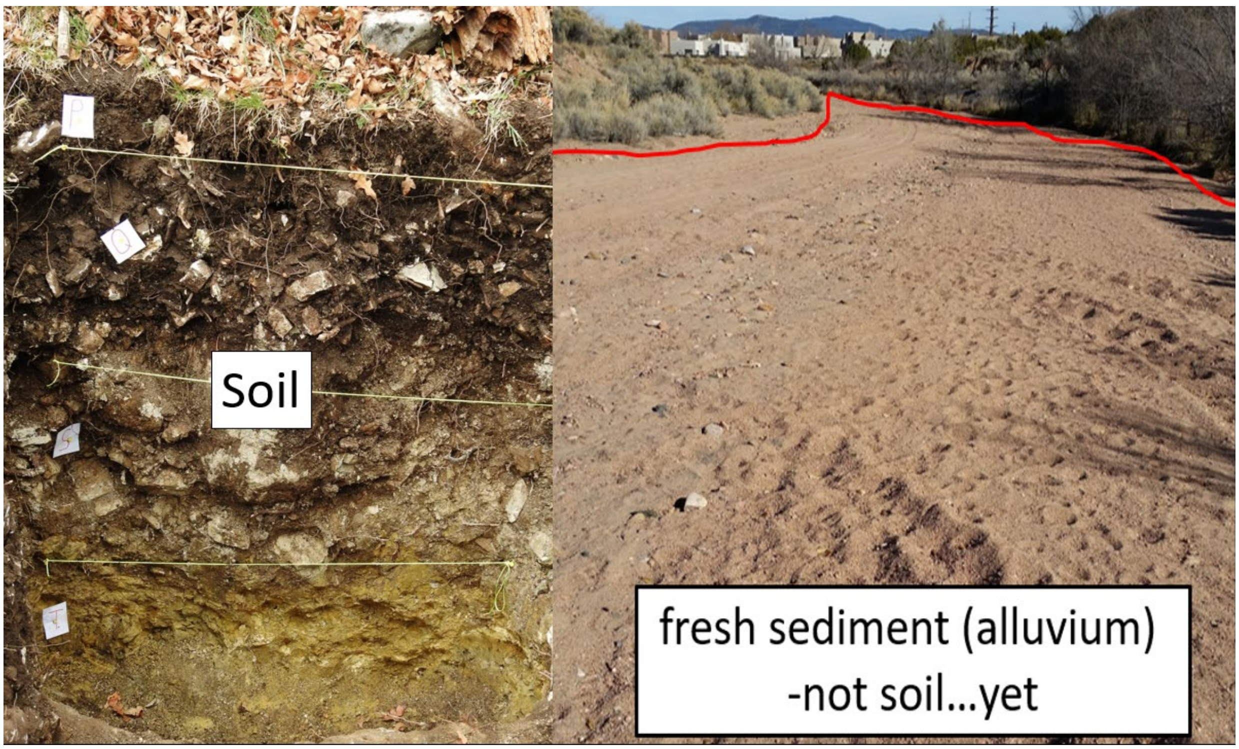


Figure 5. Two unconsolidated materials that appear on the immediate surface of the Earth. The fresh sediment on the right was washed down the arroyo very recently, and plants have not established in it, so it isn't soil...yet. On the left is a soil profile from a previous NM Envirothon exam!

Table 1. ***Five examples of materials that are not soil—based on the technical definition (see Figure 6 below).***

Material	Unconsolidated?	On the immediate surface of the Earth?	A natural medium for the growth of land plants?
Active Sand Dune[4]	Yes	Yes	No
Rock Outcrop	No	Yes	No[6]
Fresh Sediment in an Arroyo	Yes	Yes	No
Underwater Sediments	Yes	No	No
Soil Buried by Volcanic Activity[5]	Sometimes	No	It was before the eruption.

[4]An active sand dune is still moving, so plants have not yet colonized it. There are lots of dunes east of the Pecos between Roswell and Monahans, TX; most are vegetated, but some are active. White Sands National Monument is another great place to see dunes of both flavors.
[5]New Mexico has had lots of volcanic activity, and you can find buried “soils” in many places here. One great place to look is in the Rio Grande Gorge near Taos. For example, if you cross the John Dunn Bridge heading west, you’ll see red layers just beneath the basalt (dark volcanic rock) walls. These red layers are ancient soils that were baked (like bricks) underneath magma that flowed over the ground. Because these baked, buried soils are no longer at the immediate surface, they are no longer soil by our definition…but they’re still pretty awesome!
[6]Solid bedrock at the surface is not soil, but soils often develop in cracks in the rock, and we see plants growing in these cracks.

Figure 6. An active sand dune in White Sands National Monument.

Figure 7. High mountains of Patagonia. No soil here…yet. The human in the image is crossing a glacier—all the material beneath is buried under water (solid water). In the background is some beautiful rock outcrop (consolidated). None of this material is supporting plant life.

Why is Soil Important?

Okay, so I've answered the question of what soil is (and isn't), but there's another question that's at least as important: Why should we care? Sure, soil is beautiful and fascinating to nerds like myself, but there are reasons why everyone should be concerned with the welfare of soils.

4 Basic Resources that Soils Provide Plants:

1. Water. Plant roots draw water up from soils in a process called transpiration. In order for it to get to roots, it must travel through soil pores.
2. Nutrients. Plants absorb most of the nutrients they need from the soil. These nutrients are dissolved as ions in the soil solution (soil water), and are stuck to the surfaces of clay and humus particles. Examples of nutrient ions are nitrate (NO_3^-), ammonium (NH_4^+), phosphate (PO_4^{3-}), potassium ion (K^+), calcium ion (Ca^{2+}), and sulfate (SO_4^{2-}). Nutrients are most abundant in soils that are high in clay and/or organic matter, and are most easy for plants to absorb in soils that are relatively neutral in pH (close to 7).
3. Oxygen (O_2). While plants produce O_2 aboveground in photosynthesis, roots need to breathe O_2 in order to perform respiration. O_2 is not produced underground; in order for it to get to roots, it must travel from the atmosphere through soil pores.
4. Anchorage. A tree can't stand upright if its roots don't have something to hold onto. Roots anchor plants upright by grabbing onto soil.

5 Basic Resources that Soils Provide Humans:

1. **Food**. Yes, folks travel from all over the world to eat dirt in Chimayó, but soils feed most of us in a less-direct way. While we grow some specialty crops in ponds or plastic tubes, most of the food we eat comes from plants that grow in real soils. You probably already knew this, but it's news to a lot of people who've grown up far from agriculture.
2. **Building materials**. Another fact that surprises most Americans: you can build a house out of soil. The adobe bricks in the walls of so many of our buildings—including the oldest standing church in the U.S.—were made out of soil.
3. **Support for structures**. Even if your house was made from wood, its foundation probably rests on soil.
4. **Medicines**. Many medicines are made from natural chemicals found in the soil. Several antibiotics, for example, are produced by organisms in the soil which use these chemicals to fight against bacteria. Yes, there's all sorts of chemical warfare going on underground, and modern medicine is taking advantage of it!
5. **Cosmetics**. As you'll see in other guides, soils come in many colors, and humans have been decorating their bodies with soil-based cosmetics for thousands of years. Certain types of clay—found in soils—can be used in facial masks to clean your pores.

Beyond the 5 Basic Resources noted above, soils play a crucial role in the Hydrologic Cycle—which you've probably studied in the Aquatics Section.

- **Soils filter water and recharge aquifers.** As you'll learn from other guides, soil is composed of solids, liquids, and gases. The spaces between solid particles and **aggregates** are called **pores** (see Soil Structure below). As water from rainfall or floods moves through these pores, it is filtered. Given the right soil properties, soil removes the stuff we don't want to drink (bacteria, viruses, toxic chemicals, etc.) before the **percolating** water makes it to an aquifer. If you drink well water, you can thank soil for having filtered it long ago. Soil also filters and stores nutrients. This is good for land plants, and it prevents eutrophication (your aquatics expert should know what this means).
- **Soils store water.** Much like a sponge, a healthy soil can hold a lot of water against the force of gravity. If you completely saturate a sponge (dunk it, squeeze out the air, and let it fill with water) and hold it above the sink, you'll note that a certain amount of water will pour out of it. However, a lot of water remains stored in the pores. The same is true for soils. In some cases, rainwater can be stored in a soil for months—slowly delivering water to plant roots. This is very important here in the Southwest, where it may not rain for months on end.
- **Soils prevent flooding.** Liquid water obeys gravity. Once it hits the ground, it will take the easiest path downwards. If water can't **infiltrate** the soil (because the soil is already **saturated**, is **compacted**, or is covered by pavement or buildings), the it will flow across the surface. We call this type of flow **runoff**. This runoff water often concentrates in gullies (arroyos), which carry it to ditches, streams, and rivers. This is how we get flash floods, and it explains why flash floods are common in cities and in areas with lots of bare bedrock (like the canyonlands of the Four Corners Region).
- **Soils prevent drought.** Streams and rivers are attached to aquifers. As long as the water table is as high as the streambed, the stream flows. This is why many of our streams and rivers continue to flow for months after the last rains (or for months after the snow has melted). In a larger watershed, it can take months or even years for a drop of rain to percolate through soils, then through fractured bedrock or sediments below, then through an aquifer, before it finds its way into a stream.

