POROSITY AND PERMEABILITY

Porosity and permeability are related properties of any rock or loose sediment. Both are related to the number, size, and connections of openings in the rock. More specifically, porosity of a rock is a measure of its ability to hold a fluid. Mathematically, it is the open space in a rock divided by the total rock volume (solid and space). **Permeability** is a measure of the ease of flow of a fluid through a porous solid. A rock may be extremely porous, but if the pores are not connected, it will have no permeability. Likewise, a rock may have a few continuous cracks which allow ease of fluid flow, but when porosity is calculated, the rock doesn't seem very porous.

Directions: In this activity, you will use loose sediment of varying sizes to demonstrate the relationships between porosity and permeability. Answer the following questions before you begin your experiment.

Purpose:

What is the purpose of this experiment?

(Answers will vary but encourage students to be specific. The purpose of this experiment is to demonstrate the relationship between porosity and permeability.)

Hypothesis:

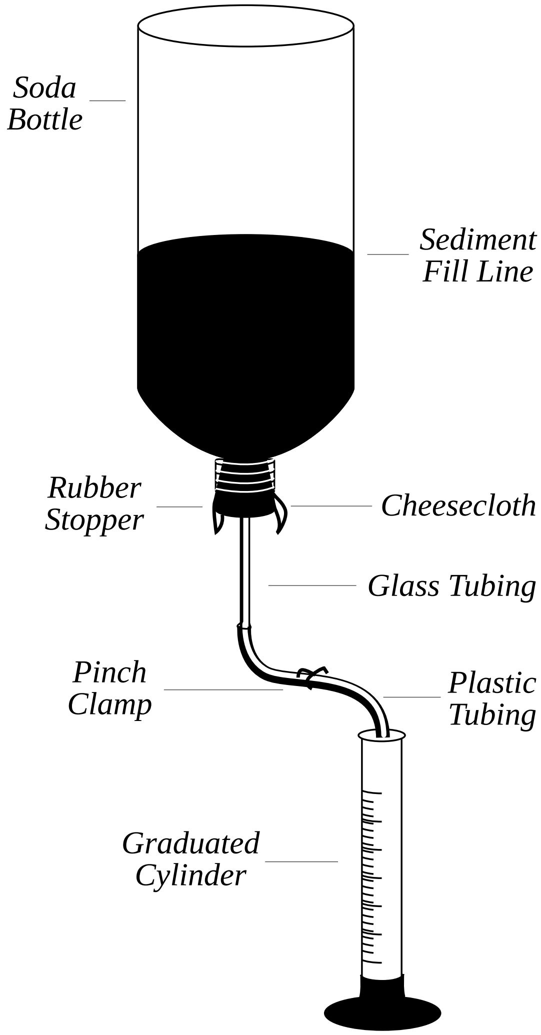
What do you expect to find as the relationship between porosity and permeability?

(Answers will vary but encourage students to be specific.)

Materials:

1-liter soda bottle
2 graduated cylinders (1-liter) or other liquid measure
marbles (uniform size, not too large)
rubber stopper with hole
short length of rubber tubing
plastic tubing
pinch clamp
copper shot (BB's)
cheesecloth
stopwatch
clean sand
rubber bands
short length of glass tubing
petroleum jelly (Vaseline®)

Procedure:



