Particle Size Distribution Protocol

Purpose

To measure the distribution of different sizes of soil particles in each horizon of a soil profile

Overview

Using dry, sieved soil from a horizon, students mix the soil with water and a dispersing solution to completely separate the particles from each other. Students shake the mixture to fully suspend the soil in the water. The soil particles are then allowed to settle out of suspension, and the specific gravity and temperature of the suspension are measured using a hydrometer and thermometer. These measurements are taken after 2 minutes and 24 hours.

Student Outcomes

Students will be able to apply laboratory tests for particle size distribution to soil samples. Students will be able to apply mathematical formulas to calculate soil particle size distribution as a percent of sand, silt, and clay. Students will be able to relate soil particle size to suspensions, specific gravity, and settling rates.

Science Concepts

Earth and Space Sciences

Earth materials are solid rocks, soil, water, biota, and the gases of the atmosphere.
Soils have properties of color, texture, structure, consistence, density, pH, fertility; they support the growth of many types of plants.
Soils consist of minerals (less than 2 mm), organic material, air and water.

Physical Sciences

Objects have observable properties.

Scientific Inquiry Abilities

Identify answerable questions.
Design and conduct an investigation.
Use appropriate tools and techniques including mathematics to gather, analyze, and interpret data.
Develop descriptions and explanations, predictions and models using evidence.
Communicate procedures and explanations.

Time

3 class periods

Level

Middle and Secondary

Frequency

Three times for each horizon in a soil profile

Materials and Tools

Oven-dried, sieved soil (sieved with a Number 10 sieve with 2 mm mesh attached to a frame)
500-ml graduated cylinders (minimum of three recommended)
Distilled water
1 empty plastic 2-liter bottle with top
Soil Dispersing Reagent (Sodium Hexametaphosphate or non-sudsing dish detergent such as is used in an automatic dishwasher)
Spoon or glass rod for mixing
250 mL or larger containers (minimum of three recommended)
Thermometer
Hydrometer
100-mL graduated cylinder
Pencil or pen
Squirt bottle for washing soil out of beaker
Meter stick
Plastic wrap (or other cover for cylinder)
Balance accurate to 0.1 g
Soil Particle Size Distribution Data Sheet

Preparation

Dry and sieve soil samples, and store them in sealed containers.
Collect required equipment.
Calibrate the balance to 0.1.
Prepare dispersing solution.

Prerequisites

Soil Characterization Protocol

Particle Size Distribution–Introduction

The amount of each particle size group (sand, silt, or clay) in a soil is known as the soil particle size distribution. The texture measurement in a soil characterization is only an approximate measure of the amount of each particle size group in a soil sample. By performing the *Particle Size Distribution Protocol*, these estimates can be checked by measuring quantitatively the amount of each of the particle sizes in a sample.

Sand is the largest soil particle size (2.0 mm - 0.05 mm), silt is intermediate in size (0.05 mm - 0.002 mm), and clay is the smallest (less than 0.002 mm). Particles greater than 2 mm are called stones, rocks or gravels and are not considered to be soil material.

2.0 mm	0.05 mm	0.002 mm	
Stones	Sand	Silt	Clay

When a mixture of particle sizes is suspended in a column of water, the heavy large particles settle first. When a soil sample is stirred or shaken, sand particles will settle to the bottom of the cylinder after 2 minutes, while the clay and silt size particles will stay in suspension. After 24 hours, the silt particles will settle, leaving only the clay in suspension.

By using tables and charts, the exact percentages of sand, silt, and clay can be calculated and the textural class name can be determined for a soil sample.

Teacher Support

Preparation

Before conducting the *Particle Size Distribution Protocol* have the students do the following activity:

1. Pour a mixture of sand, silt and clay into a glass jar until it is about 1/3 full.
2. Fill the jar with water.
3. Put a lid on the jar and shake it.
4. Observe what happens to the soil particles.

Teachers can relate student observations to the *Particle Size Distribution Protocol* by discussing how results will differ before and after a dispersing solution is added.

Before conducting the *Particle Size Distribution Protocol*, have students measure the texture of the soil horizon by feel.

Explain how to use a hydrometer and have students practice taking measurements.

Have students practice mixing a soil sample. Use plain water, a 500 mL graduated cylinder, and a plastic wrap cover.

Make sure students understand the concept of Specific Gravity. (See next section for definition.)

Measurement Procedures

Sand, silt, and clay particles are rarely found separately in soils. Instead, they are usually clumped together in aggregates called "peds." A "dispersing" solution is used to break up the peds and separate the particles from each other.

The amounts of sand, silt and clay are measured according to the rate at which each particle type settles in water. If the particles are not separated completely from each other, results will be incorrect because aggregates of smaller particles will settle like larger particles.

