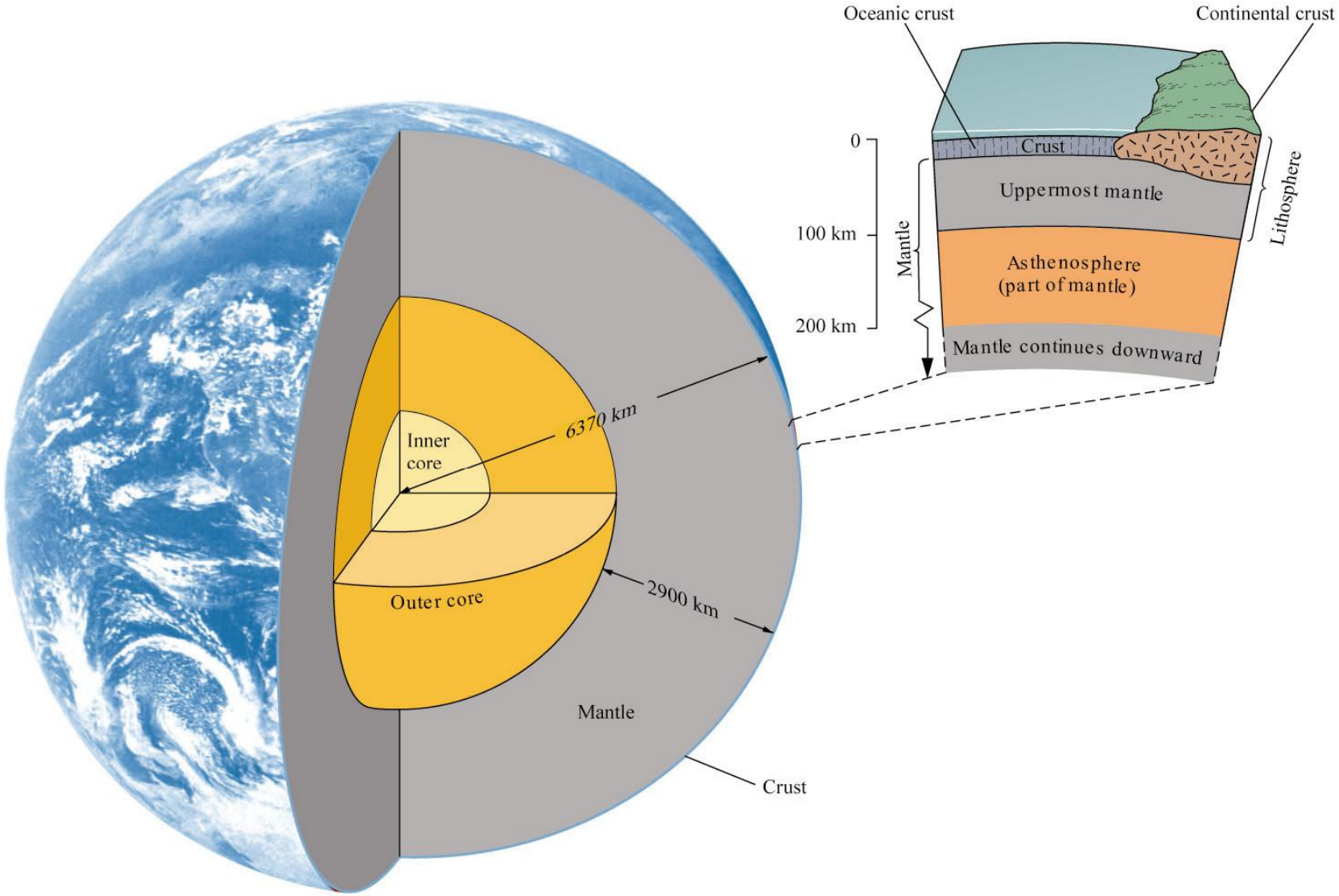
# Soil Formation

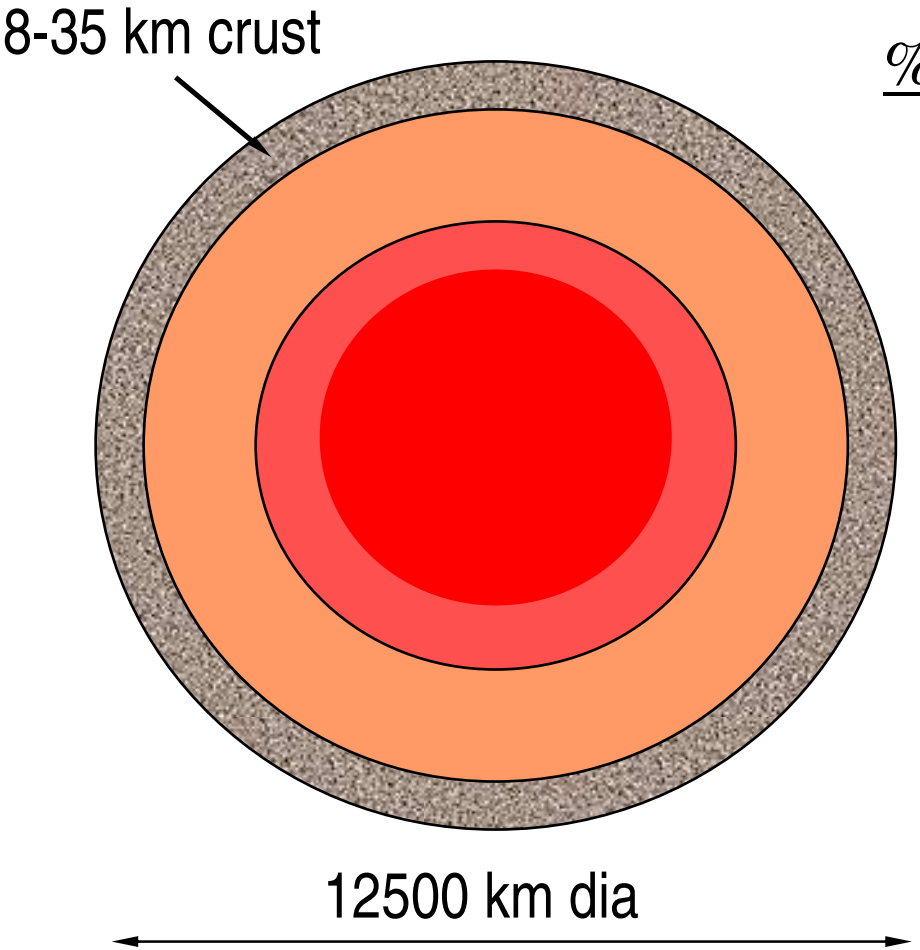
# Geologic Processes

- Crust— Extremely thin, less-dense soil.
- Mantle—Makes up majority of earth.
  - Surrounds core of iron.
  - Inner portion is solid.
  - Outer portion capable of flow.

