Name _____

PERMEABILITY, POROSITY and CAPILLARITY
Earth Science Lesson

This lesson explores the relationship between sediment shape and size with respect to the ability of water to travel through and in between sediments as well as the ability of pore spaces between sediments to hold (store) water.

There are a few definitions that you must know:

Sediments-Solid fragmental material that originates from weathering of rocks and is transported or deposited by air, water, or ice, or that accumulates by other natural agents, such as chemical precipitation from solution or secretion by organisms, and that forms in layers on the Earth's surface at ordinary temperatures in a loose, unconsolidated form; e.g., sand, gravel, silt, mud, alluvium.

Infiltration-Soaking into ground of water on surface. The flow of a fluid into a solid substance through pores or small openings; specifically, the movement (percolation) of water into soil or porous rock.

Permeability-The permeability of rock is its capacity for transmitting a fluid. The degree of permeability depends upon the size and shape of the rock material and the size and shape of the pores (spaces between sediments).

Porosity-Percentage of open space (pores) in rock or other earth material. Porosity determines how much water rock material or soil is able to store (hold).

Capillarity-The action by which a fluid, such as water, is drawn up in small pore spaces as a result of surface tension. Syn: capillary action. The forces of cohesion between water molecules and also adhesion, between the water and the rock material, create a surface tension which allows water molecules to migrate upwards and sideways against the opposing downward pull of gravity.

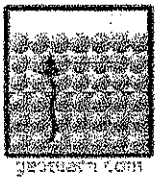
Soil-Material that forms at earth's surface as result of organic and inorganic processes. Soil varies with climate, plant and animal life, time, slope of land, and parent material.

Soil Profile- A vertical strip of soil stretching from the surface down to the bedrock and including all of the successive soil horizons.

Rounded Sediments
Larger Size

Fair Capillarity!
Capillarity does occur when sediments are rounded. However, these particles are large in size and the larger the pore spaces between particles, the poorer the capillarity.

Rounded Sediments
Smaller Size



Best Capillarity!
Maximum Capillarity occurs when sediments are ***rounded*** and ***smaller in size***.

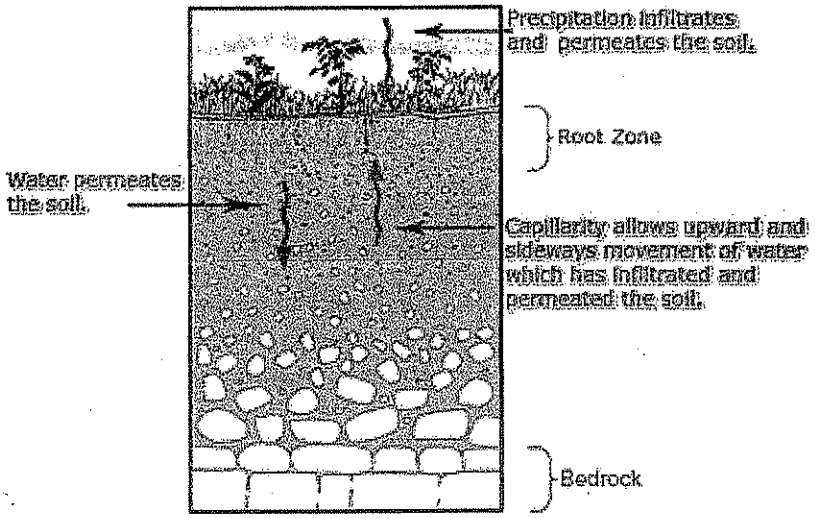
Size matters when it comes to capillarity!

Angled Sediments
Mixed Sizes

Poor Capillarity!
Capillarity ***does not*** easily occur when sediments are angled and also when they are angled and of mixed sizes. These particles have very little pore space between each other and so capillarity is poor to none.

Consider a Soil Profile:
Permeability, Porosity and Capillarity are important. In order for vegetation to survive, water must be able to infiltrate and permeate down into the soil to reach the root level. Soils that are porous will be able to hold and store water between periods of precipitation. Capillarity insures that water which has permeated past the root zone will be able to migrate upwards and sideways over time, bringing additional water back to the root zone even during times when precipitation is not taking place. Capillary water, held in soil pore spaces against the force of gravity, is the main source of water for plants.