A hydrometer measures the specific gravity of a liquid or suspension. Specific Gravity is defined as the mass of a liquid relative to the mass of an equal volume of water. In pure distilled water at 20˚ C, the hydrometer reading will be 1.000. When soil is suspended

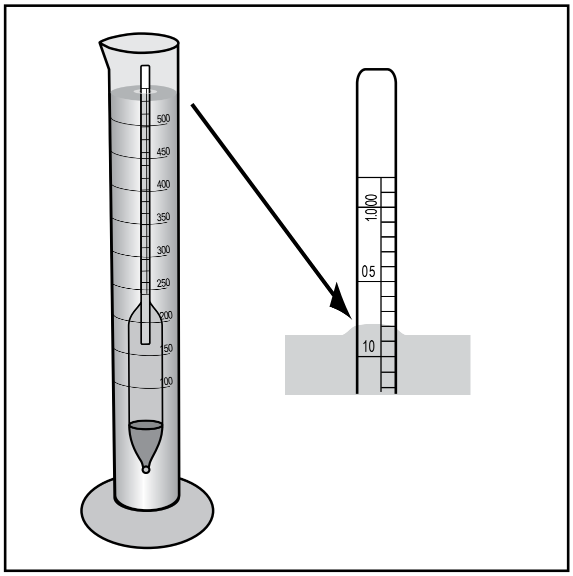


Figure-SO-PA-1

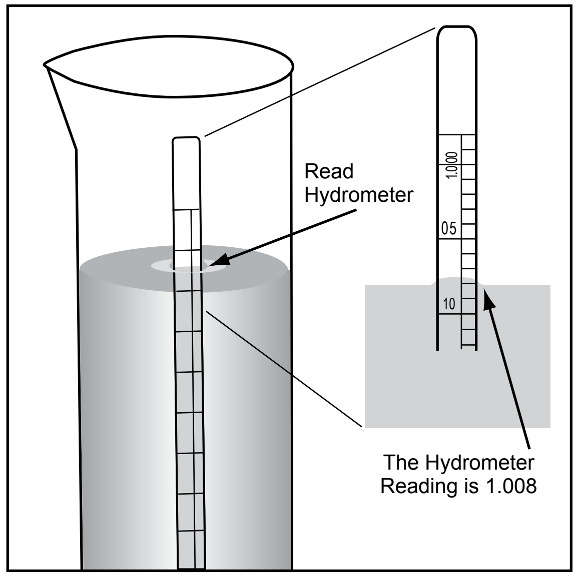


Figure-SO-PA-2

in the water, the specific gravity, and therefore the hydrometer reading, increases.

In order to measure the specific gravity of the soil/water suspension for this protocol, the hydrometer is placed in the soil suspension 30 seconds before the reading is to be made to allow the hydrometer to become still in the water. At the appointed time (at 2 minutes and again at 24 hours), the hydrometer is read at the level where the number scale touches the surface of the water.

To read the new value, always start with 1.0 and then add the last 2 numbers based on the position on the hydrometer. For example, the hydrometer reading in Figure SO-PA-1 and Figure SO-PA-2 is: 1.008

The initial sample preparation for this protocol may be done in advance. The protocol itself can be done in two class periods on successive days.

Managing Materials

The ideal material for dispersing soil is Sodium Hexametaphosphate. This compound can be purchased as "Soil Dispersing Material" from GLOBE equipment distributors or from a chemical supply house. An alternative for dispersing soil particles is a non-sudsing soap used for washing dishes, such as standard automatic dishwasher soap. It is important that this soap contains sodium and phosphate and does not produce suds that will make the hydrometer measurements difficult.

GLOBE wants students to do this protocol three times for each soil horizon. If teachers have three 500 mL cylinders and three 250 mL containers (jars or beakers), then students can measure three samples at the same time. If teachers have more equipment, students can measure multiple horizons at the same time.

Questions for Further Investigation

What natural changes could alter the particle size distribution of a horizon?

How does the particle size distribution affect the types of vegetation that can grow on a soil?

How does climate affect the particle size distribution of a horizon?

How does parent material affect the particle size distribution of a horizon?

How does particle size distribution affect soil temperature?

How does particle size distribution affect soil fertility?

How does particle size distribution affect soil moisture?

How do streams, rivers, and floodwaters affect the textures of soil in river deltas?

Soil Particle Size Distribution

Lab Guide

Task

To determine the particle size distribution for each horizon in a soil profile

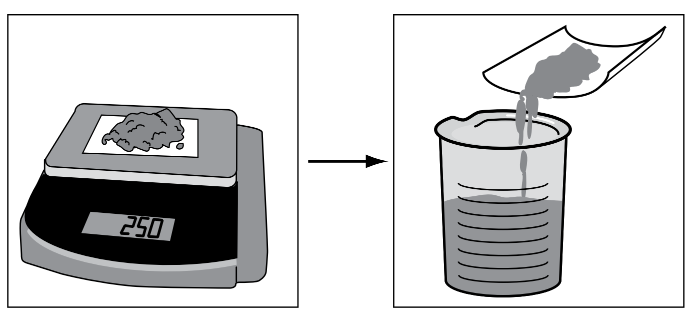
What You Need

- ❑ Dry, sieved soil
- ❑ 2 Liters distilled water
- ❑ Three 250 mL or larger, beakers
- ❑ 1 empty plastic 2 liter bottle
- ❑ Hydrometer
- ❑ Thermometer
- ❑ Plastic wrap (or other cover for cylinder)
- ❑ *Particle Size Distribution Data Sheet*
- ❑ 100-mL graduated cylinder
- ❑ Pencil or pen
- ❑ Soil dispersing reagent
- ❑ 500-mL clear cylinders
- ❑ Squirt bottle for washing soil out of beaker
- ❑ Meter stick
- ❑ Balance accurate to within 0.1 g

In the Lab

1. Prepare the dispersing solution by mixing 50 g of Sodium Hexametaphosphate (or other soil dispersing agent such as non-sudsing dishwater detergent) in 1 L of distilled water. Stir or shake until the dispersing agent has completely dissolved.