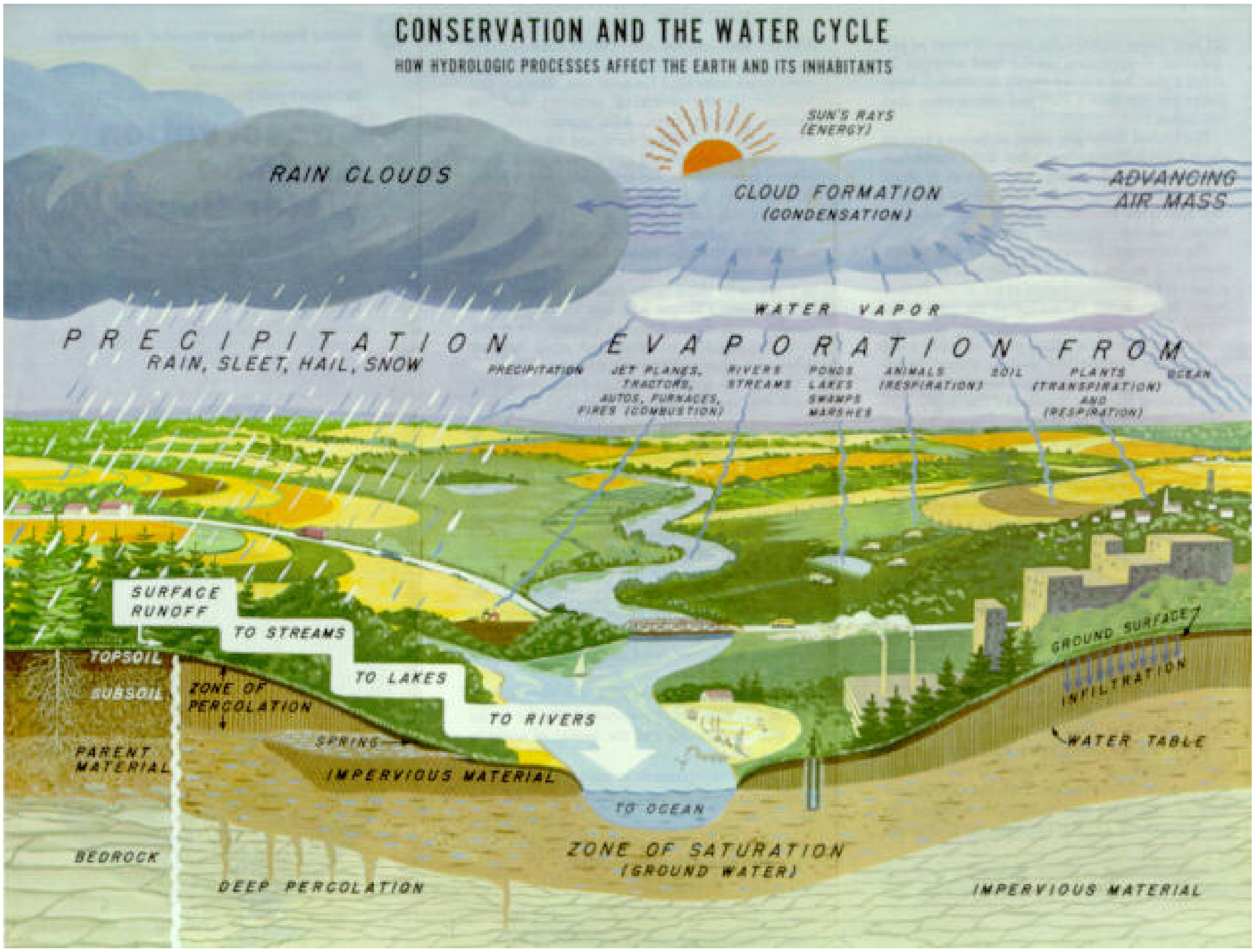


Figure 8. The Hydrologic Cycle. For more info see: https://www.wcc.nrcs.usda.gov/factpub/aib326.html

A couple of other things to thank soil for:

- **Soils break down toxins.** As you'll see in other guides, soil is full of life. Many of the organisms in soil get their energy by digesting stuff that is toxic to humans. For example, certain fungi can digest crude oil. So, not only do soils filter toxins from water, they can also digest many of them. No, this doesn't mean that you should dump toxic waste on the ground; if digestion does occur, it is often slow and incomplete.
- **Soils store carbon.** Like all organic materials, soil organic matter is loaded with carbon. In fact, there is roughly twice as much carbon in our soils as in our atmosphere! You've probably heard that many climate scientists believe that carbon dioxide is a greenhouse gas—meaning that it helps the atmosphere to trap heat. Soils absorb carbon as dead tissues are incorporated in the soil, and they release carbon as this tissue decomposes. Whether a soil absorbs more carbon than it releases depends, in part, on how we manage it.

What is Soil Composed Of?

Soils are made up of **three phases of matter**: solid, liquid, and gas. In solids, the atoms or molecules don't move around much, so solids are difficult to deform or compress. In liquids, atoms or molecules can move around each other freely, but are still pretty tightly-packed. Liquids readily change shape, but do not compress much. Gases are composed of atoms or molecules that are moving around freely, with a whole lot of space between them. Thus, a gas readily changes shape and is easy to compress. Plasma doesn't occur in soil—except in a brief instant during a lightning strike or nuclear blast.

The central point here is that the spaces between solid soil particles contain soil, too—the liquid and gaseous phases of soil.

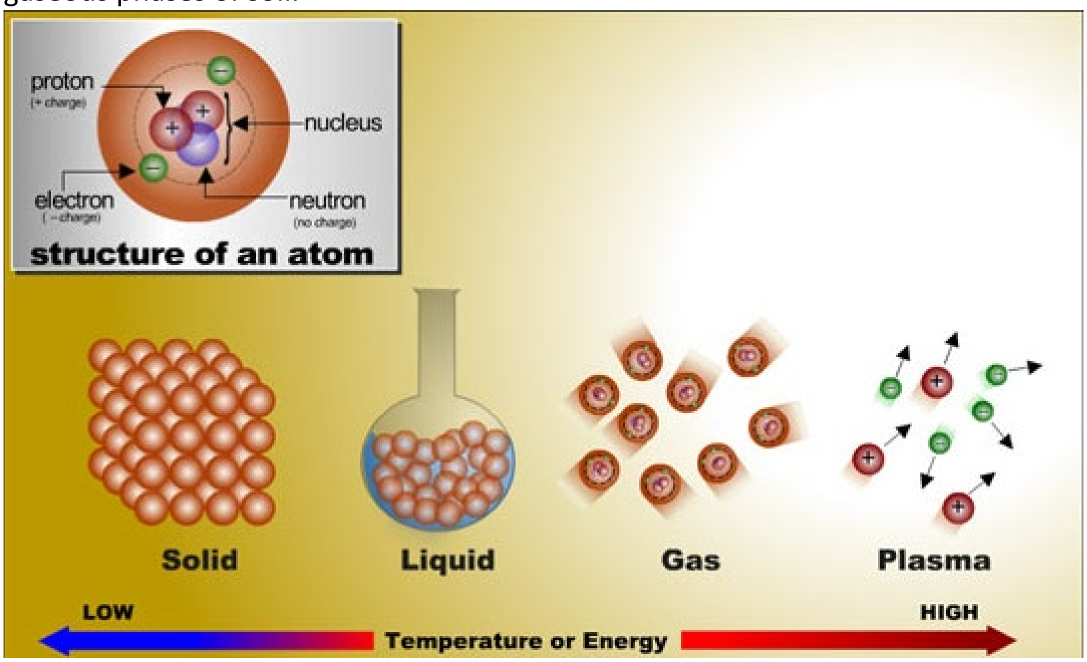


Figure 9. The phases of matter.

Q: Which of the soils in Figure 10 below contains liquid, and which contains gas?

Figure 10. Two soil profiles. The one on the right felt bone-dry to the touch. The pit to the left was filling with water as I dug.

A: Both of them!!!

All soils contain all three phases of matter. Take a sample of soil that feels bone-dry and bake it at 100° C overnight, and you'll find that it loses weight. What is lost is water that was held very tightly to soil particles. On the other hand, a soil that is soaking wet will still contain some gas that is trapped in tiny pores. As weather and management change, the proportions of solids, liquids, and gases change; but all three phases are always present in real soil.