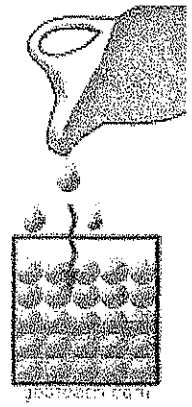
The cross section below shows a Soil Profile.



PERMEABILITY – BIGGER SIZES

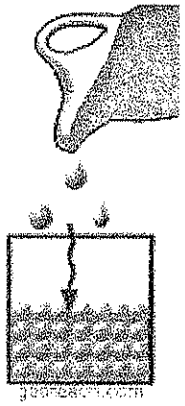
Permeability is the capacity of the rock or body of sediment for transmitting a fluid. This ability is dependent upon pore spaces between sediments, be they sediments comprising soil or those compacted and cemented within a clastic sedimentary rock. Optimum permeability exists where sediments are ***rounded and large***. Pore spaces are also large and water easily passes in between sediments. Permeability is poorest when sediments are of mixed sizes and shapes.
Igneous and metamorphic rocks, with their intergrown crystals, are too dense to allow water infiltration unless they have many interconnected cracks. In such a situation, water can enter these cracks. Clastic sedimentary rocks, on the other hand may have pore spaces between sediments that comprise the rock and so water may infiltrate some specimens belonging to this rock group.

Rounded Sediments



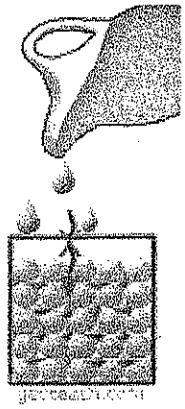
Best Permeability!
Water is able to easily infiltrate and permeate *quickest when **large, rounded** sediments are present.*
Size and shape matter!

Rounded Sediments Different Sizes



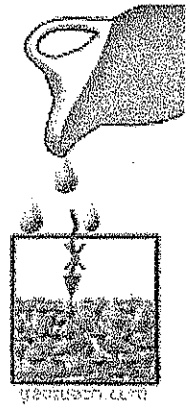
Good Permeability!
Water is able to infiltrate and permeate *smaller sized, rounded sediments,* though not as quickly as with the larger sediments in the box to the left. Size matters when it comes to permeability!

Angled and Rounded Sediments



Poor Permeability!
Water ***does not*** easily infiltrate and permeate *a mixture of rounded and angled sediments.*

Angled Sediments Mixed Sizes



Poor Permeability!
Water ***does not*** easily infiltrate and permeate *a mixture of angled sediments. This is true whether the angled sediments are the same size or a mixture of different sizes.*

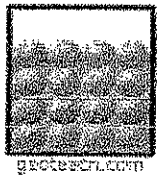
POROSITY

Porosity is the ability of the rock or body of sediment to hold, or store, water. Water is stored in pore spaces between sediments so the more pore space that is available, the better the porosity.
Rounded particles allow for maximum pore space and so rocks or soil comprised of a large percentage of rounded sediments will be more porous.
It does not matter what size the rounded particles are; large or small sediments allow for ample pore space between particles.
However, rocks and soil composed of angled sediments or a mixture of rounded and angled sediments, be they small or large in size, will not exhibit good porosity. The

angled edges of particles "fill in" pore spaces, closing them and prohibiting water from entering or being stored between the rock fragments.
Igneous and metamorphic rocks, with their intergrown crystals, are too dense to allow pore spaces between crystals. Water storage cannot occur within the rock however in nature, water may lie in large cracks in rocks belonging to these groups. An exception would be porous, vesicular igneous rocks such as pumice, scoria and vesicular basalt. Sedimentary rocks, on the other hand may have pore spaces between sediments that comprise the rock and so water may infiltrate and be stored in some specimens belonging to this rock group. Therefore, some clastic sedimentary rocks can be porous.

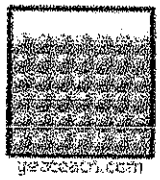
Size does not matter

Rounded Sediments
Larger Size



Good Porosity!
Sediments that are rounded naturally create larger pore spaces between each particle. Pore spaces hold water. The storing of water makes sediment *porous*.

Rounded Sediments
Smaller Size



Good Porosity!
Maximum Porosity occurs when sediments are ***rounded.***
Size does not matter but shape does!
Round is best!
The porosity of this sample and the one to the left is the same.