# Structure of the Earth



# Elements of Earth




% by weight in **crust**

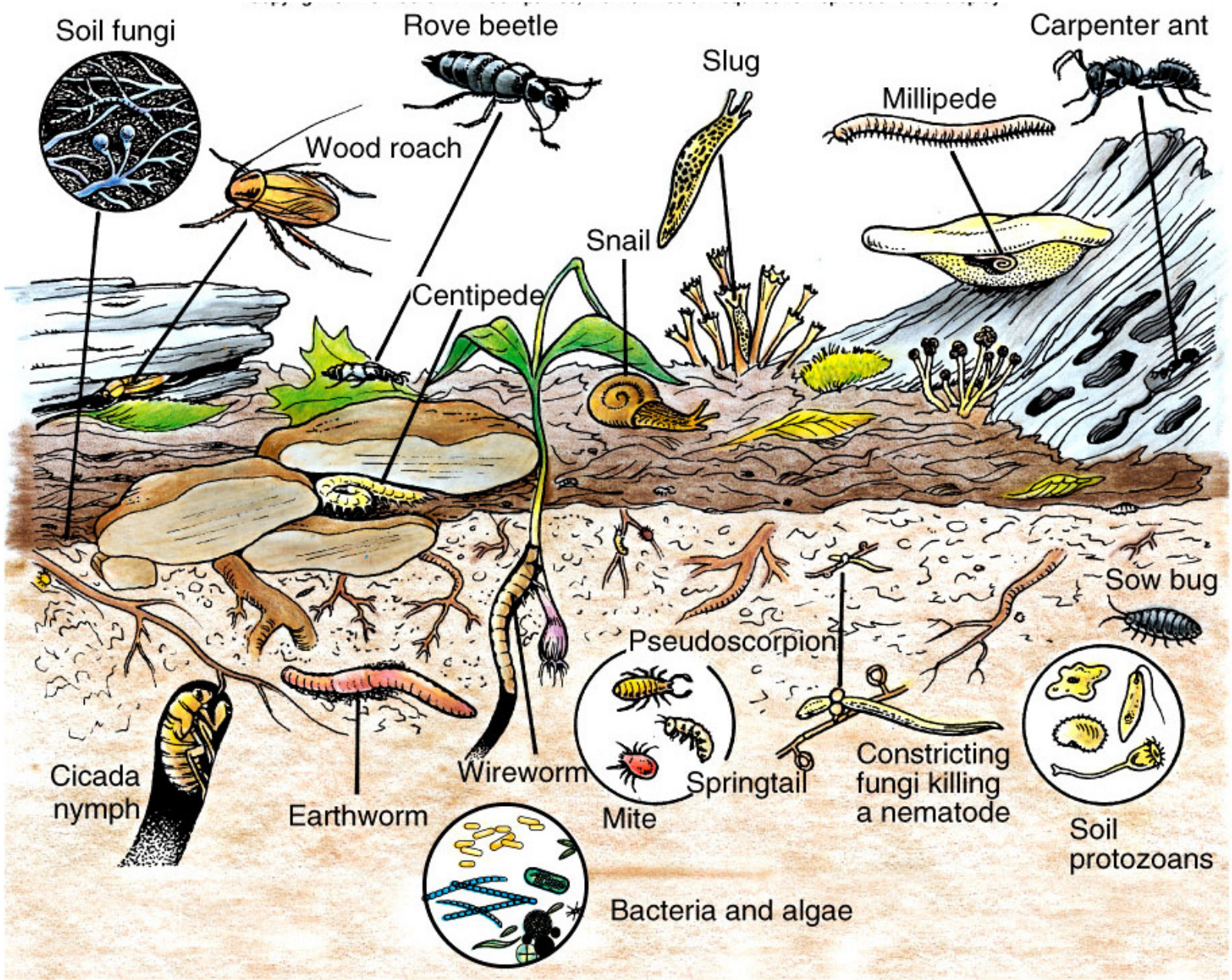
| | | |
|---|---|---|
| O | = 49.2 | 82.4% |
| Si | = 25.7 | |
| Al | = 7.5 | |
| Fe | = 4.7 | |
| Ca | = 3.4 | |
| Na | = 2.6 | |
| K | = 2.4 | |
| Mg | = 1.9 | |
| other | = 2.6 | |