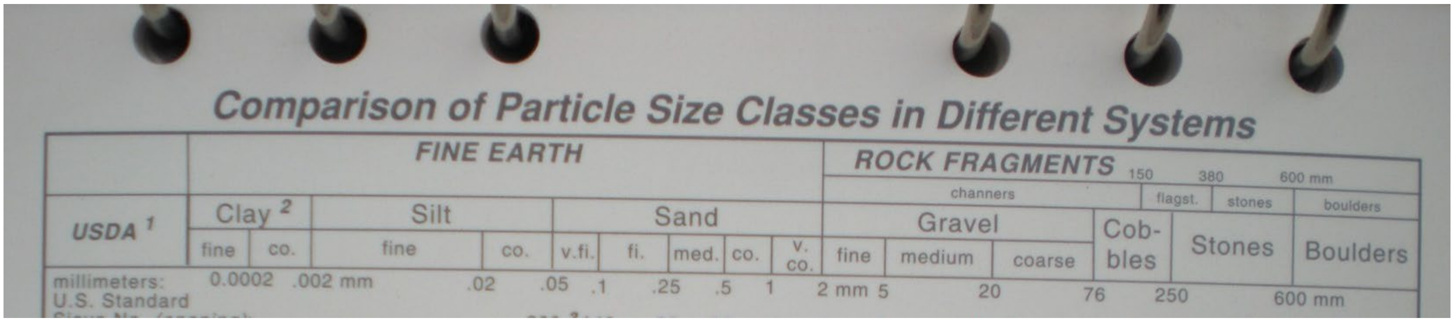
The Solid Phase of soil is made-up of particles. A 5-ton boulder is a particle, and so is a tiny grain of sand. A soil particle can be either *mineral* or *organic*, as we discussed above. Particles can also be divided based on their sizes. The most important division we make is at 2 mm. The portion of soil that will pass through a sieve with 2 mm openings is called that the **fine earth fraction**; this is where most of the "magic" happens—where most of the water and nutrients are held, and where most of the chemistry occurs. The **coarse fraction** is composed of particles that will not pass though the 2 mm sieve, and mostly just take up space. However, coarse fragments very slowly weather (break down) into fine earth, and coarse fragments at the surface act like a mulch in preventing erosion and water loss by evaporation.

Figure 11. A soil sample that has been separated using a 2 mm sieve. The fine earth fraction passed through the square openings and was collected in the pan to the right. The coarse fraction remained on top of the screen to the left. To use a sieve, stack the screen on top of the pan, rub and shake the sample. Sometimes, I have to use the butt of my soils knife to break up aggregates (defined below). The knife (which is very dull) can also be used to pry the screen and the pan apart.

The *fine earth fraction* is further divided into three particle size classes: **sand**, **silt**, and **clay**. If you have perfect vision, you can see the smallest individual sand grains. Silt particles are too small to see with the naked eye, and clay particles require very powerful microscopes to see individually. Ranges in size for the three particle size classes are:

Sand: 0.05 – 2 mm
Silt: 0.002 – 0.05 mm
Clay: <0.002 mm (clay particles can be *way* smaller than 0.002 mm!)

Table 2. Particle size classes. Why on Earth would I include a crummy photo from the Field Book for Describing and Sampling Soils, which I provide at the exam, and have posted a PDF of on the NM Envirothon website? Hint-hint.



Comparison of Particle Size Classes in Different Systems

	FINE EARTH									ROCK FRAGMENTS					
										channers			flagst.	stones	boulders
USDA [1]	Clay [2]		Silt		Sand					Gravel			Cob-bles	Stones	Boulders
	fine	co.	fine	co.	v.fi.	fi.	med.	co.	v. co.	fine	medium	coarse			

millimeters: 0.0002 .002 mm .02 .05 .1 .25 .5 1 2 mm 5 20 76 250 600 mm
U.S. Standard

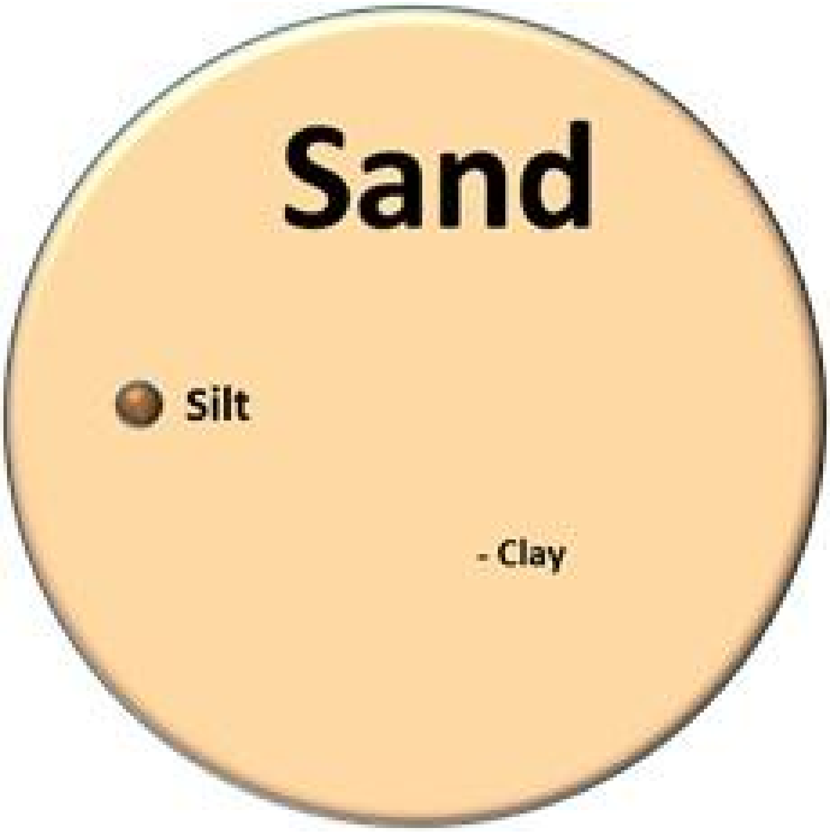


Figure 12. A comparison of the three particle size fractions—magnified, of course. At this scale, only the very largest clay particles would be visible. Clay particles are really, really tiny! The sand grain here would be 0.05 mm across—barely visible to the naked eye.

Why do soil scientists bother to divide soils into different size fractions? Because particles of different sizes have different properties that influence how a soil behaves. Table 3 below gives a brief comparison.

Table 3. A comparison of the properties of the three particles size fractions of the fine earth.

Particle Size Class	Size Range	Important Properties
Sand	0.05 – 2 mm	• Sand feels gritty. • Spaces between sand grains allow water and gas to move easily. • Sand grains don't "stick together" like clay particles.
Silt	0.002 – 0.05 mm	• Silt feels smooth or "buttery". • Silt particles don't "stick together" like clay particles. • Silt particles are easily carried by water and wind.
Clay	Clay: <0.002 mm	• Clay feels sticky, and holds a shape when moist. • Clay particles "stick together". • Clay particles are easily carried by water and wind, but only when they have been detached from each other. • Unlike sand and silt, clay can hold onto a great deal of water and nutrients.

Soil Texture refers to the proportions of these three classes of particles. Even though we might refer to a soil as "sand" or "clay", almost any soil sample will contain some amount of all three particle size classes. For example, potters' clay contains a good deal of sand and silt. Of the many properties of soil, texture is perhaps the most important because it affects every aspect of soil behavior—erosion, nutrient availability, drainage, water-retention, etc. Different soil textures have different names and different characteristics. For example, a *loamy sand* is easy to dig through, and water moves through it quickly, but it generally can't hold onto much water or nutrients (unless it contains a lot of organic matter). A *silty clay loam* can store loads of water and nutrients, but water won't move quickly through it unless it has great structure (more on structure below).

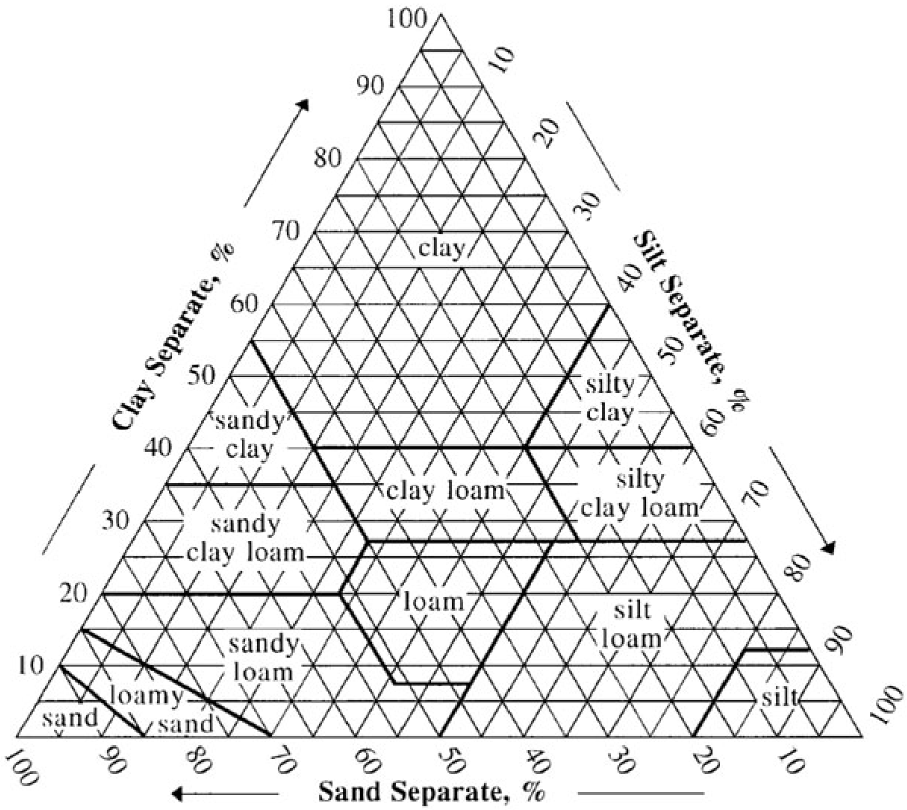


Figure 9. The Soil Textural Triangle in all its glory. At least one soil scientist has a tattoo of this diagram.