Angled Sediments
Mixed Sizes

Poor Porosity!
Sediments that are angled, jagged and irregular in shape do not allow for ample pore spaces between each particle. Therefore, soil made up of such a mix of sediments would not be porous and would not be suited for water storage.

CAPILLARITY

Capillarity is the action by which water actually moves against the downward pull of gravity. Water is able to travel upwards and sideways within rock material. Surface tension created by the forces of cohesion (attraction between water molecules) and adhesion (attraction between water molecules and the rock material) allow slow migration within pore spaces between rock particles.
Capillarity is best when sediments are round and small. The smaller the pore space, the better the capillarity.
Capillarity is worst when sediment is poorly sorted with angled particles and mixed sizes and shapes present. The angled particles prevent ample pore space between rock fragments so there is no space available through which water can migrate.
Capillarity is not present in igneous and metamorphic rocks nor is it at its best within the structure of clastic sedimentary rocks. It is most prevalent and most important in unconsolidated (loose) sediments as would be present in soils.

NAME: _____ DATE: _____

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PERMEABILITY, POROSITY and CAPILLARITY
Earth Science Worksheet 2

Directions: Print out this worksheet and answer all questions in the spaces provided..

Base your answers to questions 1-4 on the following graphs.

1-Which graph shows the relationship between soil particle size and the **rate at which water infiltrates** permeable soil if the Y axis represents ***Rate of Infiltration***?

Graph Number: _____

2-Which graph shows the relationship between soil particle size and **capillarity** if the Y axis represents ***Capillarity***?

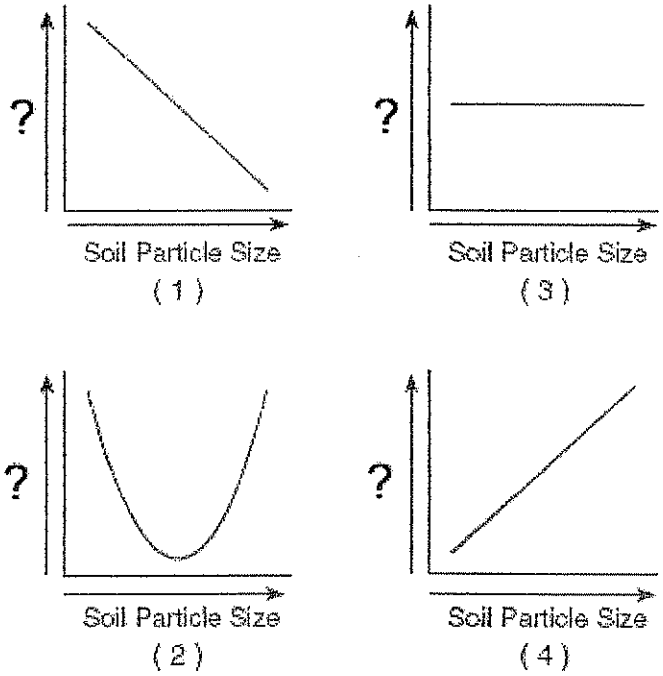
Graph Number: _____

3-Which graph shows the relationship between soil particle size and **porosity** if the Y axis represents ***Porosity***? Assume all particles are round.

Graph Number: _____

4-Which graph shows the relationship between soil particle size and **permeability** if the Y axis represents ***Permeability***? Assume all particles are round.

Graph Number: _____



Base your answer to question 5 on the following illustration. Circle the correct answer.

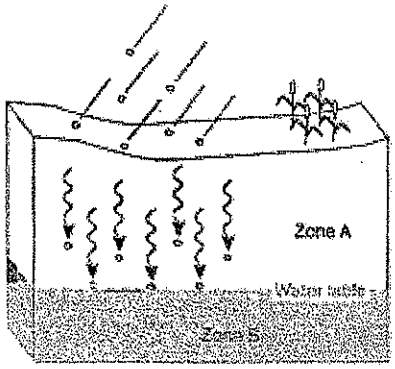
The diagram to the right is a cross-sectional view of rain falling on a farm field and then moving down to the water table.
5- Which word best describes the movement of rainwater through Zone A?

a- runoff

b- saturation

c- infiltration

d- precipitation



NAME: _____ DATE: _____

CLASS: _____ TEACHER: _____

Base your answers to questions 6-8 on the following diagram which shows 2 sediment tubes each containing equal volumes of sediment.