1. Cut the bottom off the soda bottle.
2. Place several layers of cheesecloth over the small opening and put a rubber band over it to hold it in place.
3. Place the rubber stopper in the opening over the cheesecloth.
4. Carefully place the glass tubing in the rubber stopper. Do not push it through the cheesecloth. It may help to lubricate the glass tubing with petroleum jelly.
5. Attach the rubber or plastic tubing to the exposed glass tubing. Place the pinch clamp on the rubber tubing to act as a faucet valve.
6. Place the bottle upside down so it can be used as a funnel. Then make a mark on the side of the bottle about 10 centimeters (3.9 inches) from the small opening to ensure that you will use the same volume of sediment each time.
7. Fill the funnel up to the mark with the marbles. Make sure the top of the sediment is as flat as possible.
8. Fill the graduated cylinder with water. Make a note of the volume. Slowly fill the funnel with water until the level of the water is just above the top layer of sediment. Record the volume of water poured into the funnel as V_1, Trial 1 in Table 2. Be careful to avoid trapping air in the pores. Tap the sides of the funnel to release any air that may be trapped in the pores.
9. Place the empty graduated cylinder under the funnel. When one partner removes the pinch clamp, a second partner should begin timing the flow of water. Stop the timer when the first 50 - 100 mL are collected in the cylinder. Record the time as Flow Time, Trial 1 in Table 1. The volume you collect should be easy to time with the stopwatch. Regardless of the volume measured, measure the same volume for each trial and each sediment type. Record this volume as Measured Volume of Water in Table 1.
10. Let the funnel drain completely (within reason) and record the total volume of water collected as V_2, Trial 1 in Table 3.
11. Repeat steps 7 - 10 for Trials 2 and 3.
12. Remove the sediment and thoroughly clean the funnel. Put another type of sediment in the funnel and repeat the experiment and record the same data for the remaining two sediment types.
13. Calculate the Average Flow Time in Table 1, Average V_1 in Table 2, and the Average V_2 in Table 3 for each sediment type.

Observations:

Table 1 - Permeability

Sediment Type	Measured Volume of Water (mL)	Flow Time (sec) Trial 1	Flow Time (sec) Trial 2	Flow Time (sec) Trial 3	Average Flow Time (sec)	Flow Rate (mL/sec)
Marbles						
Shot						
Sand						

Table 2 - Porosity

Sediment Type	Original Volume of Water, V_1 (mL) Trial 1	Original Volume of Water, V_1 (mL) Trial 2	Original Volume of Water, V_1 (mL) Trial 3	Average Original Volume of Water, V_1 (mL)	Total Volume of Sediment (mL)	Percent Porosity
Marbles						
Shot						
Sand						

Table 3 - Effective Porosity

Sediment Type	Recovery Volume, V_2 (mL) Trial 1	Recovery Volume, V_2 (mL) Trial 2	Recovery Volume, V_2 (mL) Trial 3	Average Recovery Volume, V_2 (mL)
Marbles				
Shot				
Sand				

Conclusion:

1. In order to calculate percent porosity for each sediment type, you must know the volume of sediment you used each time. Since you marked your funnel at the sediment fill line, calculate the volume of sediment necessary to fill that space. Assume that your bottle approximates a cone. Use the following formula:

$$V_{cone} = \frac{\Pi r^2 h}{3}$$

Measure the radius and height of the cone in centimeters (cm). Express the volume you calculate in milliliters (mL); remember that $1 cm^3 = 1$ mL. To check the accuracy of your answer put the lid on the funnel and fill it with water up to the sediment fill mark. Empty the water into one of your graduated cylinders and read the volume. Record this value as Total Volume Sediment in Table 2.

2. Porosity for a sediment made of spherical particles, regardless of particle size, depends on the way the spheres are packed and will vary from almost 50% to approximately 27%. Based on the total volume sediment, (determined above) calculate the porosity for each sediment type in the experiment.

$$\% \text{ Porosity} = \frac{V_1 \text{ (volume pores or average volume water)} \times 100}{\text{Total sediment volume}}$$

Record your answers in Table 2. Are they significantly different from each other? If so, suggest a reason.

(Values will probably be most different for larger grain sizes because of "wall effects" that will disrupt particle packing.)

3. How do the rate-of-flow values compare for the three sediments? What does this tell you about the permeability of the different sediment types?

(Rate of flow should be highest for large grain sizes—lowest for small grain sizes. Permeability stringly depends upon size of pores and surface area of sediment grains.)

4. How do the recovery volumes compare for the three sediment types? Explain the differences and relate it to your explanation of permeability.

(Recovery volume is largest for large grain sizes, and smallest for small grain sizes. Smaller pores and larger surface areas in samples with small grain sizes mean more water held by frictional forces.)