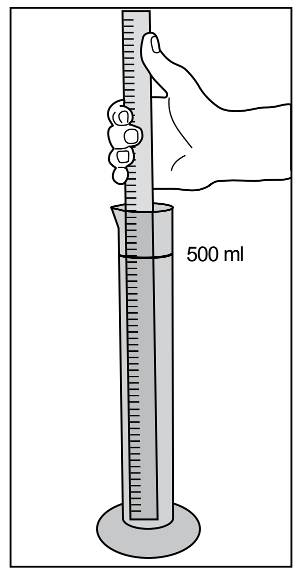
2. Weigh 25 g of dried, sieved soil and pour it into a 250 mL or larger container.



3. Add 100 mL of the dispersing solution and 50 mL of distilled water to the beaker. Stir vigorously with a spoon or stirring rod for at least one minute. Be sure the soil is thoroughly mixed and does not stick to the bottom of the beaker. Do not let any of the soil suspension spill out the top. Rinse any soil off the spoon or stirring rod into the container using a little distilled water.

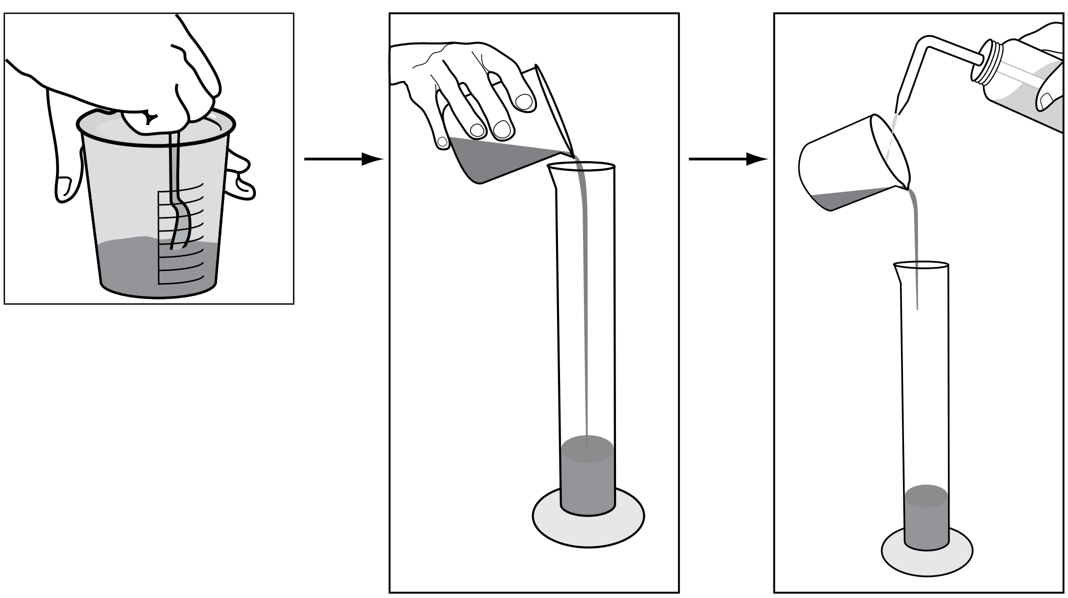
4. While the soil suspension is sitting, measure the distance between the base and the 500 mL mark of the cylinder. Place the meter stick inside the cylinder to get this measurement.

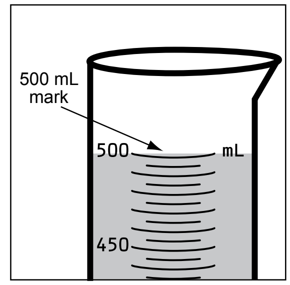
   Read the temperature at which your hydrometer has been calibrated (such as 15.6° C [60° F] or 20° C). This value is found on the body of the hydrometer.



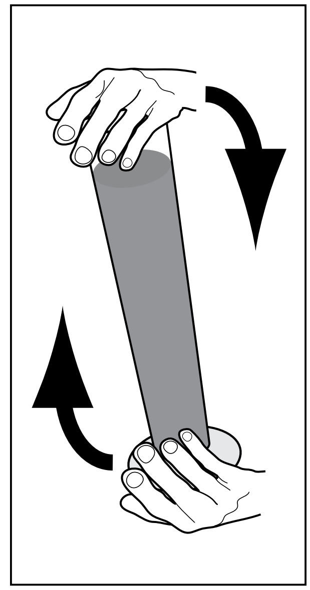
5. Complete the top section of the Particle Size Distribution Data Sheet.

6. After at least 24 hours, stir the suspension in the container and pour it into a 500 mL graduated cylinder. Use a squirt bottle to rinse all soil out of the container and into the cylinder.