6- Which of the 2 columns to the right contains sediments with the best capillarity?

Sediment tube: _____

7- Give a reason for your answer. Be sure to compare both tubes.

_____

_____

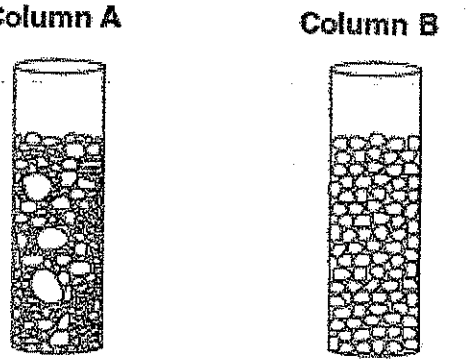
_____

8- Compare the permeability of the sediments in both tubes with supporting explanations.

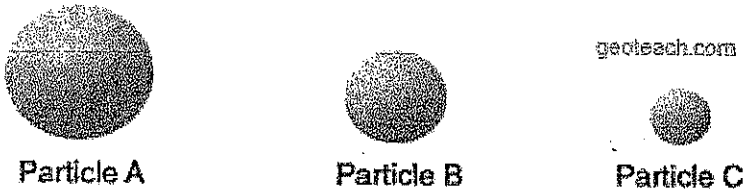
_____

_____

_____



Base your answers to questions 9-10 on the following diagram which shows 3 different sized sediments. Place the letter for the correct answer on the line provided.



Assuming an equal volume (amount) of each sediment exists in a soil profile, then:

9- Which soil would have the best capillarity?

The soil with particle: _____

10- Which soil would have the best permeability?

The soil with particle: _____

 Name ______________

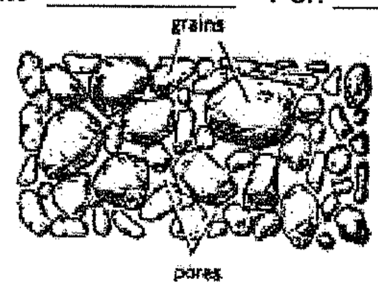
Date __________ Per. _____

The amount of water that a soil can hold between its grains depends upon the porosity of the soil. Solid rock has no pore space at all. However, all soils contain some openings, usually filled with air or water.

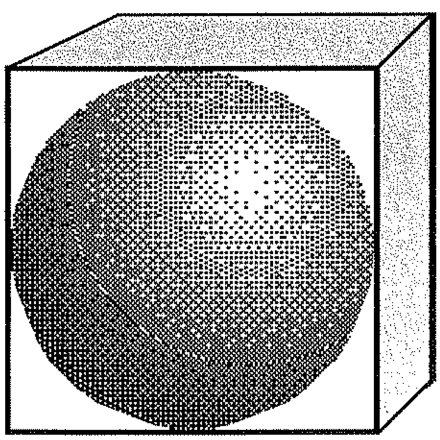
The percentage of pore space is called the **porosity** of a material.

$$\textit{Porosity} = \frac{\textit{volume of pore space}}{\textit{total volume of sample}}$$

The three cubes below show how the porosity of a material relates to the sizes of the particles and their packing. Cube A contains a single sphere 4 cm in diameter. Cubes B and C are filled with spheres 1 cm in diameter.



Porosity is the Open Space Between the Soil Grains



CUBE: $V = S^3 = (4\text{ cm})^3 = 64\text{ cm}^3$

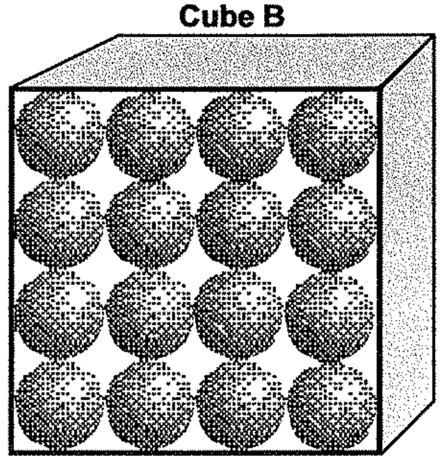
SPHERE: $V = \frac{4}{3}\pi r^3$
$= \frac{4}{3} \times 3.14 \times 8\text{ cm}^3$
$= 33.5\text{ cm}^3$