POROSITY

Directions: In the following table, the volume of open space is given for a 1 cubic meter sample of a given rock type. Calculate the porosity as a percent for each rock type by using the following formula:

$$\frac{\text{Volume of pores}}{\text{Total rock volume}} \times 100 = \text{porosity (\%)}$$

One cubic meter(m^3) = *1,000,000* cubic centimeters (cm^3)

Rock type	**<u>Typical</u> Vol. open space (cm^3)**	**Porosity (%)**
Fractured basalt	5.5×10^4	*5.5*
Granite	1.0×10^4	*1.0*
Limestone	1.5×10^5	*15.0*
Sandstone	2.5×10^5	*25.0*
Shale	1.0×10^5	*10.0*
Tuff (non-welded, Yucca Mt. area)	4.5×10^5	*45.0*
Welded Tuff (proposed repository host rock)	1.2×10^5	*12.0*

1. What does the scientific notation 10^4 mean in the example for fractured basalt?

   (multiply 5.5 times 10,000 [10 x 10 x 10 x 10] to 55,000.)

2. What does the notation (cm^3) in column 2 tell you?

   (units for volume are cubic centimeters.)

3. Which rock type listed above is <u>most</u> porous? *(non-welded tuff)*

4. Why is the porosity of tuff important in siting the repository?

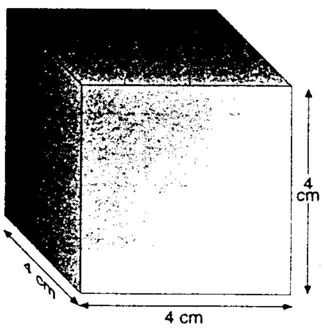
   (Fluids must move through the open spaces, pores, in a rock. If porosity, i.e., the number of pores, is small, flow usually will be restricted. Because the most likely way radioactive materials from a repository could reach the environment is through ground water, characteristics of the rock related to flow of water to or away from the repository are very important to consider.)

PERMEABILITY

Permeability is a measure of the ease of flow of a fluid, like water, through a porous rock. Water flowing next to the pore wall will be slowed by friction and may actually attach to the wall. The non-moving water is a small fraction of the total amount of water flowing in a coarse-grained rock, but it is increasingly important as grain size decreases.

As grain size decreases, the volume of solids, and porosity, may remain constant, but surface area always increases. More surface area means more places for water to attach, thereby reducing flow through, and permeability of, the rock.

A simple geometric calculation illustrates the relationship between grain size and surface area.



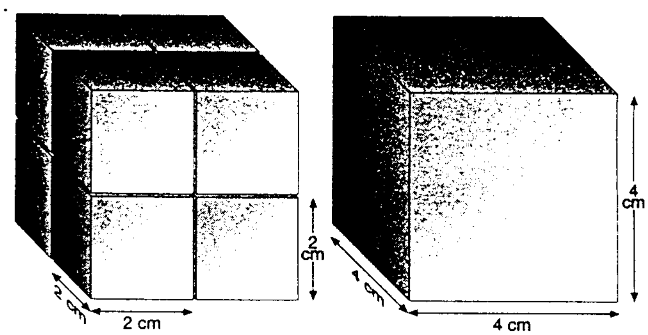
Directions: Start with a single grain from a porous rock. Imagine that the grain is a perfect cube 4 centimeters (1.6 inches) on a side.

Helpful Formulas	
Surface Area $_{Cube}$ = Area on face (l x w) x Number of faces (6)	*S.A.= (l x w) x 6*
Volume $_{Cube}$ = length (l) x width (w) x height (h)	*V = l x w x h*

1. Calculate the surface area and volume of the grain.

   Surface area ______________________

   Volume ______________________



2. Without changing the amount of solid volume, surface area can be increased by cutting the cube into eight equal, but smaller, cubes. Demonstrate through a calculation that the area is now greater than the original.

   ______________________ By how much? ______________________

3. What is the total volume of the new, smaller cubes? ______________________

4. Why does an increase in surface area mean an increase in friction between pore walls and water and, therefore, an increase in resistance to water flow through the rock?

   ____

   ____

5. Why is permeability important to consider in evaluating a host rock for a repository?

   ____

   ____