# What is “Soil?”

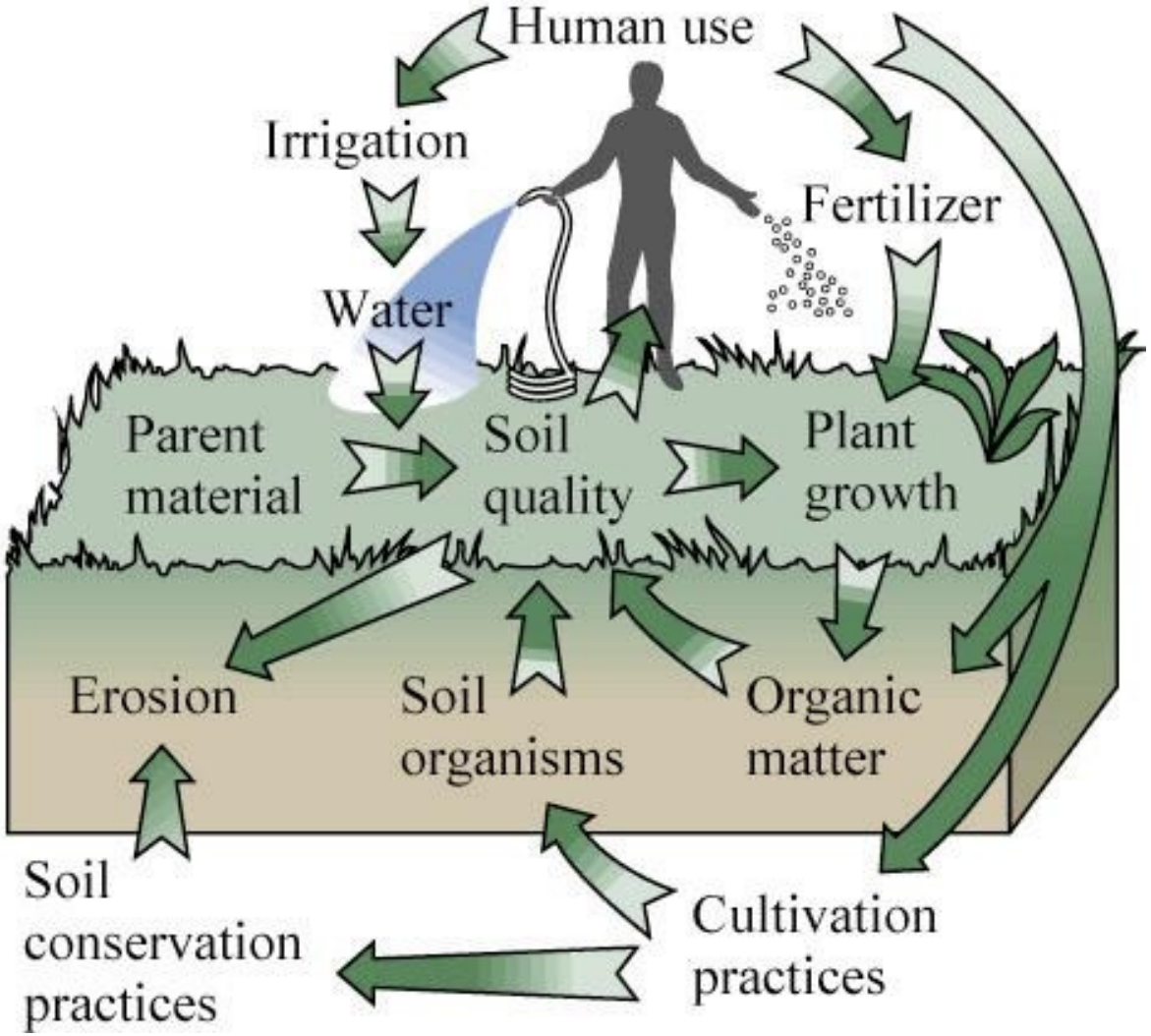
- Each discipline defines soil in a different way, depending on how soil affects it.