The **Soil Textural Triangle** is a rather strange diagram that allows us to determine texture based on the percentages of sand, silt, and clay. Unlike a typical graph in algebra with an X-axis and a Y-axis, the textural triangle has three axes (plural of axis). Clay increases as you move upwards. Sand increases as you move down and to the left. Silt increases as you move down and to the right.

As an example, I have a sample of the fine earth fraction with 32% clay and 10% sand. First, I trace a horizontal line corresponding to 32% clay (see Figure 15 below). Then, I trace a diagonal line corresponding to 10% sand. These lines intersect in the *silty clay loam* box, so that's my texture: silty clay loam. Now, to determine the percentage of silt, I could do one of two things. I could use simple algebra:

Sand + Silt + Clay = 100
Silt = 100 – Sand – Clay
Silt = 100 – 10 – 32
Silt = 58

Or I could let the triangle do the math for me. Either way, you can check your work, as your 3 values should add up to 100. See Figure 15 for an illustration.

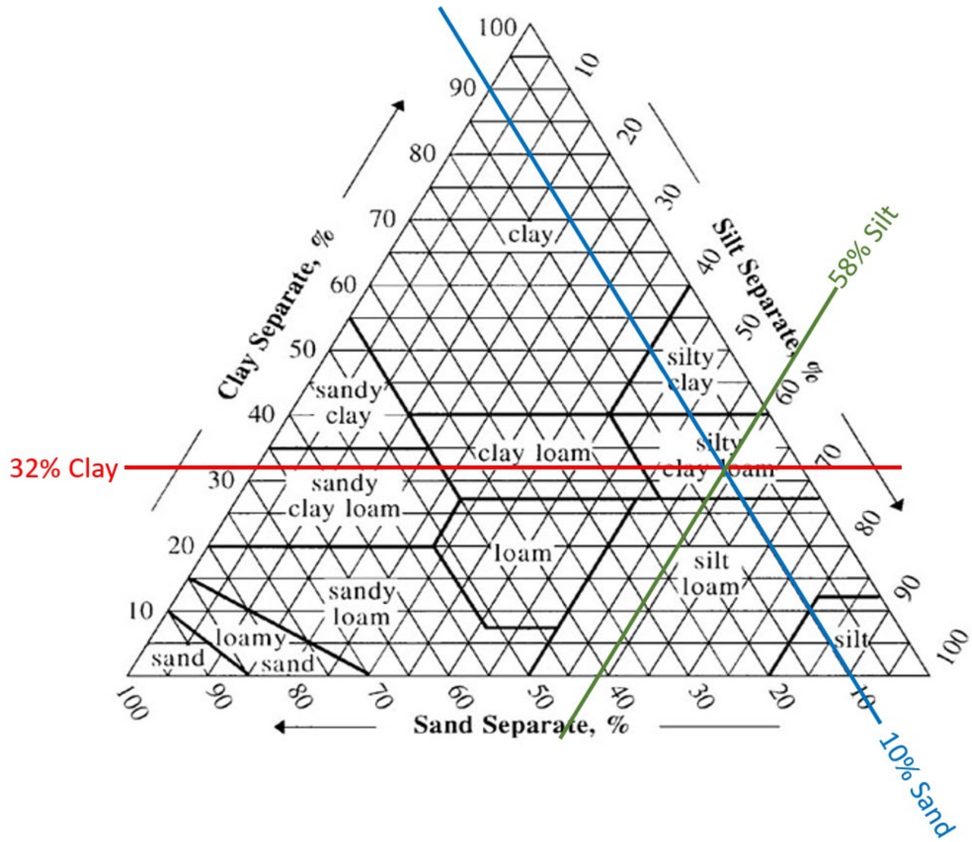


Figure 14. A soil sample with 32% clay (red line) and 10% sand (blue line). These lines intersect in the silty clay loam box, so its texture is silty clay loam. If we draw a third line (green) on the silt axis, and through the intersection of the other two lines, we find that the percentage of silt is 58.

While there are several ways of determining texture, the simplest method is **texture by feel**. Basically, we moisten a soil sample, mix it up, and play with it. Believe it or not, with some practice, most people can learn to estimate clay within a few percent by playing with mud-pies! Don't worry though, you won't be expected to be that precise. There is a separate texturing guide on the soils page, which will be provided at the Soils Exam, but here are a few basic tips.

Clay particles are really tiny, they're flat, and they're usually attracted to each other (and to your skin)—much like magnets. For this reason, a soil sample that is high in clay will feel sticky as you mix it in your hand. It will also be **plastic**—meaning that it will hold a shape (a ball, a cube, a worm, a unicorn).

Sand grains are large enough to see (with good vision), and feel rough or "gritty". Larger sand grains are easy to feel, while it takes some sensitivity to feel the grit of the finest sand grains.

Silt particles are too small to see, and don't feel gritty. They also don't stick together much. A soil sample that is very high in silt will feel smooth or buttery, but not sticky. Most people like this feeling. However, silt is very tough to feel if a sample contains much sand. For this reason, we often estimate percentages of clay and sand, then calculate silt using one of the methods above.

While the Texture Guide on the Soils Page is really useful, I’m adding a few tips below.

The most common way to estimate clay percentage is the Ribbon Method. First, add some water, and mix a sample into the right consistency (it should feel sort of like cookie dough…unless it’s very low in clay). Next, try pushing some over your forefinger with your thumb. A soil with a modest amount of clay (roughly 10% or more) will make a ribbon of some length (say a centimeter or more). The longer the ribbon gets before it breaks, the more plastic the soil is. The more plastic a soil is, the more clay it contains. So if you’re asked which of two samples contains more clay, see which one makes a longer ribbon. Since no two people do this the same way, it’s best to have one person make this comparison…and make sure not to keep your two samples separate.

Figure 15. Estimating clay using the Ribbon Method. This sample is very high in clay (50%), and made a ribbon 8 cm long!

There are a few more observations we can use to estimate clay percentage. First, a sample that is high in clay will feel stickier than one that is low in clay. Second, a high-clay sample will absorb more water before it feels wet. Third, it takes more work to mix a high clay sample into a putty.

The simplest way to estimate sand percentage is by rubbing a small amount of soil between your thumb and forefinger. After ribboning, take a pinch about the size of a pea, squirt a little extra water on it, hold it up by your ear, and give it a rub. If you don’t feel any roughness or hear a subtle grinding, then the sample is low in sand (let’s say 20% or less). If the sample is loaded with larger sand particles, it will feel really rough, and you’ll hear some obvious grinding. It’s usually pretty easy to rub two samples and determine which one contains more sand.

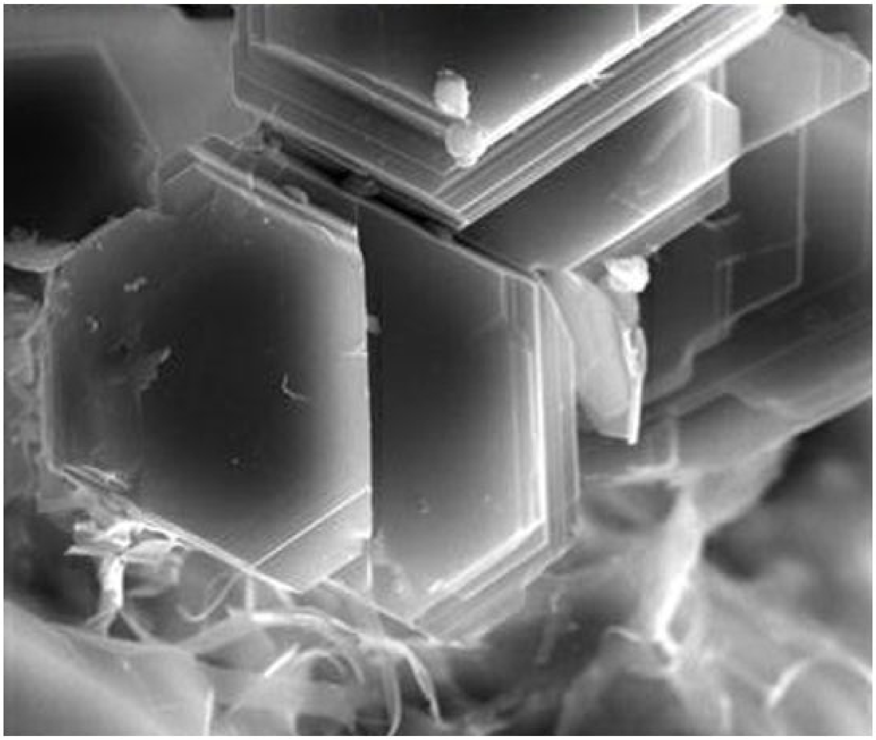
Figure 16. The Pinch Test--also known as "The Rub"

Silt is usually the hardest particle size to observe during hand texturing. You can't see individual silt grains, they don't feel gritty or sticky, and a sample of pure silt won't make much of a ribbon. Rather than trying to estimate silt percentage directly, we estimate percentages of clay and sand, then calculate silt as demonstrated above.

Soil Texture—Why Should I Care?