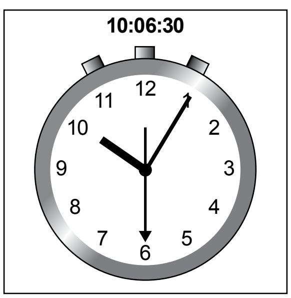




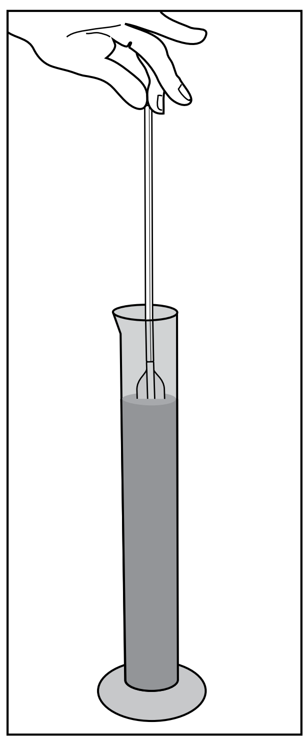
7. Add enough distilled water to fill the cylinder to the 500 mL mark.

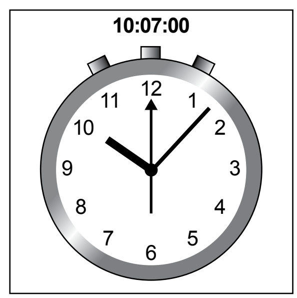


8. Securely cover the top of the cylinder using plastic wrap or other cover. Place your hand over the mouth of the cylinder and mix the soil suspension vigorously by rotating the covered cylinder hand-over-hand at least 10 times. Be sure that the soil is thoroughly mixed in the suspension and that no soil is sticking to the bottom of the cylinder. Also, try not to let any of the soil suspension leak out of the top of the cylinder.
9. Gently set the cylinder down in a safe place and immediately begin timing with a stopwatch or clock that has a second hand.
10. Record the time that the cylinder was set down to the second. (In the example to the right, the starting time is: 10:05 and 0 seconds.)
11. After **1 minute and 30 seconds** has passed, carefully lower (do not drop) the hydrometer into the cylinder and let it float in the soil suspension. Carefully steady the hydrometer to stop its bobbing motion.



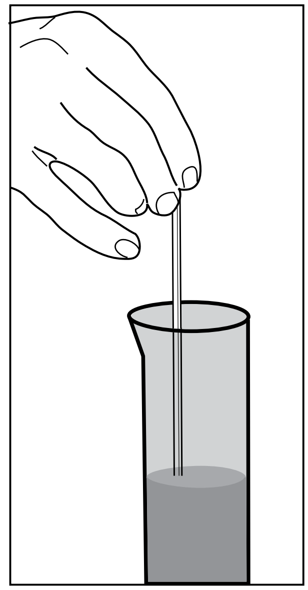
Time Cylinder was set down





Time Hydrometer is read

12. At exactly **2 minutes** after the cylinder was set down, read the line on the hydrometer that is closest to the surface of the soil suspension and record that number on the *Particle Size Distribution Data Sheet*.



13. Remove the hydrometer, rinse it away from the cylinder, dry it and gently put it down in a safe place.

14. Suspend the thermometer in the suspension for about one minute.

15. At the end of a minute, lift the thermometer from the suspension enough so that you can read the temperature and record the result on the *Particle Size Distribution Data Sheet*.

16. Rinse the thermometer off and dry it.

17. Leave the cylinder undisturbed for 24 hours. After 24 hours, take another hydrometer and temperature reading. Record the results on the *Particle Size Distribution Data Sheet*. (The 24-hour hydrometer reading should be 24 hours from the initial timing start.)

18. Discard the soil suspension by pouring it into a special pail and spill the contents outside in a special place for discarding soil materials.

Particle Size Distribution Protocol – Looking at the Data

Note: If you need help, see the example following this section.

A. Calculate the Percent Sand, Silt, and Clay in Your Soil Sample Using the Following Work Sheet:

1. In A, enter the 2-minute hydrometer reading.	A. 2 minute hydrometer reading ______________
2. In B, enter the 2-minute temperature reading.	B. 2 minute temperature reading ______________ ˚C
3. In C, enter the grams of soil/L in suspension using the hydrometer reading in A and converting it with Table SO-PA-1 following step 18.	C. Grams/L of soil (silt + clay) from table _______ g
4. In D, multiply the difference between the temperature reading (from B) and 20˚ C by 0.36 to correct for temperatures above or below 20˚ C	D. Temperature correction [0.36 x (B-20˚ C)] [0.36 x (B ______ - 20)] = ________________ g
5. In E, enter the sum of grams of soil/L (from C) and the temperature correction (from D).	E. Corrected silt and clay in suspension (C+D) C ______ + D ______ = ___________________ g
6. In F, multiply the value for g/L of soil from E by 0.5 to correct for the fact that you have used a 500 mL cylinder.	F. Grams of soil (silt + clay) in 500 mL (E ______ x 0.5) = _______________________ g
7. In G, find the grams of sand in your sample, by subtracting grams of silt + clay in suspension (F) from the initial 25 g total soil in the sample.	G. Grams of sand in sample (25 g – F______) = _______________________ g
8. In H, determine the exact percentage of sand, by dividing grams of sand by the total amount of soil (25 g) and multiplying by 100.	**H. Percent Sand** [(G ______ / 25) x 100]= __________________ %
9. In I, enter the hydrometer reading measurement at 24 hours.	I. 24-hour hydrometer reading _______________
10. In J, enter the 24-hour temperature reading.	J. 24-hour temperature reading ___________ ˚C
11. In K, enter the grams of soil/L in suspension at 24 hours (clay) using the hydrometer reading in I and converting it with Table SO-PA-1 following step 18.	K. Grams/L of soil (clay) from table ____________ g