# Why is Soil Important?

- Agriculture
- Engineering
- Home for flora and fauna
- Life Support


Soil fungi
Rove beetle
Carpenter ant
Slug
Millipede
Wood roach
Snail
Centipede
Sow bug
Pseudoscorpion
Cicada nymph
Earthworm
Wireworm
Springtail
Mite
Constricting fungi killing a nematode
Soil protozoans
Bacteria and algae

# Soil and Its Uses



# Soil and Land

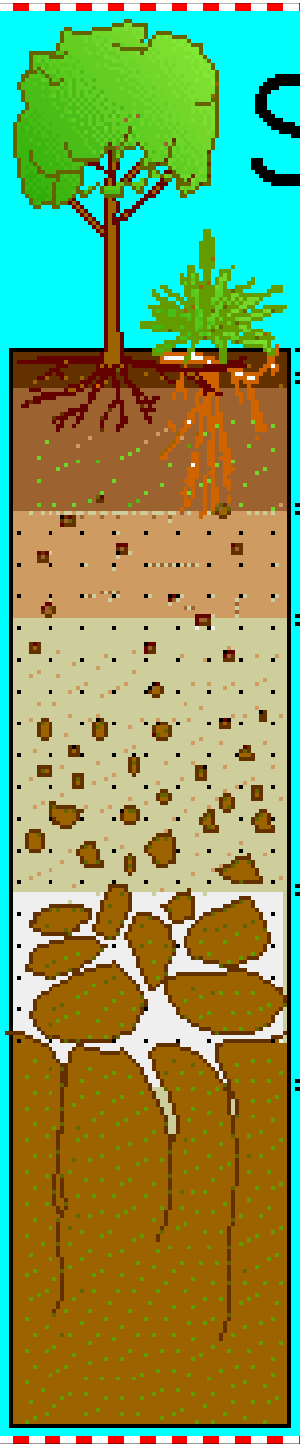
- Land—Portion of world not covered by water.
- Soil—Mixture of minerals, organic material, living organisms, air, and water.

# What is “Soil?”

.

- “In an engineering sense, soil is the relatively loose agglomerate of mineral and organic materials and sediments found above the bedrock.”
    - R.D. Holtz and W.D. Kovacs (1981)

# Soil Layers



O Horizon (humus)

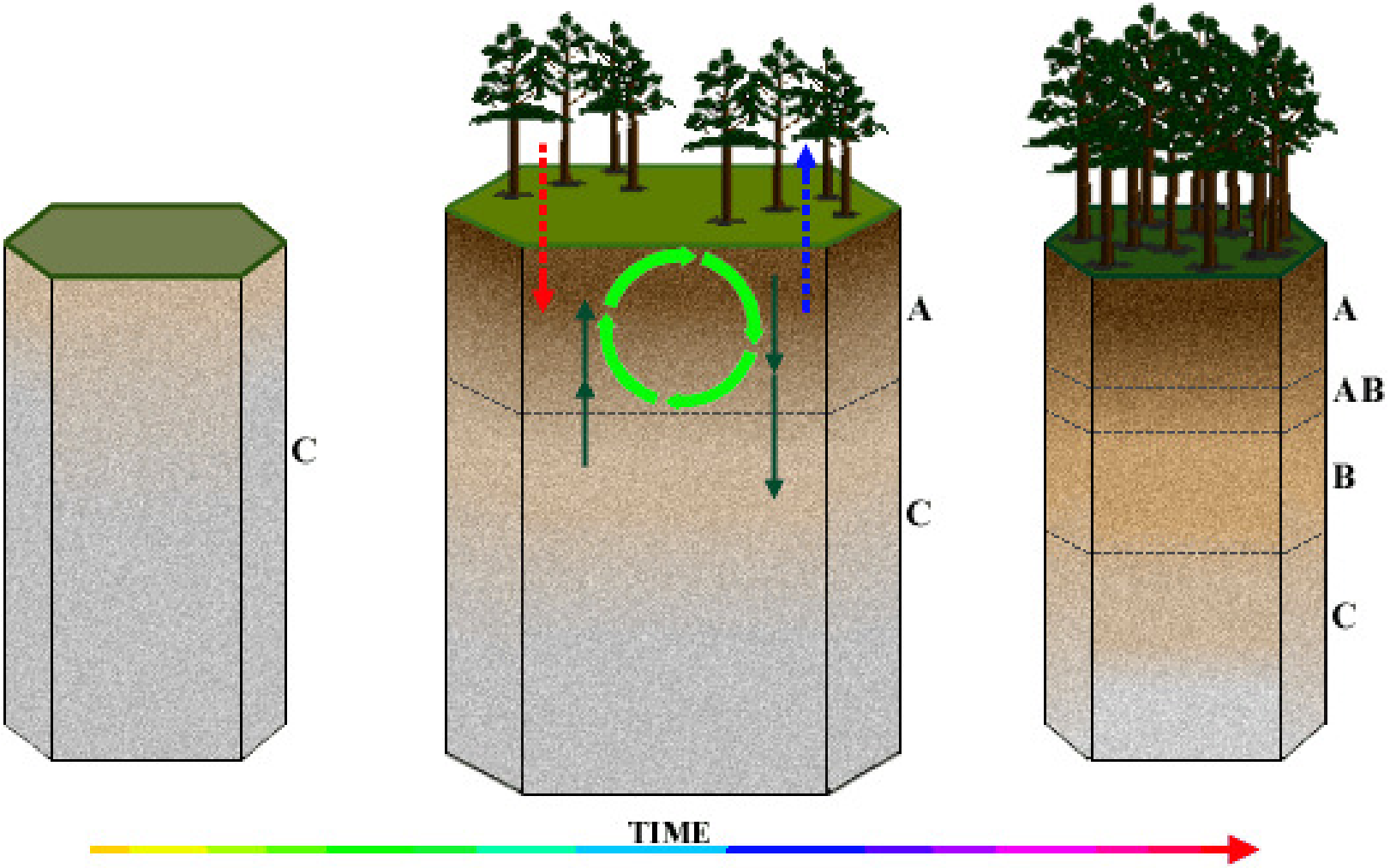
A Horizon (topsoil)