Sure, it's fun to play with mud-pies, and I'm grateful that they pay me to do it, but why should you care about soil texture? Well, as I said above, soil texture affects every aspect of a soil's behavior. While a full book could be written on this topic, I'll just give you the basics here.

Clay particles are quite tiny, and they are usually flat, so a very small sample of clay has a tremendous amount of surface area. For an analogy, think of a stack of printer paper. As a stack, it doesn't take up too much <u>volume</u>, but if we were to lay out the sheets side-by-side, the paper would cover a lot of <u>area</u>, and both sides of each sheet are counted in the total surface area.



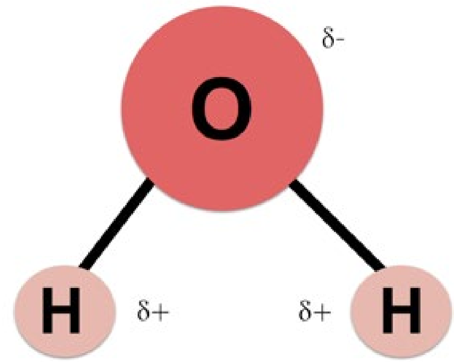


Figure 17. On the left are clay particles viewed through a **very** powerful microscope. At this scale, we still can't see the water molecules or the ions that are stuck to the surfaces. On the right is a diagram of a water (H_2O) molecule. Note that the oxygen atom is negatively-charged, and the hydrogen atoms are positively-charged.

Beyond being tiny and flat, the surfaces of clay particles are highly-charged. Some sites on a clay particle have negative charges; other sites have positive charges. In the world of chemistry, opposite charges attract (think of magnets). You may know that water molecules (H_2O) are *polar*—they are negatively-charged on the oxygen side and positively-charged on the hydrogen side. For this reason, water molecules will stick to both positively- and negatively-charged sites on clay particles. Ions (Na^+, Cl^-, H^+, NO_3^-, Ca^{2+}, etc.) are charged atoms or molecules. In a soil, an ion is attracted to a site on a soil particle with the opposite charge. See the figures on the next page.

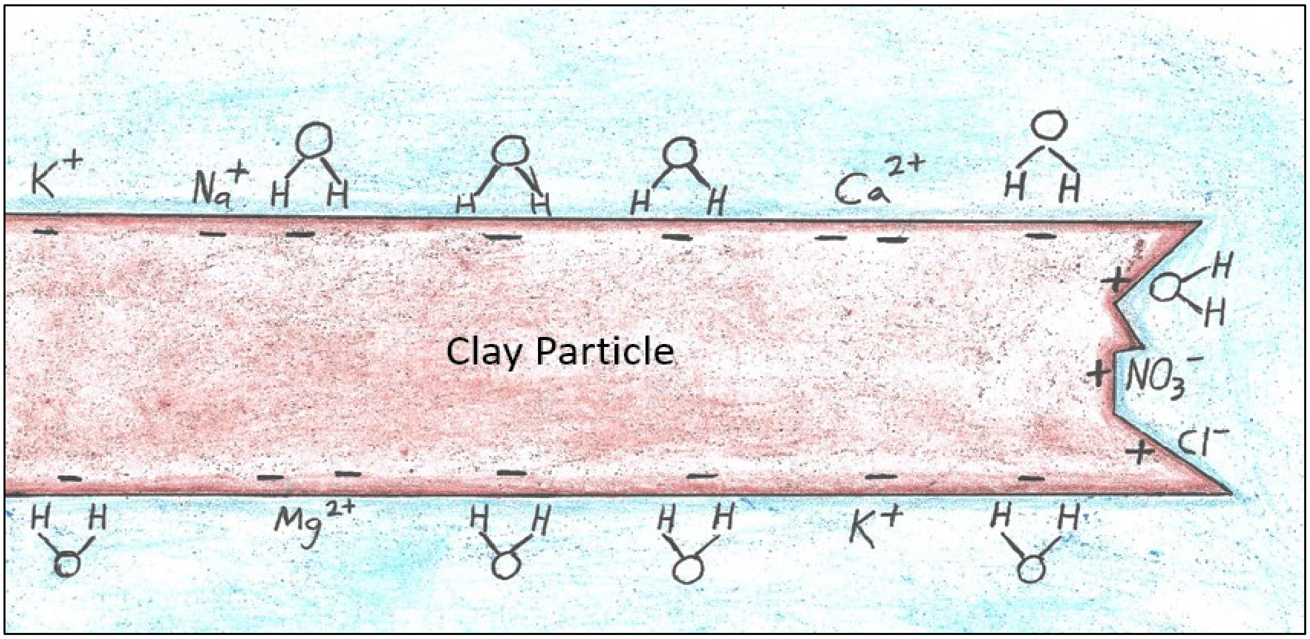


Figure 18. A sketch of a clay particle with ions and water molecules *adsorbed* onto its charged sites. Usually, most of the charged sites are negative, and positive sites are found on broken edges on clay particles. This drawing is not to scale. Cations (positively-charged ions) depicted here are sodium ion (Na^{+}), calcium ion (Ca^{2+}), and magnesium ion (Mg^{2+}). Anions (negatively-charged ions) here are chloride (Cl^{-}) and nitrate (NO_3^{-}).

Surface charge on clay particles also explains why high-clay soils feel sticky when wet—they're attracted to charges on your skin. It also explains why such soils tend to be difficult to dig through—clay particles are attracted to each other. Since most of the charge on most clay particles is negative, you'd expect these particles to repel each other. However, they are often "glued" together by cations, and/or by thin layers of water molecules.

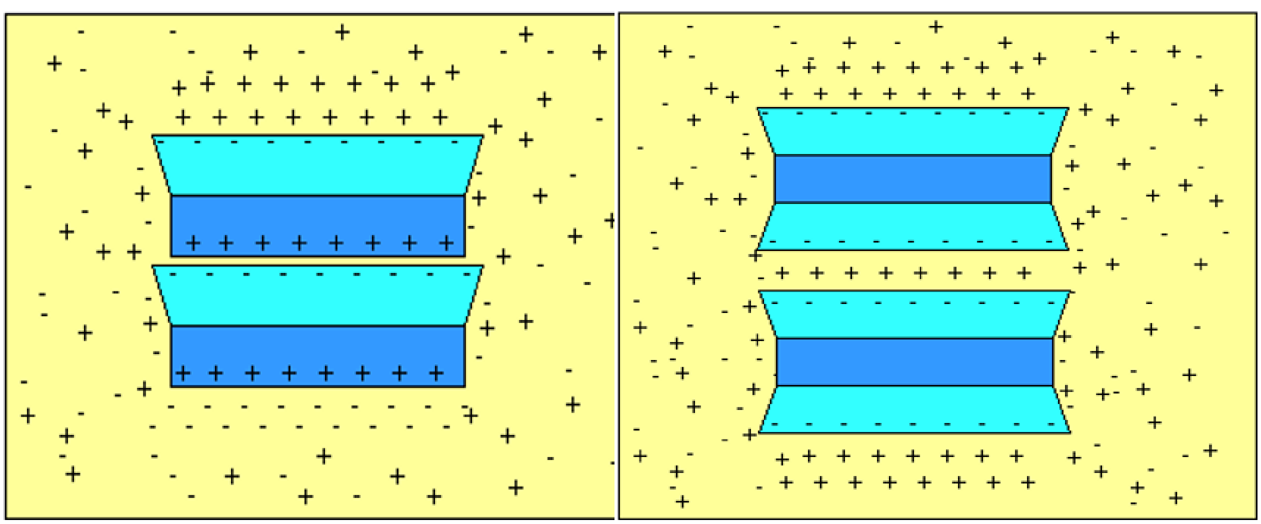
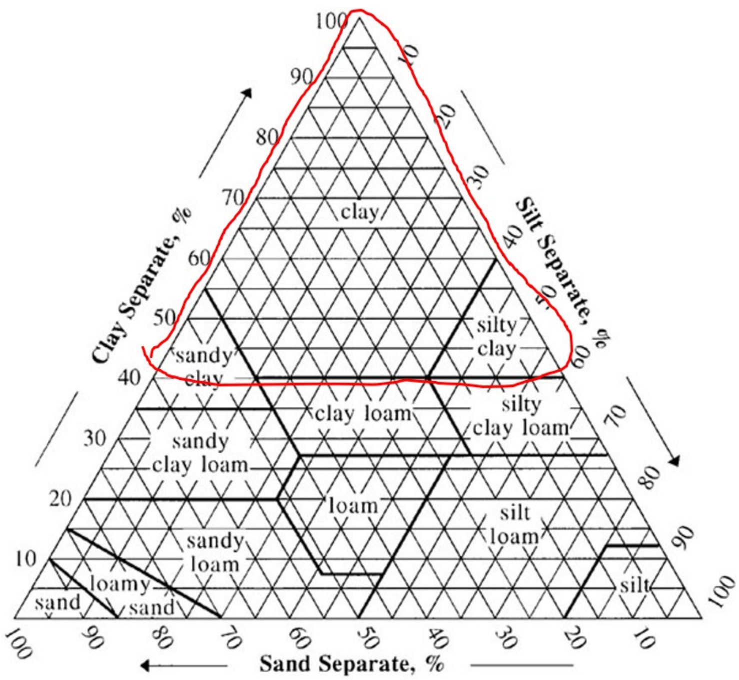


Figure 19. Clay particles surrounded by a soil solution (water and dissolved ions). On the left, positive charges on one particle are attracted to negative charges on the other. On the right, a layer of cations acts as a bridge (or glue) between two negatively-charged surfaces.