PORE SPACE $= 64\text{ cm}^3 - 33.5\text{ cm}^3$
$= 30.5\text{ cm}^3$

POROSITY $= \frac{30.5\text{ cm}^3}{64\text{ cm}^3} \times 100\%$

$= 48\%$

Cube B



CUBE: $V = S^3 = 4\text{ cm}^3 = 64\text{ cm}^3$

EACH SPHERE: $V = \frac{4}{3}\pi r^3$

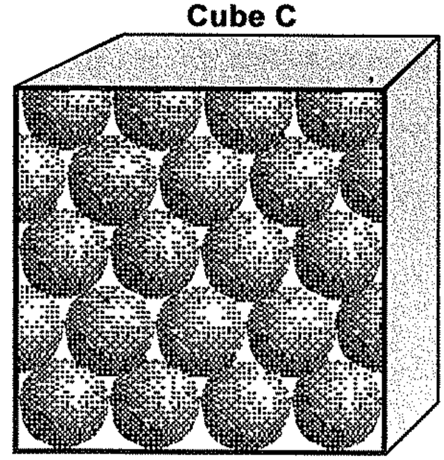
$= \frac{4}{3} \times 3.14 \times (\frac{1}{2}\text{ cm})^3$

$= .523\text{ cm}^3$
$\times$ 64 spheres
33.5 cm^3

$64\text{ cm}^3 - 33.5\text{ cm}^3 = 30.5\text{ cm}^3$

Therefore POROSITY = 48%

Cube C



Because of tighter packing, cube C contains 8 more spheres than cube B.

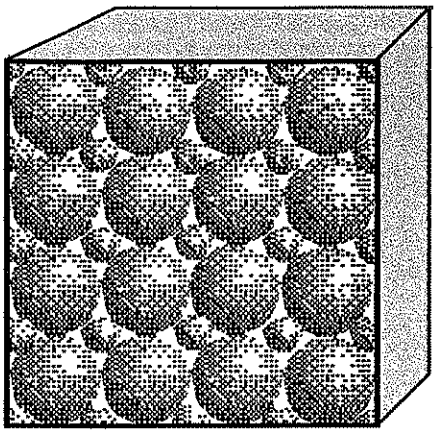
Therefore cube C has ~4 cm^3 less pore space than cube B.

$30.5\text{ cm}^3 - 4\text{ cm}^3 = 26.5\text{ cm}^3$

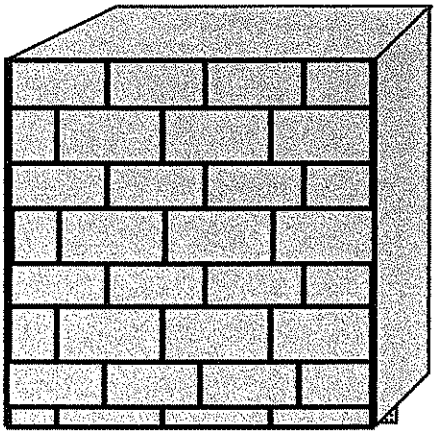
POROSITY $= \frac{26.5\text{ cm}^3}{64\text{ cm}^3} = 41\%$

1. What is the porosity of the 4 cm cube shown in diagram A? __________
2. Diagram B shows an identical cube filled with smaller spheres. The porosity of B is... __________
3. How does changing the size of the particles affect the porosity of the sample? ______________________
4. Why does C have a lower porosity? ______________________
5. How does the packing affect the porosity? ______________________

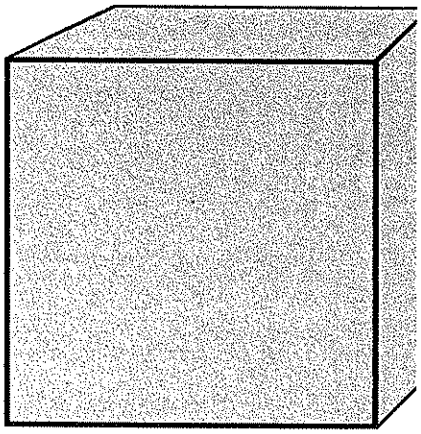
Cube D



Cube E



Cube F



You have seen that the porosity of a soil does *not* depend upon the size of the particles, however, porosity does depend upon how the particles are packed, and the mixture of particle sizes.