12. In L, multiply the difference between the temperature reading at 24 hours (from J) and 20˚ C by 0.36.

L. Temperature correction [0.36 x (B-20° C)]
[0.36 x (J ______ - 20˚ C)] = ___________ g

13. In M, enter the sum of grams of soil/L (from K) and the temperature correction (from L).

M. Corrected clay in suspension (C+D)
K ______ + L ______ = ________________ g

14. In N, multiply the number in M by 0.5 to correct for the fact that you have used a 500 mL cylinder.

N. Grams of soil (clay) in 500 mL
(M ______ x 0.5) = ___________________ g

15. In O, determine the exact percentage of clay, by dividing grams of clay in suspension (from N) by the total amount of soil (25 g) and multiplying by 100.

O. Percent Clay
[(N ______ / 25) x 100]= ______________ %

16. In P, determine the grams of silt by adding the grams of sand (from G) and grams of clay (from N) and subtracting the result from 25.

P. Grams of silt
[25 – (G ______ + N ______)] = ___________ g

17. In Q, determine the exact percentage of silt, by dividing grams of silt by the total amount of soil (25 g) and multiplying by 100.

Q. Percent Silt
[(P ______ / 25) x 100]= ______________%

18. See the Textural Triangle in Figure SO-PA-3 to determine the Soil Texture

Sample Number 1:
Sand: ______ % Silt: ______ % Clay ______ %
Soil Texture Class:____

Sample Number 2:
Sand: ______ % Silt: ______ % Clay ______ %
Soil Texture Class: ____

Sample Number 3:
Sand: ______ % Silt: ______ % Clay ______ %
Soil Texture Class: ____

Table SO-PA-1: Conversion Table (specific Gravity to Grams of Soil/L)

Specific Gravity	Grams of Soil/L	Specific Gravity	Grams of Soil/L	Specific Gravity	Grams of Soil/L
1.0024	0.0	1.0136	18.0	1.0247	36.0
1.0027	0.5	1.0139	18.5	1.0250	36.5
1.0030	1.0	1.0142	19.0	1.0253	37.0
1.0033	1.5	1.0145	19.5	1.0257	37.5
1.0036	2.0	1.0148	20.0	1.0260	38.0
1.0040	2.5	1.0151	20.5	1.0263	38.5
1.0043	3.0	1.0154	21.0	1.0266	39.0
1.0046	3.5	1.0157	21.5	1.0269	39.5
1.0049	4.0	1.0160	22.0	1.0272	40.0
1.0052	4.5	1.0164	22.5	1.0275	40.5
1.0055	5.0	1.0167	23.0	1.0278	41.0
1.0058	5.5	1.0170	23.5	1.0281	41.5
1.0061	6.0	1.0173	24.0	1.0284	42.0
1.0064	6.5	1.0176	24.5	1.0288	42.5
1.0067	7.0	1.0179	25.0	1.0291	43.0
1.0071	7.5	1.0182	25.5	1.0294	43.5
1.0074	8.0	1.0185	26.0	1.0297	44.0
1.0077	8.5	1.0188	26.5	1.0300	44.5
1.0080	9.0	1.0191	27.0	1.0303	45.0
1.0083	9.5	1.0195	27.5	1.0306	45.5
1.0086	10.0	1.0198	28.0	1.0309	46.0
1.0089	10.5	1.0201	28.5	1.0312	46.5
1.0092	11.0	1.0204	29.0	1.0315	47.0
1.0095	11.5	1.0207	29.5	1.0319	47.5
1.0098	12.0	1.0210	30.0	1.0322	48.0
1.0102	12.5	1.0213	30.5	1.0325	48.5
1.0105	13.0	1.0216	31.0	1.0328	49.0
1.0108	13.5	1.0219	31.5	1.0331	49.5
1.0111	14.0	1.0222	32.0	1.0334	50.0
1.0114	14.5	1.0226	32.5	1.0337	50.5
1.0117	15.0	1.0229	33.0	1.0340	51.0
1.0120	15.5	1.0232	33.5	1.0343	51.5
1.0123	16.0	1.0235	34.0	1.0346	52.0
1.0126	16.5	1.0238	34.5	1.0350	52.5
1.0129	17.0	1.0241	35.0	1.0353	53.0
1.0133	17.5	1.0244	35.5	1.0356	53.5
				1.0359	54.0
				1.0362	54.5
				1.0365	55.0