Now that we understand the basics of clay particles, we'll look at some common characteristics of high-clay soils.

In general, soils that are dominated by **clay:**

- Are "tight", meaning that they're difficult for roots to push through. Try growing a carrot in a clay, and you'll find that the taproot (the orange part) is stunted. [7]
- Are capable of holding large amounts of water. If you can only irrigate once a month, it's nice to have a high-clay soil.
- Remain "dry" after small rain events. This is because clays can hold thin films of water so tightly that roots can't suck this water out of the soil.[8] In drier parts of NM, high-clay soils are very unproductive unless irrigated.
- Are capable of holding onto large amounts of nutrients—which they release to plant roots. Most of the nutrients that plants need come from the soil in the form of ions. For example; nitrogen, phosphorus, and potassium are taken up by roots as nitrate (NO_3^-), ammonium (NH_4^+), phosphate (PO_4^{3-}), and potassium ion (K^+).
- Do not allow water to infiltrate or percolate rapidly. This is because the pores (spaces) between clay particles are mostly very narrow, and water flows much more rapidly through larger pores. [7]
- Do not allow rapid gas exchange. Roots and most soil organisms need O_2 (oxygen gas) to function, and O_2 must enter the soil from the atmosphere above. [7]

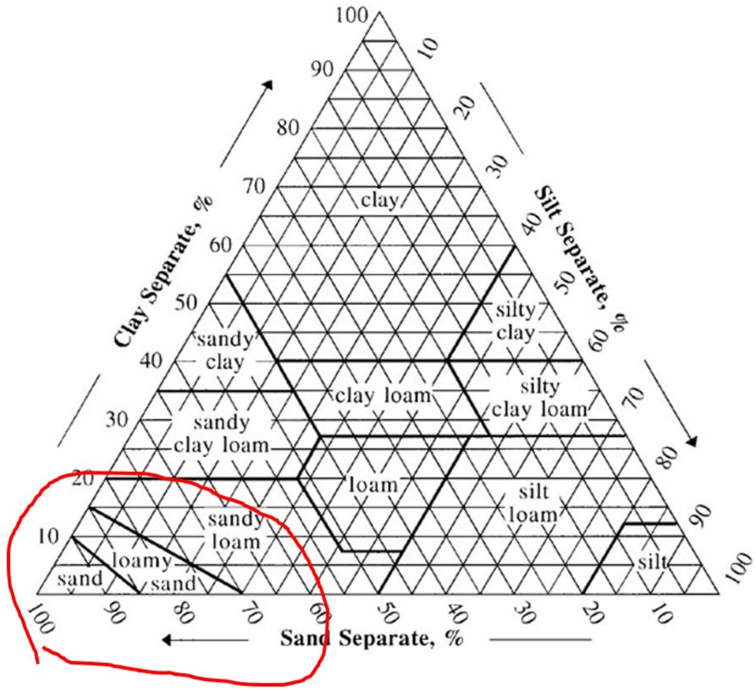


[7]An exception here is a high-clay soil with great *structure* (see below). In this case, there are a lot of large pores between *aggregates*. These pores make it easy for roots to grow, for water to flow, and for the soil to "breathe."

[8]Water that is held so tightly to clay particles that plant roots can't take it up is known as *hygroscopic water*. You can't feel or see this water, but it can account for over 5% of the volume of a high-clay soil. This fancy term might be worth a point or two on the exam.

In general, soils that are dominated by **sand:**

- Are "loose", meaning that they're easy for roots to push through. Sandy soils are choice for "root crops" such as carrots, onions, and potatoes.
- Allow water to infiltrate and percolate rapidly. [9]
- Allow rapid gas exchange. [9]
- Become "wet" after small rain events. This is because sand grains don't hold water as tightly as clay particles. This is an advantage where rain events are infrequent and often small.
- Cannot store much water. This is a big problem if you can't irrigate often. Another issue is that, if you apply a lot of water to a sandy soil, most of the water will percolate down below the rooting zone before the plants can take it up. This water removes valuable nutrients from the soil (where you want them, and often carries them into aquifers (where you don't want them).
- Cannot store large amounts of nutrients. [10]



[9]This is because the pores (spaces) between adjacent sand particles are usually much larger than the pores between smaller particles. Water and gas travel faster through large pores than through small pores. For more on this, see the section on soil structure below.

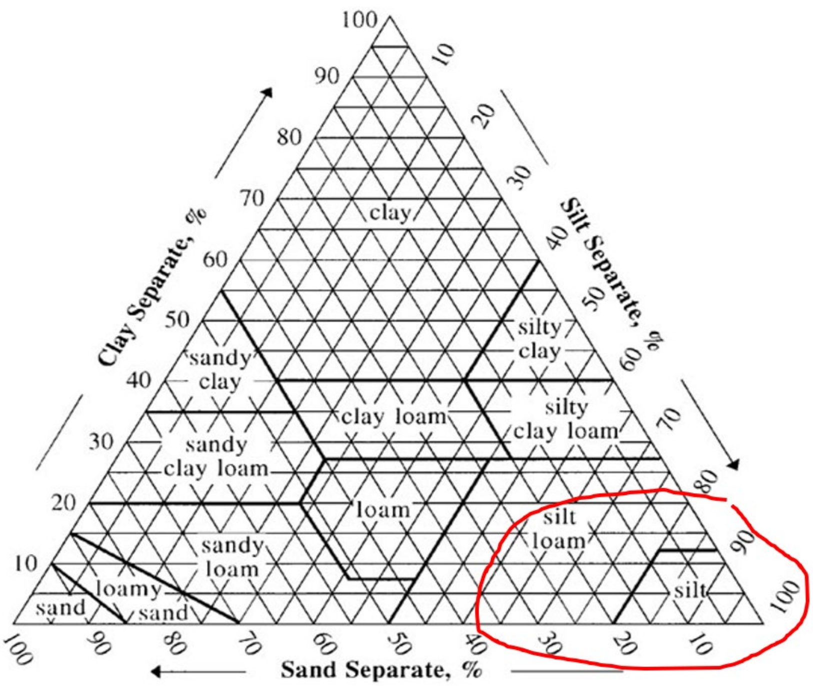
[10]In general, soils that are higher in clay will hold more water and nutrients than soils that are dominated by sand (low in clay). This is because sand particles have very little surface charge and very little surface area. However, decomposed organic matter can hold tremendous amounts of water and nutrients. By increasing the organic matter content by a percent or two (by mass), we can double the amount of water and nutrients that a very coarse-textured soil can hold.

If you'll recall, **silt** particles are smaller than sand grains and larger than clay particles. Because of a silt's relatively small size, a sample of silt will have a decent amount of total surface area, and the pores between silt particles will be relatively small. Thus, in most silty soils, water and gas move much more slowly than they do in sand-dominated soils. However, unlike clay, silt doesn't have much surface charge. For this reason, soils that are high in silt and low in clay can't hold onto much water or nutrients—unless they contain a good deal of organic matter.

The most important property of silt particles is how easy they are to *erode*. In the Soil Erosion guide, you'll learn that erosion occurs when wind or flowing water detaches particles from the soil surface and carries them away. You probably have a sense that larger objects are harder to move than smaller ones. It takes a fast current to move a boulder down a river, and it takes high winds to carry all but the smallest sand grains. Thus, larger particles (i.e. sands) aren't as prone to being removed. You might guess that clay particles would be the most susceptible to erosion, as they are miniscule and very easy to move. However, because clay particles are covered with charged sites, they stick to pretty much anything. Thus, it isn't easy to detach clay particles at the soil surface. In summary, sand particles are hard to carry and clay particles are hard to detach. Without protection, silt particles are sitting ducks for erosion.

In general, soils that are dominated by silt:

- Cannot hold nearly as much water or nutrients as soils higher in clay.
- Do not allow rapid water flow or gas exchange.
- Are easy for roots to push through. Remember, silt grains aren't highly-charged, so they don't stick together like clay particles.
- Are highly-vulnerable to erosion!



<u>Soil Structure</u> refers to the way that individual soil particles stick together in larger masses called *aggregates* or *peds*. Unlike rock fragments, aggregates can be crushed and run through a sieve, although this may require some work if the soil is dry and high in clay. In a soil with a significant amount of clay, a pea-sized aggregate can contain billions of individual particles.

If you pick at the vertical wall of a soil pit with a knife, you can usually pry out some peds. Often, you'll find that aggregates have different shapes and sizes depending on which *horizon* they come from. Granular structure is common in topsoils (A horizons) that contain a lot of organic matter. Blocky and prismatic structure types are common in B horizons. In soils that have been plowed or compacted by vehicles or large animals, we often find platy structure somewhere within the upper 25 cm of soil.

Young soils and highly disturbed soils often don't have any structure. C horizons, by definition, have little or no soil structure. Without structure, the soil will be single-grained if it is low in clay or massive if higher in clay. You'll find single-grained materials in a sandbox; you'll find clods of massive soil in ruts where people have driven on muddy roads.