6. Compare cube D above with cube B at the center of page 1.
   Which diagram shows a greater porosity, cube B or cube D? _____

7. Why does mixing the particle sizes
   decrease the porosity of the soil? _____

8. Note that in cube E, the particle shape has been
   changed. Why is the porosity of cube E very low? _____

9. Cube F is solid rock. What is the porosity of solid rock? _____

Answer the following: Decreases, Increases or, Remains the Same.

10. As the particle size increases, the porosity of a soil... _____

11. When soil particle are more closely packed, the porosity... _____

12. As the soil particles become more round, the porosity... _____

13. If solid rock is cracked and broken, its porosity... _____

14. As the grain size decreases, the porosity of a soil... _____

15. Only three of the factors below affect the porosity of a soil. Circle them.

Packing of Grains	Particle Shape	Particle Density
Volume of the Sample	Particle Size	Mixture of Sizes

16. Use the formula on page 1
    to calculate the porosity of
    200 mL of soil that can hold
    80 mL of water. ➔
    (Be sure to show the formula and the necessary steps.)

(C) when the particles are [illegible]

(D) when the particles are [illegible]

(E) when [illegible] of the [illegible] to occur

(F) when the [illegible] are [illegible] each

12) Why does [illegible] clay [illegible] cold?

(A) [illegible]

(B) [illegible]

(C) [illegible]

(D) [illegible]

[illegible]

[illegible]

[illegible]

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PERMEABILITY, POROSITY and CAPILLARITY
Earth Science Worksheet

Directions: Print out this worksheet and answer all questions in the spaces provided..

Base your answers to questions 1-4 on the following graphs.

1-Which graph shows the relationship between soil particle size and the **rate at which water infiltrates** permeable soil if the Y axis represents ***Rate of Infiltration***?

Graph Number: _____

2-Which graph shows the relationship between soil particle size and **capillarity** if the Y axis represents ***Capillarity***?

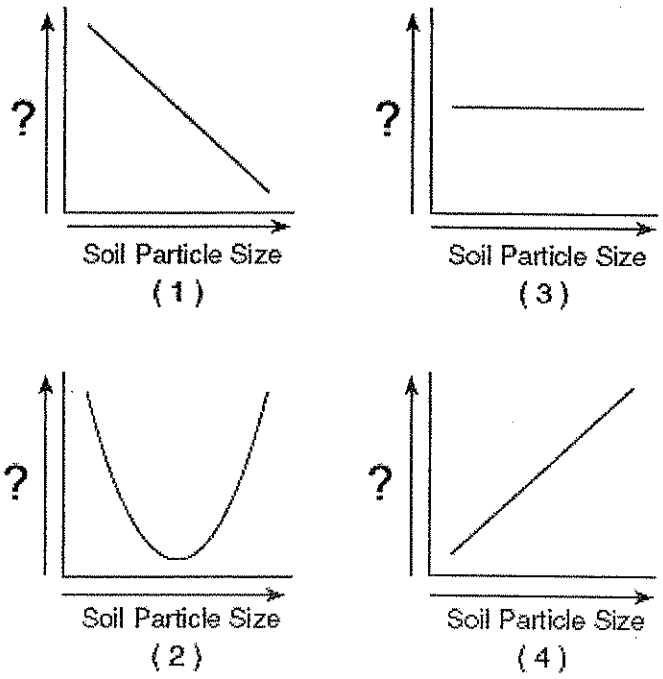
Graph Number: _____

3-Which graph shows the relationship between soil particle size and **porosity** if the Y axis represents ***Porosity***? Assume all particles are round.

Graph Number: _____

4-Which graph shows the relationship between soil particle size and **permeability** if the Y axis represents ***Permeability***? Assume all particles are round.

Graph Number: _____



Base your answer to question 5 on the following illustration. Circle the correct answer.