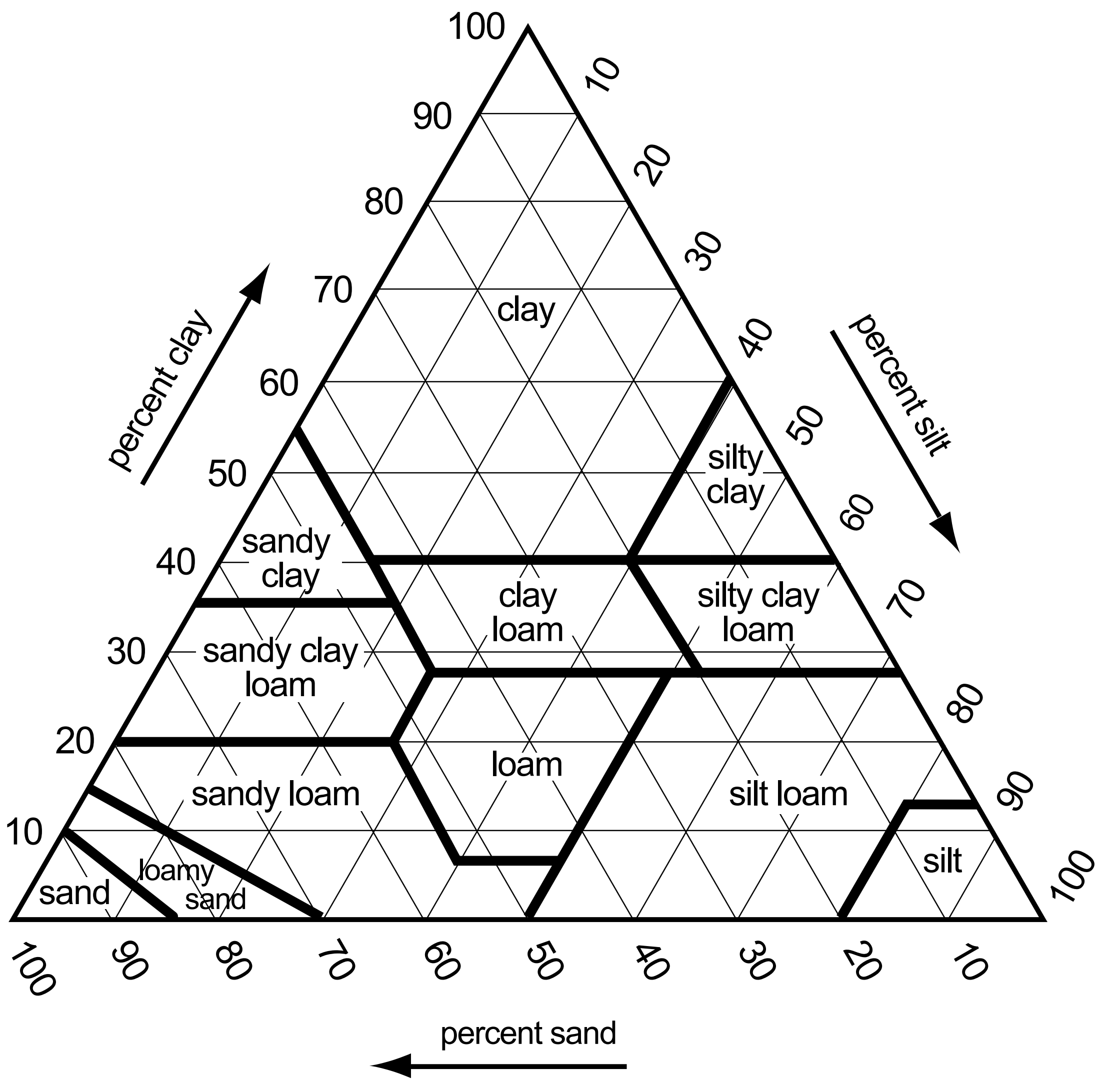
B. Determine the Textural Class of your Soil Sample using the Textural Triangle:

Soil Scientists have created classes that break the distribution of particle sizes (soil textures) into 12 categories. The textural triangle (Figure SO-PA-3) is one of the tools soil scientists use to visualize and understand the meaning of soil texture names. This textural triangle is a diagram that shows how each of these 12 textures is classified based on the percent of sand, silt, and clay in each.

Follow these steps to determine the textural class name of your soil sample:

1. Place a plastic sheet or tracing paper over the textural triangle.
2. Place the edge of a ruler at the point along the base of the triangle that represents the percent of sand in your sample. Position the ruler on the line that slants in the direction that the numbers are slanting for percent sand and draw a line along the ruler edge.
3. Place the edge of the ruler at the point along the right side that represents the percent silt in your sample. Position the ruler on the line that slants in the direction that the numbers are slanting for percent silt.
4. Mark the point along the ruler edge where the two line cross. Place the top edge of one of the rulers on the mark, and hold the ruler parallel to the horizontal lines. The number on the left should be the percent of clay in the sample. Note that the sum of the percent of sand, silt, and clay should sum to 100%.
5. The descriptive name of the soil sample (textural class) is written in the shaded area where the mark is located. If the mark should fall directly on a line between two descriptions, record both names.