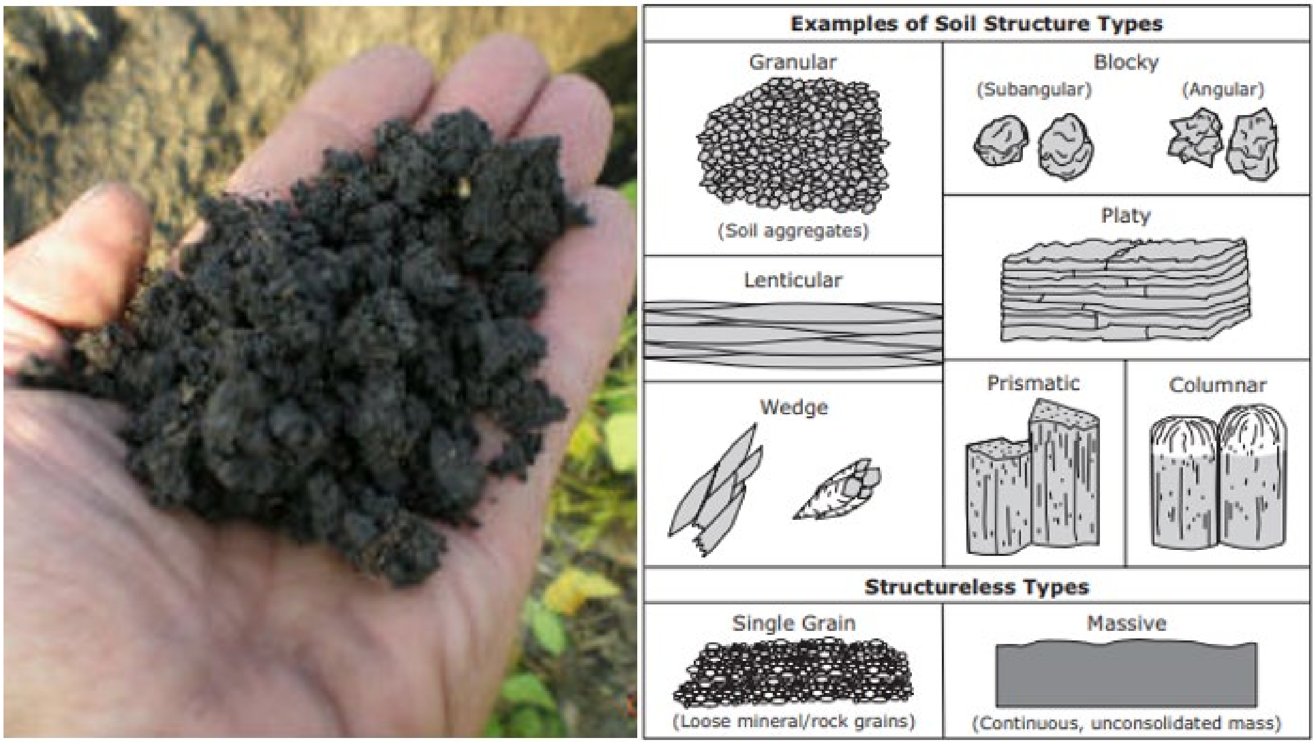


Figure 20. On the left is a sample of topsoil. The smaller aggregates here have granular structure. On the right is a screenshot from the Field Book for Describing and Sampling Soils—which is posted on the Soils Page of the NM Envirothon website, **and** will be provided at the Soils Exam.

Describing soil structure is pretty simple. From a given horizon, pick out a handful of soil with a dull knife, being careful not to destroy peds as you do. If it comes out in one big clod or two, see if you can gently break these clods into smaller aggregates. If you can't, your sample is structureless and massive. Assuming you have some aggregates in your hand (or in your sieve pan), decide which type of structure is most common. Next, determine the structure grade. Consult the chart in the Field Book if necessary. For reference, the handful of sample in Figure 21 has a strong structure grade (aggregates were easy to see before being sampled). Lastly, determine the most common size of the peds. Note that there are different size charts for different structure types.

(SOIL STRUCTURE) - GRADE—

Grade	Code	Criteria
Structureless	0	No discrete units observable in place or in hand sample.
Weak	1	Units are barely observable in place or in a hand sample.
Moderate	2	Units well formed and evident in place or in a hand sample.
Strong	3	Units are distinct in place (undisturbed soil) and separate cleanly when disturbed.

(SOIL STRUCTURE) - SIZE—

Size Class	Code		Criteria: structural unit size [1] (mm)		
	Conv.	NASIS	Granular, Platy [2], (Thickness)	Columnar, Prismatic, Wedge [3] (Diameter)	Angular & Subangular Blocky and Lenticular (Diameter)
Very Fine (Very Thin) [2]	vf (vn)	VF (VN)	< 1	< 10	< 5
Fine (Thin) [2]	f (tn)	F (TN)	1 to < 2	10 to < 20	5 to < 10
Medium (Medium)	m (m)	M (M)	2 to < 5	20 to < 50	10 to < 20
Coarse (Thick) [2]	co (tk)	CO (TK)	5 to < 10	50 to <100	20 to < 50
Very Coarse (Very Thick) [2]	vc (vk)	VC (VK)	≥ 10	100 to<500	≥ 50
Extremely Coarse	ec (—)	EC (—)	—	≥500	—

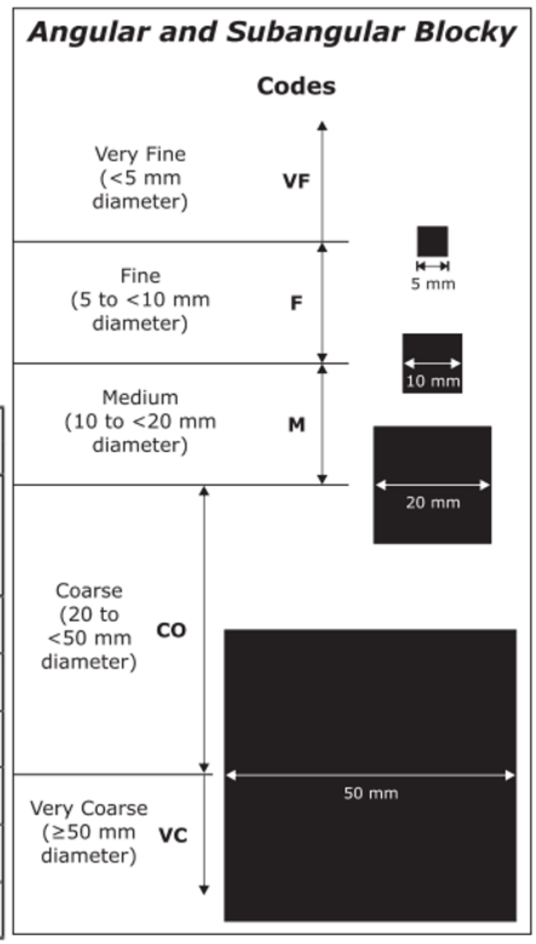


Figure 21. More guides on Structure from the Field Book for Describing and Sampling Soils.

Why does soil structure matter?

As you learned above, plant roots get four basic resources from soil: water, nutrients, O_2, and anchorage. Good structure helps soils provide each of these resources to plants. It also helps soils to prevent erosion, flash-flooding, and drought (more on this in other guides).

In most cases, water enters the soil from above as rain or snowmelt. In order to *infiltrate* the surface and *percolate* through the soil, water must move through spaces (pores) between soil particles. The larger these pores are, the faster water can flow through them. If a soil has no structure and is high in clay and/or silt, it will have very few large (visible) pores. At best, it will have a few channels made by roots and burrowing creatures (worms, ants, centipedes, etc.). However, if the same soil develops good structure, there will be visible spaces between aggregates. These “large” spaces allow water to move downwards rapidly. If this isn’t possible, rain or snowmelt will flow across the soil surface instead (runoff) and cause erosion. Thus, structure helps water to go where the roots are, and helps to keep soil in-place and out of our streams and rivers.

Similarly, O_2 is made by leaves aboveground and consumed by roots and soil organisms underground. Like water, gasses travel more rapidly through larger pores. So, good structure helps roots and soil organisms "breathe."

Finally, roots have a much easier time growing through soil that has large pores. Without good structure, high-clay soils are very hard for roots to push through.