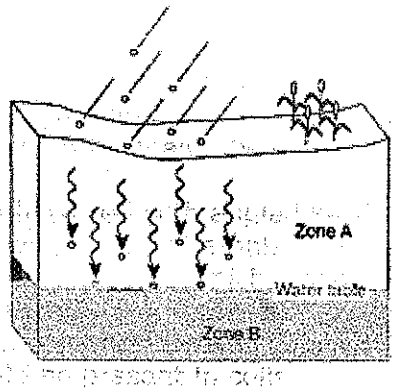
The diagram to the right is a cross-sectional view of rain falling on a farm field and then moving down to the water table.
5- Which word best describes the movement of rainwater through Zone A?

a- runoff

b- saturation

c- infiltration

d- precipitation



A) greater permeability and gre
B) less permeability and greater
C) greater porosity and grea
D) less permeability and greater

18) In which area will surface runoff
during a heavy rainfall?

A) wooded area
B) parking lot

17) Surface runoff is generally
A) greatest in poorly drained
B) possible in flat, sandy
C) influenced by
D) slow in

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Base your answers to questions 6-8 on the following diagram which shows 2 sediment tubes each containing equal volumes of sediment.

6- Which of the 2 columns to the right contains sediments with the best capillarity?

Sediment tube: _____

7- Give a reason for your answer. Be sure to compare both tubes.

_____

_____

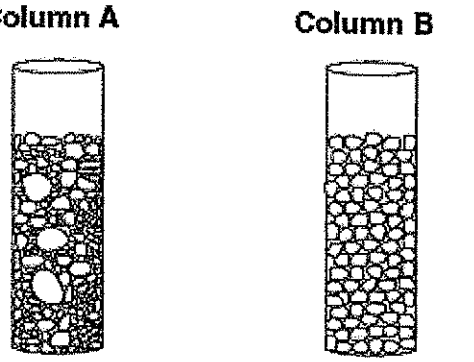
_____

8- Compare the permeability of the sediments in both tubes with supporting explanations.

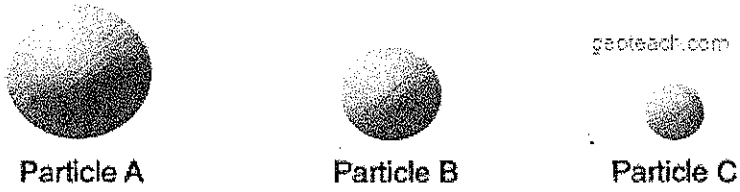
_____

_____

_____



Base your answers to questions 9-10 on the following diagram which shows 3 different sized sediments. Place the letter for the correct answer on the line provided.



Assuming an equal volume (amount) of each sediment exists in a soil profile, then:

9- Which soil would have the best capillarity?

The soil with particle: _____

10- Which soil would have the best permeability?

The soil with particle: _____

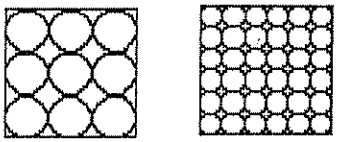
1) When rain falls on a soil surface, flooding at that location would most likely occur if the

A) soil pore spaces are filled to capacity
B) soil surface is covered with vegetation
C) soil surface is permeable
D) infiltration rate exceeds the precipitation rate

2) When rainfall occurs, the water will most likely become surface runoff if the surface of the soil is

A) covered with trees
B) highly permeable
C) steeply sloped
D) loose and sandy

3) The diagram below represents two identical containers filled with samples of loosely packed sediments. The sediments are composed of the same material, but differ in particle size. Which property is most nearly the same for the two samples?



A) porosity
B) water retention
C) infiltration rate
D) capillarity

4) As the temperature of the soil decreases from 10°C to -5°C, the infiltration rate of ground water through this soil will most likely

A) decrease
B) remain the same
C) increase

7) Water will infiltrate surface material if the material is

A) permeable and saturated
B) permeable and unsaturated
C) impermeable and saturated
D) impermeable and unsaturated

8) Which property of loose earth materials most likely increases as particle size decreases?

A) infiltration
B) capillarity
C) permeability
D) porosity

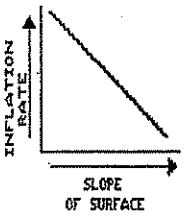
10) During a rainstorm, when is surface runoff *least* likely to occur?