Figure SO-PA-3: Textural Triangle



An Example of Student Research

A. Calculating the Percent Sand, Silt and Clay for their Soil Sample

Students recorded the following 2 minute and 24 hour hydrometer readings:

	Specific Gravity	Temperature
2 minutes	1.0125	21.0
24 hours	1.0089	19.5

For each hydrometer reading of specific gravity, they converted to grams/liter of soil from the conversion table, and corrected for temperature.

For the 2 minute reading

The specific gravity reading is closest to 1.0126, which equals 16.5 grams of silt and clay per liter in suspension. They corrected this value for temperature. Since the temperature reading was 1 degree higher than 20˚ C, they added 0.36 to the 16.5 grams/liter:

$$16.5 + 0.36 = 16.86 \text{ g/L}$$

Next, they multiplied 16.86 g/L by 0.5 L (which was the volume of water used in the protocol) to change from grams/liter to grams:

$$16.86 \times 0.5 = 8.43 \text{ (8.4 g)}$$

This is the amount of silt and clay in suspension.

They determined the amount of sand, by subtracting 8.4 g from the original amount of soil added in the Protocol (25.0 g):

$$25.0 \text{ g} - 8.4 \text{ g} = 16.6 \text{ g of sand}$$

They calculated the percent of sand in the sample by dividing 14.1 g by the original amount of soil added in the Protocol (25.0 g) and multiplied by 100 to get percent:

$$(16.6 \text{ g}/25.0 \text{ g}) \times 100 = 66.4\% \text{ sand}$$

For the 24 hour reading

The specific gravity reading was 1.0089, which they read directly off the chart as 10.5 g/L. This value represents the amount of clay per liter in suspension. They then corrected the 10.5 g/L for temperature. Since the temperature reading was 0.5 degrees lower than 20° C, they subtracted 0.36 x 0.5 from the 10.5 grams/liter:

$$0.36 \times 0.5 = 0.18$$

$$10.5 - 0.18 = 10.32 \text{ g/L}$$

Next, they multiplied 10.32 g/L by 0.5 L (which was the volume of water used in the protocol) to change from grams/liter to grams:

10.32 x 0.5 = 5.16 (rounded to 5.2 g)

5.2 g is the amount of clay that was in the original 25 g of soil used in the Protocol.

They calculated the percent of clay in the sample by dividing 5.2 g by the original amount of soil added in the Protocol (25.0 g):

(5.2 g/25.0 g) x 100 = 20.8% clay

They calculated the amount of silt by adding the grams of sand to the grams of clay, and subtracting that sum from the original amount of sample (25 g):

16.6 g (sand) + 5.2 g (clay) = 21.8

25 g - 21.8 g = 3.2 g silt

which they converted to percent by dividing by 25:

For this sample, the final result was:

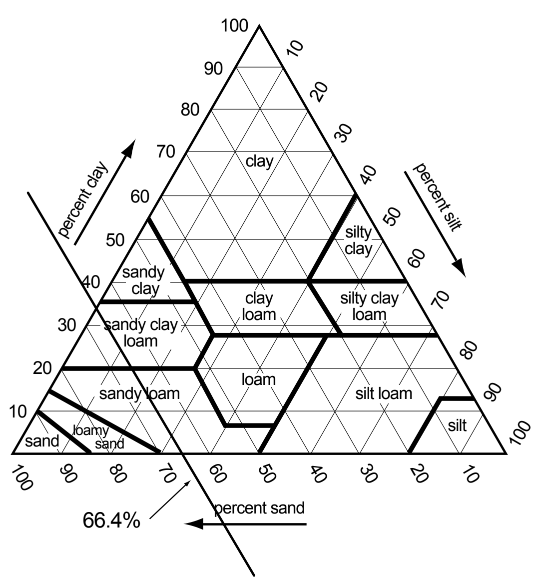
% Sand	% Silt	% Clay
66.4	12.8	20.8

B. Determining the Textural Class of Their Soil Sample

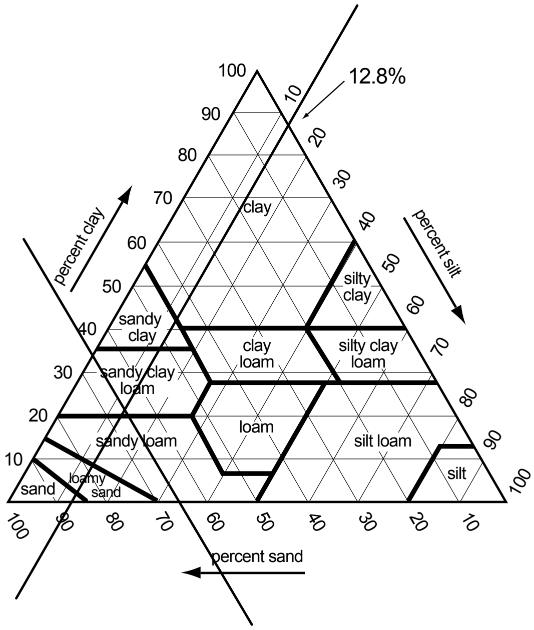
The students determined the textural class of their soil sample using the Textural Triangle.