E Horizon (eluviation layer)

B Horizon (subsoil)

C Horizon (regolith)

R Horizon (bedrock)




Juma & Nickel

# What is Soil?

Combination of:

- mineral material
- organic matter
- pore space ( Air and Water)

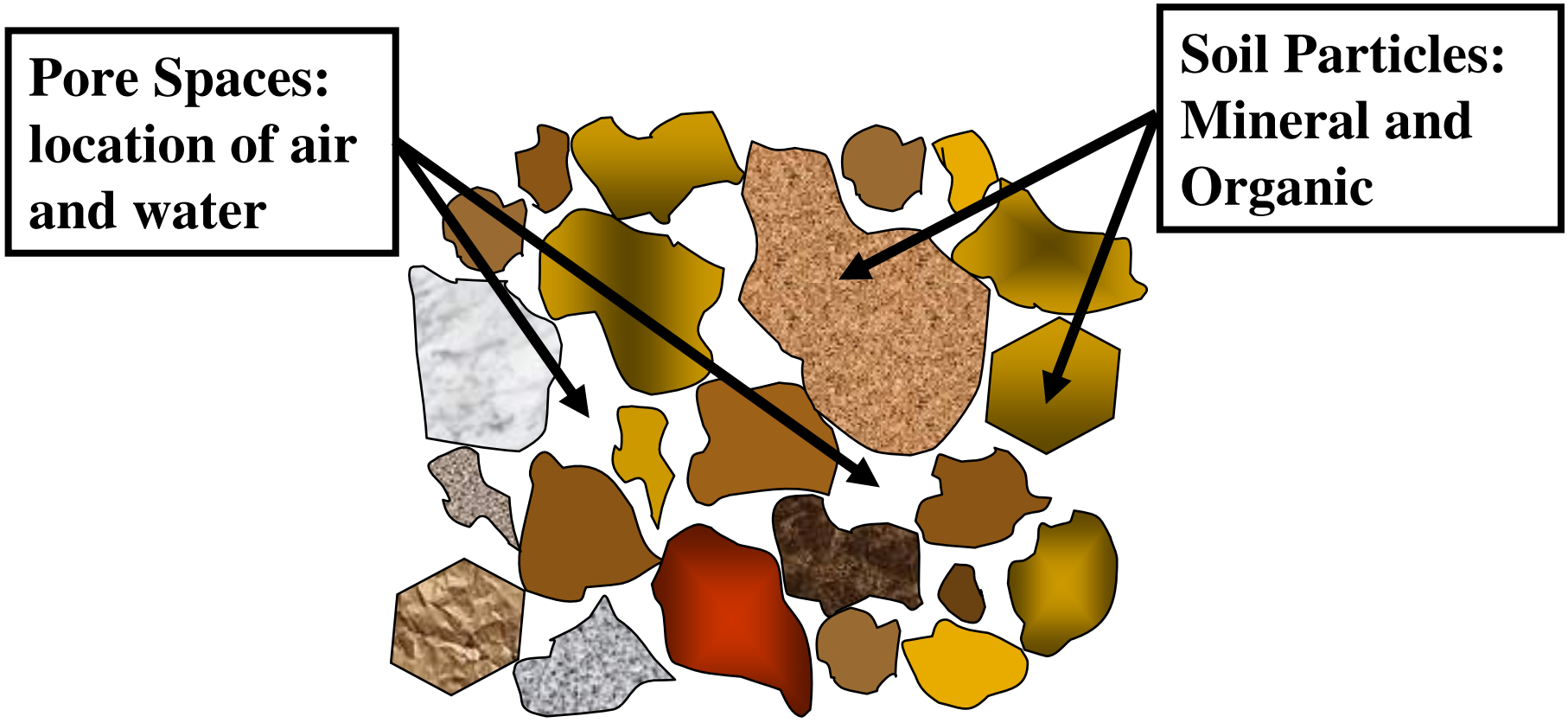
# What is Soil?