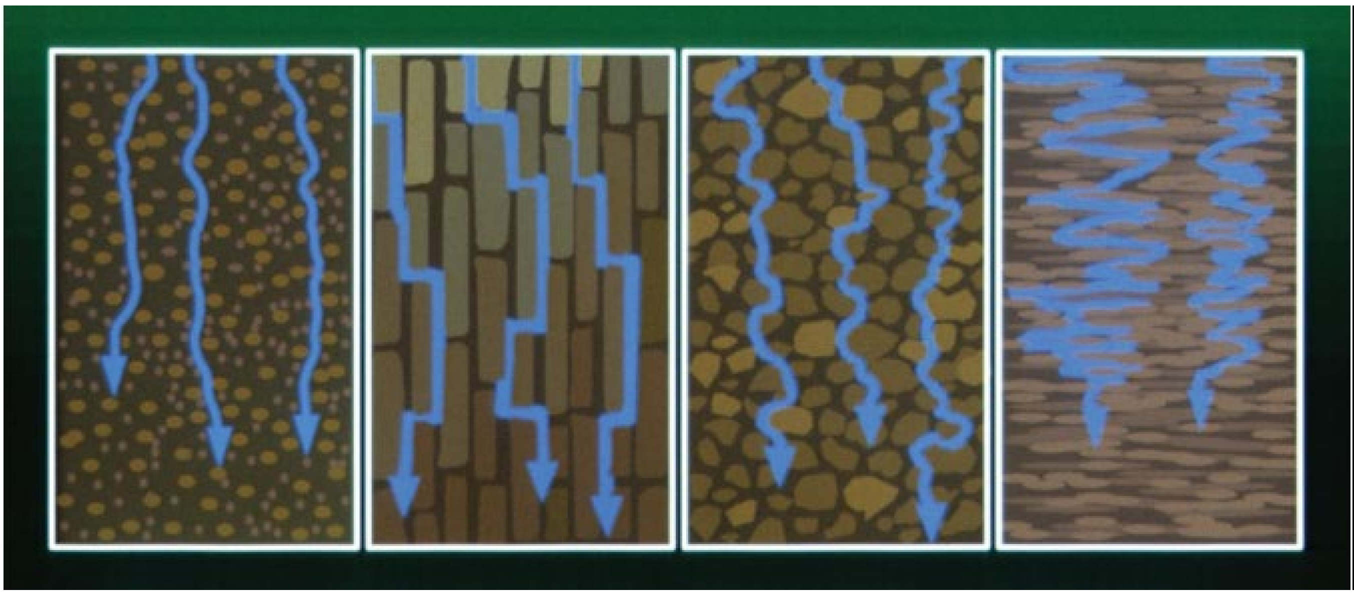


Figure 22. Diagram of soils with different types of structure. On the left is a grassland topsoil with granular structure. This soil has loads of large pores between the small aggregates, which allow water to move rapidly, and nearly straight-down. Second from the left is a soil with prismatic structure. While its aggregates are large and visible pores are far-between, this soil allows a decent amount of flow through these mostly-vertical channels. Next is a soil with subangular blocky structure; this soil will also allow water to percolate at a moderate rate. On the right is a layer that was compacted by plowing. Its aggregates have been squished-down into flat plates. Pore spaces are generally small and mostly horizontal, so it takes a very long time for water to percolate through this layer.

Some factors that improve soil structure are: high soil organic matter, healthy communities of soil organisms, and plant communities that are productive and diverse. Some factors that degrade soil structure are: tillage (e.g. plowing), vehicle traffic, and heavy animal traffic. More information on this in other guides.

Here's a video that sums up much of what we've just discussed on the effects of structure and texture on water movement.

Bulk Density and Porosity

Most of you probably understand the concept of density: the amount of mass in a given volume of a substance—or mass/volume. Liquid water has a density of 1 gram per cubic centimeter (1 g/cm^3). The average mineral soil particle has a density of 2.65 g/cm^3, so it will not float. Remember, though, that soil contains liquids and gases as well as particles. The density of a dry soil sample—known as bulk density (D_b)—tells us how much pore space it contains.

When a soil is compacted (compressed or squished-down) by heavy machinery or animals, its larger pores collapse and its density increases. Aggregates become platy (Figure 22), and pores become tiny. This makes it much harder for water and air to move through the soil, and inhibits root growth (because roots can't push through tiny pores, and because roots need oxygen just like you and I). Soils are most easily compacted when they are moist—because liquid water lubricates soil particles. Soils are hardest to compact when they are either dry or frozen. In many cold, wet parts of the world, timber harvest (logging) is often done in the winter—when soils are frozen solid and covered by snow.

A common mistake is to assume that a soil layer is compacted, and has high bulk density, because it is hard to dig through. Dry soils that are high in clay are very hard to dig through, even when they aren't compacted. In contrast, compacted sand is pretty easy to dig through. Most people assume that clay soils have high bulk density because they feel hard, and because you can't see a lot of pores in most clay soils. However, clay soils contain a tremendous amount of pores that are too small to see (micropores), so they are usually pretty low in bulk density. Sandy soils generally have high bulk densities, even when they aren't compacted, because they don't contain many micropores.

There are two reliable ways to tell if a soil layer is compacted. 1) You can compare its bulk density to a sample with the same texture from a site that you know hasn't been disturbed. This takes time and special equipment. 2) You can look for platy structure. This can be done quickly with a shovel and a knife. A final note: compaction usually occurs near the soil surface (within 25 cm or so). A dense layer that is deeper than this is probably not compacted. It could be soft bedrock like shale, which breaks apart into flat shapes that look platy.

Fun with Math!

There won't be much math on your soils exam, but you should be able to calculate bulk density (Db) and porosity. If someone on your team has passed algebra, this shouldn't be too difficult.

To calculate bulk density, we take a soil sample of known volume, dry it in an oven, and weigh it. A common way to get a sample of known volume is to hammer a metal cylinder into the soil, then carefully dig it out.

Figure 23. A soil sample in a cylinder.

Let's say our cylinder has a height of 9.5 cm and a diameter of 7.8 cm (radius of 3.9 cm). We calculate its volume as follows:

Volume = $\pi r^2 \cdot$ height

$= 3.14 \cdot (3.9\text{ cm})^2 \cdot 9.5\text{ cm}$

$= 3.14 \cdot 15.21\text{ cm}^2 \cdot 9.5\text{ cm}$

$= 453.7143\text{ cm}^3$

$= \underline{45}0\text{ cm}^3$

If I was asked to calculate volume alone, my final answer would be 450 cm^3 (2 significant figures). This is because my measurements of height and diameter only had 2 significant figures. We generally round at the very end of a calculation.

Now, let's say I dried the sample above, put it on a balance, and found its mass to be 658.9 g. I can calculate its bulk density (D_b) as follows:

D_b = mass / volume

$$= \frac{659.8\ \mathrm{g}}{\pi r^\wedge 2\ \cdot\ \mathrm{height}}$$

$$= \frac{659.8\ \mathrm{g}}{3.14\ \cdot\ (3.9\ \mathrm{cm})^2 \cdot\ 9.5\ \mathrm{cm}}$$

$$= \frac{659.8\ \mathrm{g}}{453.7143\ \mathrm{cm}^3}$$

= 1.454219 g/cm^3

= 1.5 g/cm^3

Even though my measurement of mass had 4 significant figures, I round my final answer to 2 significant figures—the smallest number of significant figures in my measurements (height and diameter).

Porosity is defined as the percentage of a soil's volume that contains liquids and gases rather than solids. In other words, porosity is a soil's percentage of pore space. Calculating porosity is pretty simple if we know the density of soil particles and the bulk density of the soil. In mineral soils, we generally assume that the average particle has a density of 2.65 g/cm^3.

Let's say we have a sample of mineral soil with a bulk density of 1.25 g/cm^3 (which is relatively low). We'd calculate its porosity as follows:

$$Porosity = \left[1 - \frac{bulk\ density}{average\ particle\ density}\right] X\ 100$$

$$= \left[1 - \frac{1.25\,\frac{g}{cm^3}}{2.65\,\frac{g}{cm^3}}\right] x\ 100$$

= [1 – 0.4717] x 100

= 52.8%

So most of the volume in this sample (52.8%) is pore space! Note that I've rounded to 3 significant figures here because both values I started with had 3 significant figures.

A final note on calculations, units, and significant figures: Your math or science teacher should be more than happy to help you with these.

That's it for your introduction to soils. If you skipped the numbered[1] footnotes or the captions to the images, I suggest you go back and read these. Otherwise, it's time to start studying the other guides on the Soils Page. I suggest reading these in numerical order. Finally, I've provided a number of links to videos and websites, which you'll find in this guide and others. Enjoy!

Image Credits

Figure 1. Photo by Logan Peterson
Figure 2. Photos by Logan Peterson
Figure 3. Photos by Logan Peterson
Figure 4. Photos by Logan Peterson
Figure 5. Photos by Logan Peterson
Figure 6. Photo by Phillip Schoenberger, NRCS
Figure 7. Photo by Aaron Miller, NRCS
Figure 8. Source: https://www.wcc.nrcs.usda.gov/factpub/aib326.html
Figure 9. Source:
http://cse.ssl.berkeley.edu/artemis/mission_sunearth_closeup1.html
Figure 10. Photos by Logan Peterson
Figure 11. Photo by Logan Peterson
Figure 12. Source: https://content.ces.ncsu.edu/extension-gardener-handbook/1-soils-and-plant-nutrients
Figures 13 and 14. Adapted from:
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167
Figure 15. Photo by Logan Peterson
Figure 16. Photo by Logan Peterson
Figure 17. Sources:
https://www.khanacademy.org/science/high-school-biology/hs-biology-foundations/hs-water-and-life/v/hydrogen-bonding-in-water
Figure 18. Illustration by Logan Peterson
http://content.ces.ncsu.edu/extension-gardener-handbook/1-soils-and-plant-nutrients
Figure 19. Source:
http://clay.uga.edu/courses/8550/CM19.html
Figure 20. Sources:
https://www.extension.umn.edu/agriculture/soils/
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054184
Figure 21. Source:
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054184
Figure 22. Source:
nrcs.usda.gov
Central photo and illustrations by Logan Peterson
Figure 23. Photo by Logan Peterson