1. First, they placed tracing paper over their Textural Triangle.

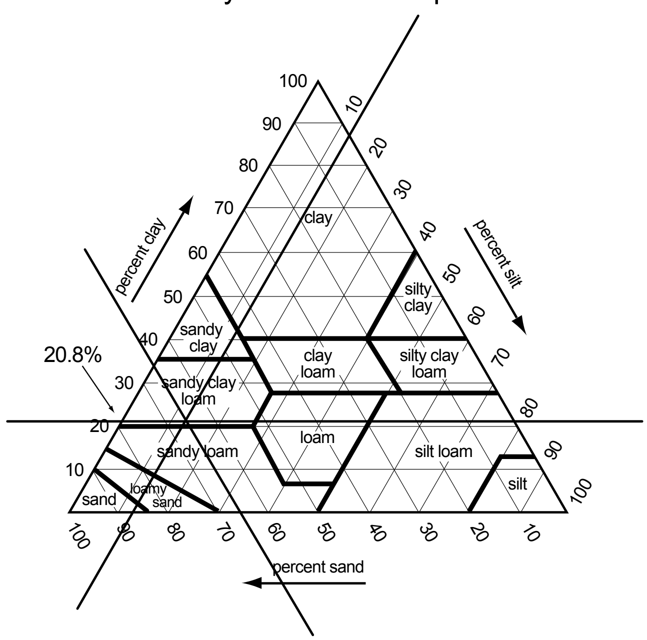
2. Second, they placed the edge of a ruler along the base of the Textural Triangle at the 66.4% sand mark and drew a line.



3. Third, they placed the edge of the ruler along the right side of the textured triangle at the 12.8% silt mark and drew a line.



4. Fourth, they marked the point where the two lines crossed. Using their ruler, they matched this point with the % clay from their sample.



5. Finally, they determined the textural class of their sample to be Sandy Clay Loam by reading the class name where the two drawn lines met.

% Sand	% Silt	% Clay	Soil Texture Class
66.4	12.8	20.8	Sandy Clay Loam

Soil Texture Practice Sheet

Use the following numbers to determine the soil texture name using the textural triangle. In the places where a number is missing, fill in the blanks. **Note:** the sum of percent sand, silt and clay should always add up to 100 percent:

	% Sand	% Silt	% Clay	Texture Name
a.	75	10	15	sandy loam
b.	10	83	7	
c.	42		37	
d.		52	21	
e.		35	50	
f.	30		55	
g.	37		21	
h.	5	70		
i.	55		40	
j.		45	10	

Answers: b. silt loam; c. 21, clay loam; d. 27, silt loam; e. 15, clay; f. 15, clay; g. 42, loam; h. 25, silt loam; i. 5, sandy clay; j. 45, loam.

For Advanced Students

Stoke's Law: To Calculate the Settling Time of Soil Particles

In the Soil Particle Size Distribution Protocol, the readings of the hydrometer are taken at a very specific time to allow either the sand or silt to settle in the cylinder. In order to determine this time for each size particle, we use an equation derived from Stoke's Law. Stoke's Law describes how fast (the velocity) a particle will settle as a function of its diameter and the properties of the liquid in which it is settling. Once this velocity is known, you can calculate the time required for a particle of a certain diameter to settle in a given depth of water.

This activity may be interesting for students for a number of reasons. Students may want to investigate how the settling rates of different particle sizes differ under conditions that are different from the ones used in the GLOBE protocol. For example, if a larger cylinder is used, or the temperature was much hotter or colder, how long would it take for the sand, silt, and clay particles to settle? In the natural world, soil particles carried by moving water settle out when the water stops moving and becomes still. By using the Stoke's Law equation, students can understand the relationships between the amount of sand, silt, and clay carried in the water, the amount of turbidity, and the time it would take for the particles (especially clay) to settle to the bottom and make the water clear.

Stoke’s Law can be written in the form of the following equation:

$$V = kd^2$$

where:

V = settling velocity (in cm/second)

d = particle diameter in cm (such as 0.2 cm - 0.005 cm for sand, 0.005 cm- 0.0002 cm for silt, and <0.0002 cm for clay)

k = a constant which depends on the liquid in which the particle is settling, particle density, the force of gravity, and the temperature (8.9×10^3 cm^{-1} sec^{-1} for soil in water at 20° C).

Example

Suppose you wanted to calculate the amount of time it would take a particle of fine sand (0.1 mm) to settle. The distance between the 500 mL mark on your graduated cylinder and the base of the cylinder is about 27 cm.

1. First, convert the diameter of the particle from mm to cm.

$$0.1 \text{ mm} \times 1 \text{ cm}/10 \text{ mm} = 0.01 \text{ cm}$$

2. Using the equation above, plug in values for the diameter of the particle, square it, and multiply by the constant.

$$V = 8900 \times (0.01)^2$$
$$= 0.89 \text{ cm/second}$$

3. Next, divide the distance between the 500 mL mark and the base on your cylinder by the velocity calculated in step 2.

$$27 \text{ cm}/0.89 \text{ cm second}^{-1} = 30.33 \text{ seconds}$$

Thus, it would take about 30 seconds for fine sand with a diameter of 0.1 mm to settle to the base of the 500 mL cylinder.