Three phase system

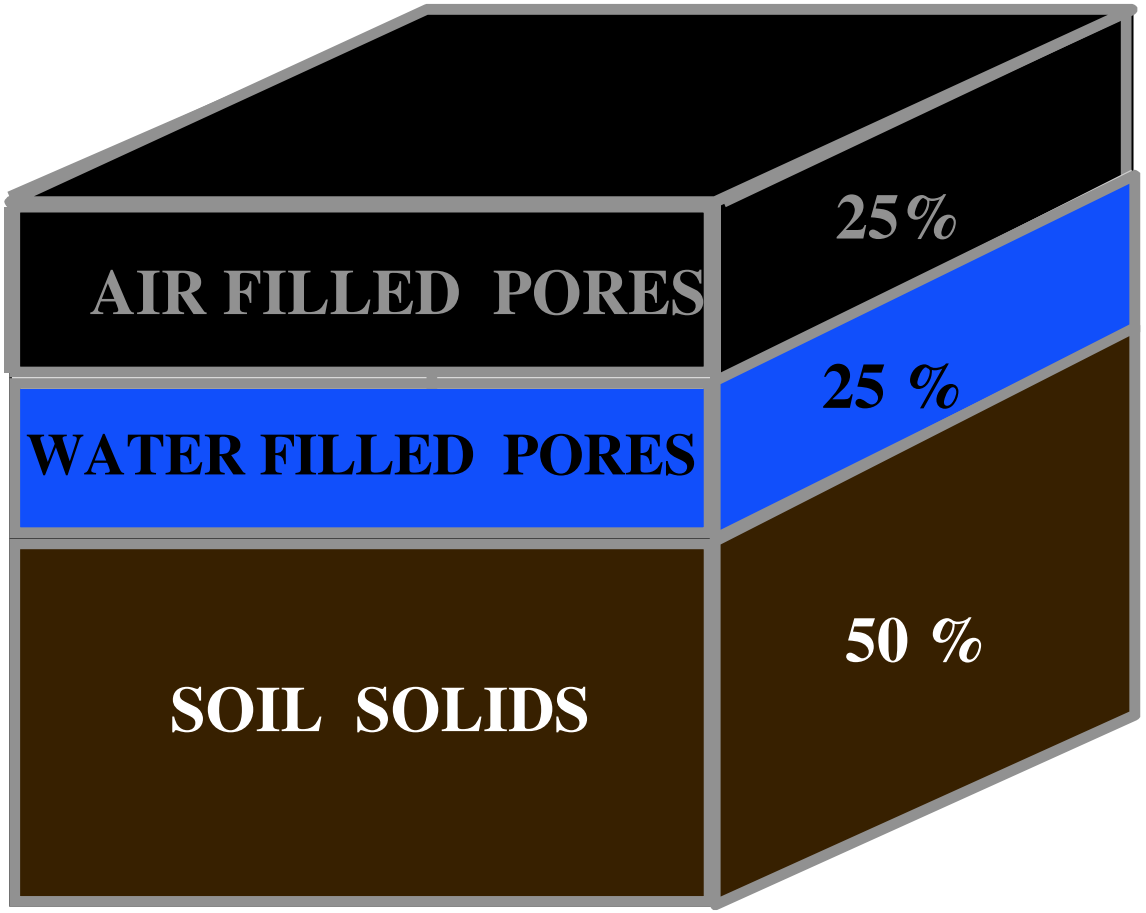
- Solid
- Water
- Gas

# SOIL: *Make it Work for You!*

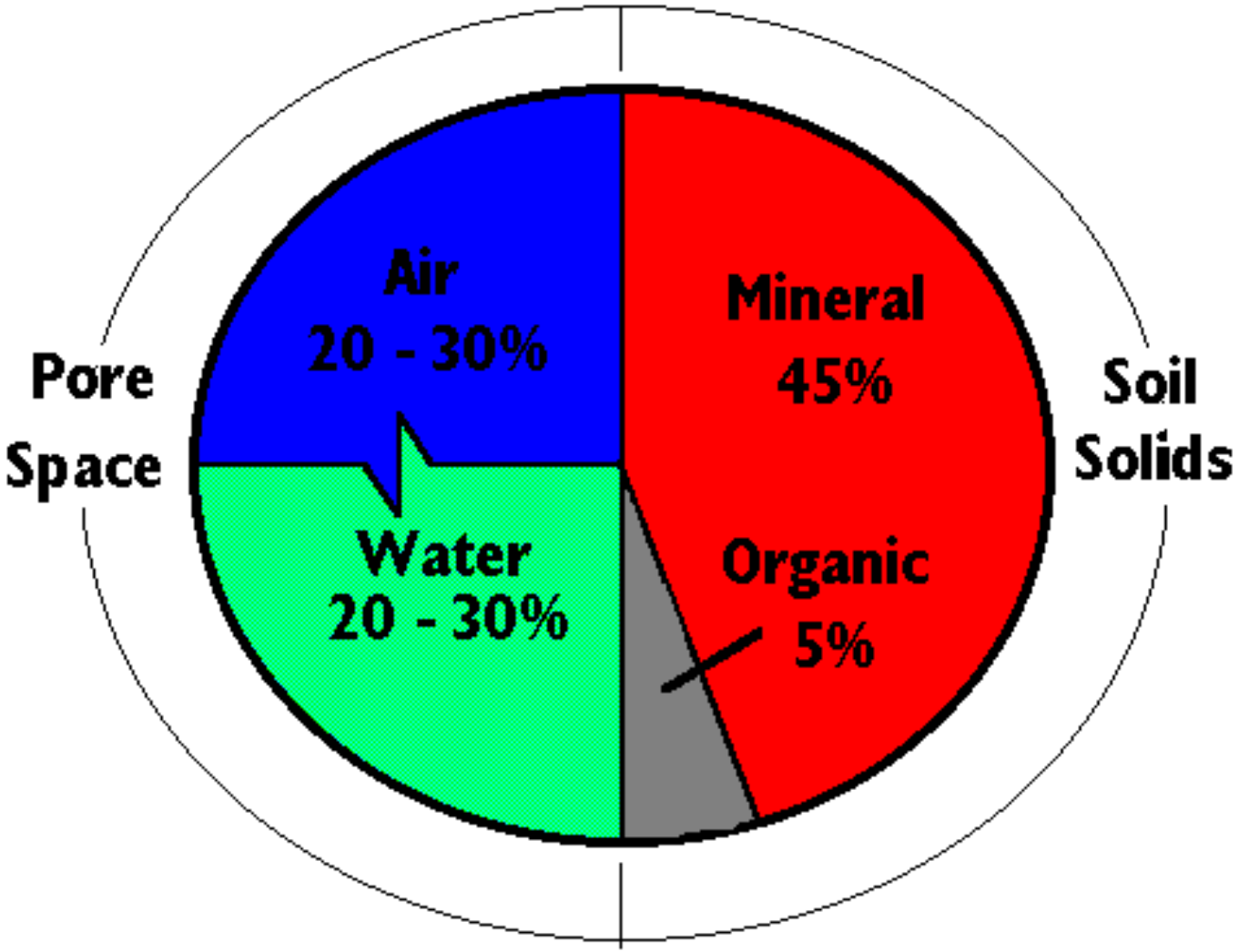
## Basic Soil Components



# SOIL COMPONENTS
## idealized soil

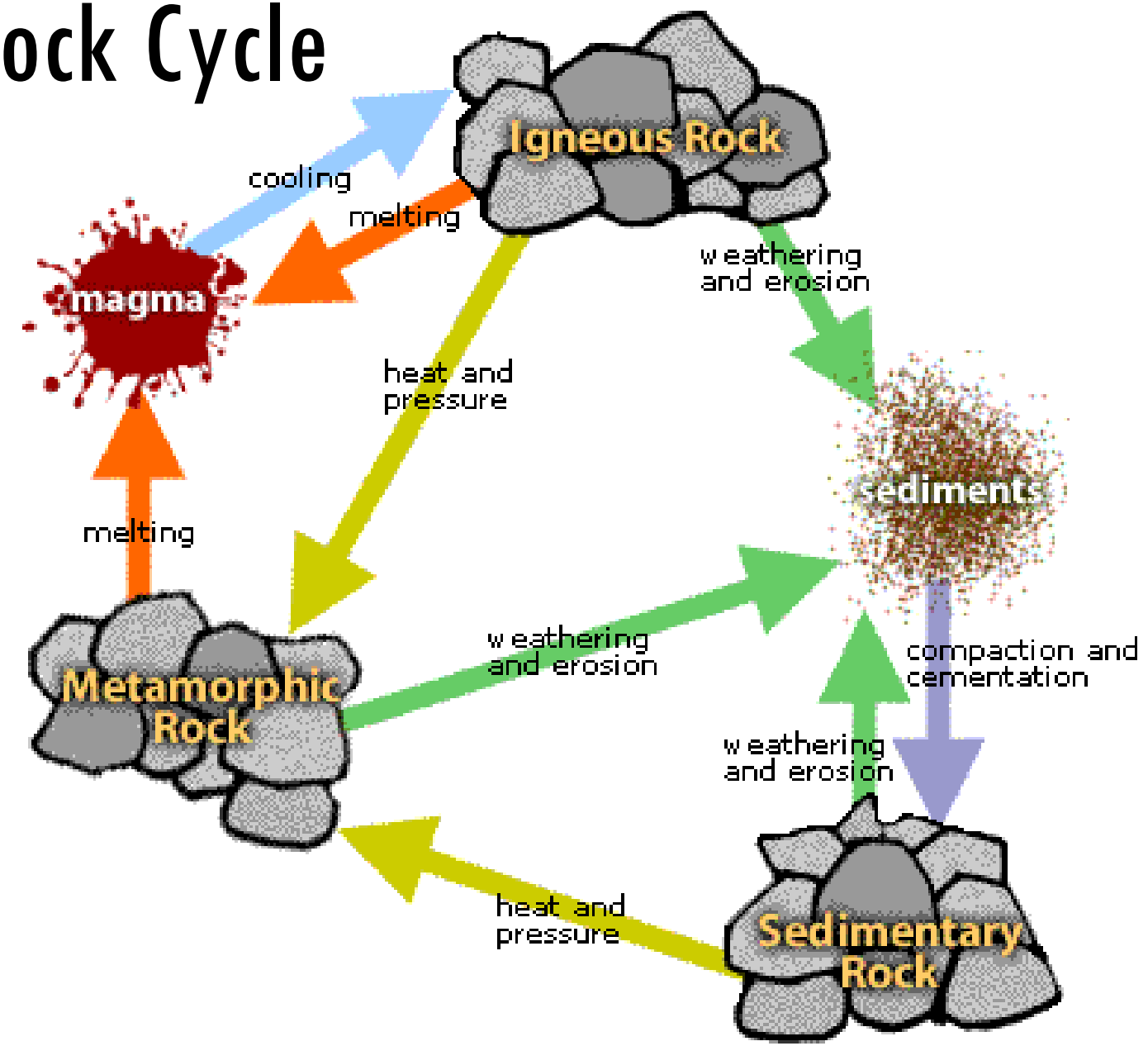


# SOIL COMPONENTS



# Development of Soil

# The Rock Cycle



# Types of rock

- Magma: molten rock
- Igneous : cold, solid magma
- Sedimentary: materials deposited from suspension or precipitated from solution
- Metamorphic: rocks changed by heat and pressure

# Weathering of Rocks and Minerals

# Weathering

- The breaking down of rocks and other materials on the Earth's surface is called weathering.  A slow, continuous process, it affects all substances exposed to the atmosphere.