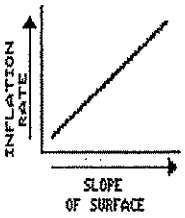
A) when the pore spaces of the ground are saturated with water
B) when the rainfall rate exceeds the permeability rate of the soil
C) when the slope of the surface is too great for infiltration to occur
D) when the permeability rate of the soil equals the rainfall rate

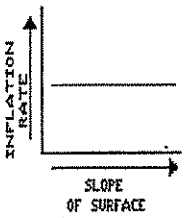
11) Why does water move very slowly downward through clay soil?

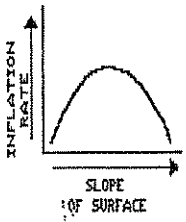
A) Clay soil has large pore spaces.
B) Clay soil has very small particles.
C) Clay soil is composed of very hard particles.
D) Clay soil is composed of low-density minerals.

9) Which graph best represents the relationship between the surface slope of a dry, sandy soil and the infiltration rate of rain?

A)


B)


C)


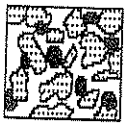
D)


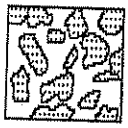
Which diagram best illustrates the condition of the soil below the water table?

KEY:
Soil Particles Water Pore Space (air)

A)


B)

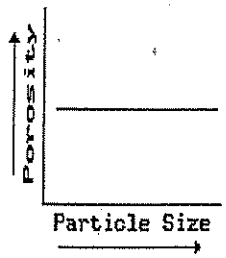

C)


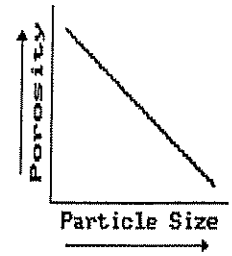
D)


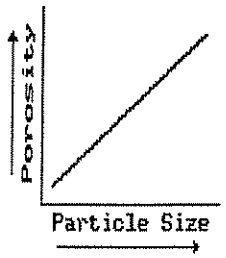
) Which is most important in determining the amount of ground water that can be stored within a rock?

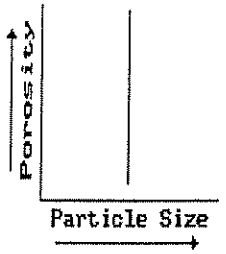
A) the rock's porosity
B) the rock's color
C) the rock's hardness
D) the rock's geologic age

13) Which graph best represents the relationship between porosity and particle size for soil samples of uniform size, shape, and packing?

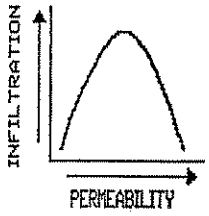
A) 

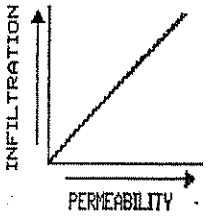
B) 

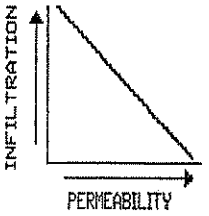
C) 

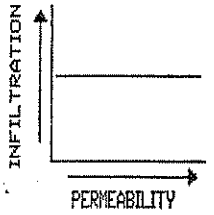
D) 

14) Which graph best represents the relationship between soil permeability rate and infiltration when all other conditions are the same?

A) 

B) 

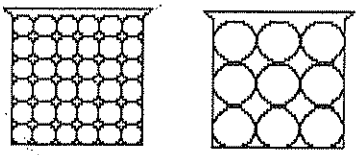
C) 

D) 

15) Most infiltration of precipitation will occur when the Earth's soil is

A) saturated and permeable
B) unsaturated and impermeable
C) saturated and impermeable
D) unsaturated and permeable

17) The diagrams below represent two identical containers filled with nonporous uniform particles. The containers represent models of two different sizes of soil particles.



Compared to the model containing larger particles, the model containing smaller particles has

A) greater permeability and greater porosity
B) less permeability and greater porosity
C) greater porosity and greater capillarity
D) less permeability and greater capillarity

18) In which area will surface runoff most likely be *greatest* during a heavy rainfall?

A) wooded forest
B) paved city street
C) level grassy field
D) sandy desert

19) Surface runoff will generally be *greatest* when the

A) ground is permeable and unsaturated
B) rainfall is light and the ground is permeable
C) infiltration rate is greater than the rainfall rate
D) slope of the land is too great to permit infiltration