# Weathering of rocks and minerals

- Rocks weather into minerals
- Physical and chemical processes
- Continues until primary particles formed
- Primary particles can be further altered

# Types of Weathering

- Rocks on the Earth's surface are broken down by two types of weathering: mechanical and chemical.

# Chemical Weathering

- When the chemical makeup of the rocks is changed it is called chemical weathering. During chemical weathering, changes occur in the mineral composition of rocks. Minerals can be added, removed or broken down (decomposed).Many substances react chemically with rocks to break them down.

# Chemical weathering

Accelerated by the presence of

- water (and its dissolved solutes)
- oxygen
- organic and inorganic acids
- Decomposition

# Chemical weathering

- converts primary minerals into secondary minerals
- e.g. feldspars and micas into clays

# Chemical processes

**There are several causes of chemical weathering**

- Carbonation
- Hydration
- Hydrolysis
- Oxidation
- Sulfuric Acid
- Plant Acid

# Carbonation

- A chemical weathering process in which dilute carbonic acid reacts with a mineral

- Carbonic acid is derived from the solution in water of free atmospheric soil-air carbon dioxide

# Carbonation

- When carbon dioxide dissolves in water, a weak acid called carbonic acid is formed. When carbonic acid reacts chemically with other substance, the process of carbonation occurs. In nature, carbonic acid is formed when carbon dioxide in the air dissolves in rain. This acid rain falls to the ground and sinks into the soil. It decomposes feldspar and limestone.

# Carbonation

- Rainwater dissolves $CO_2$ producing carbonic acid.
- This acid can dissolve limestone

$$CO_2 + H_2O \not\Rightarrow H_2CO$$

# Hydration

- Chemical combination of water with another substance
- Mineral plus water forms new mineral

$$Ca_2SO + H_2O \leftrightarrows CaSO \bullet 2\ H_2O$$

# Water

Most chemical weathering is caused by water and carbon dioxide. Water can dissolve most of the mineral that hold rocks together. Rocks that dissolve in water are said to be soluble. Water can form acids when it mixes with certain gases in the atmosphere to speed up the decomposition of rocks. Water can also combine with a mineral to form a new mineral.

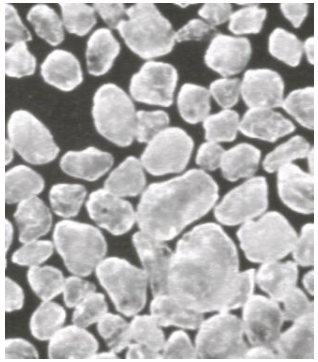
# Hydrolysis

The process by which a substrate is split to form two end products by the intervention of a molecule of water

$$2HAlSi_3O_8 + 11H_2O \leftarrow Al_2O_3 + 6H_4SiO_4$$

# Question

What is the main mineral of the sand particles in general?



Quartz

# Oxidation

- Chemical weathering is also caused by oxidation. Oxidation is the process in which oxygen chemically combines with another substance. The result of oxidation is the formation of an entirely different substance. Iron in rocks combines with oxygen in the air to form iron oxide, or rust.

# Oxidation

- A reaction in which atoms or molecules gain oxygen or lose hydrogen or electrons
- Iron plus oxygen produces rust

$$Fe^{2+} \rightarrow Fe^{3+} + \text{electron}$$

# Sulfuric Acid

- The air in certain areas is polluted with sulfur oxides. Sulfur oxides are a byproduct of the burning of coal as a source of energy. These compounds dissolve in rainwater to form sulfuric acid. Rain that contains sulfuric acid is one type of acid rain. It is much stronger than carbonic acid. Sulfuric acid corrodes rocks, metals and other materials quickly.

# Plant Acids

- Plants produce weak acids that dissolve certain minerals in rocks.  Mosses and lichens produce weak acids that dissolve some of the minerals in the rocks they grow on.  Gradually the rocks break into smaller pieces. They are important in the formation of soil.

# Physical/Mechanical Weathering

- When the forces of weathering break rocks into smaller pieces but do not change the chemical makeup of the rocks, the process is called mechanical weathering. During mechanical weathering, rocks are broken into different shapes and smaller pieces.  At the beginning the edges are jagged, as weathering continues, they become round.

# Causes of Mechanical Weathering

There are several causes of mechanical weathering.

- Temperature
- Frost action
- Organic activity
- Gravity
- abrasion

# Temperature

- Rocks can be broken apart by changes in temperature. As rocks are heat up in the sun during the day, the outside of the rock expands. The inside of the rocks remain cool and do not expand. When the air temperature drops at night, the outside of the rock cools and contracts. This continuing cycle causes particles to break off. This is called exfoliation.

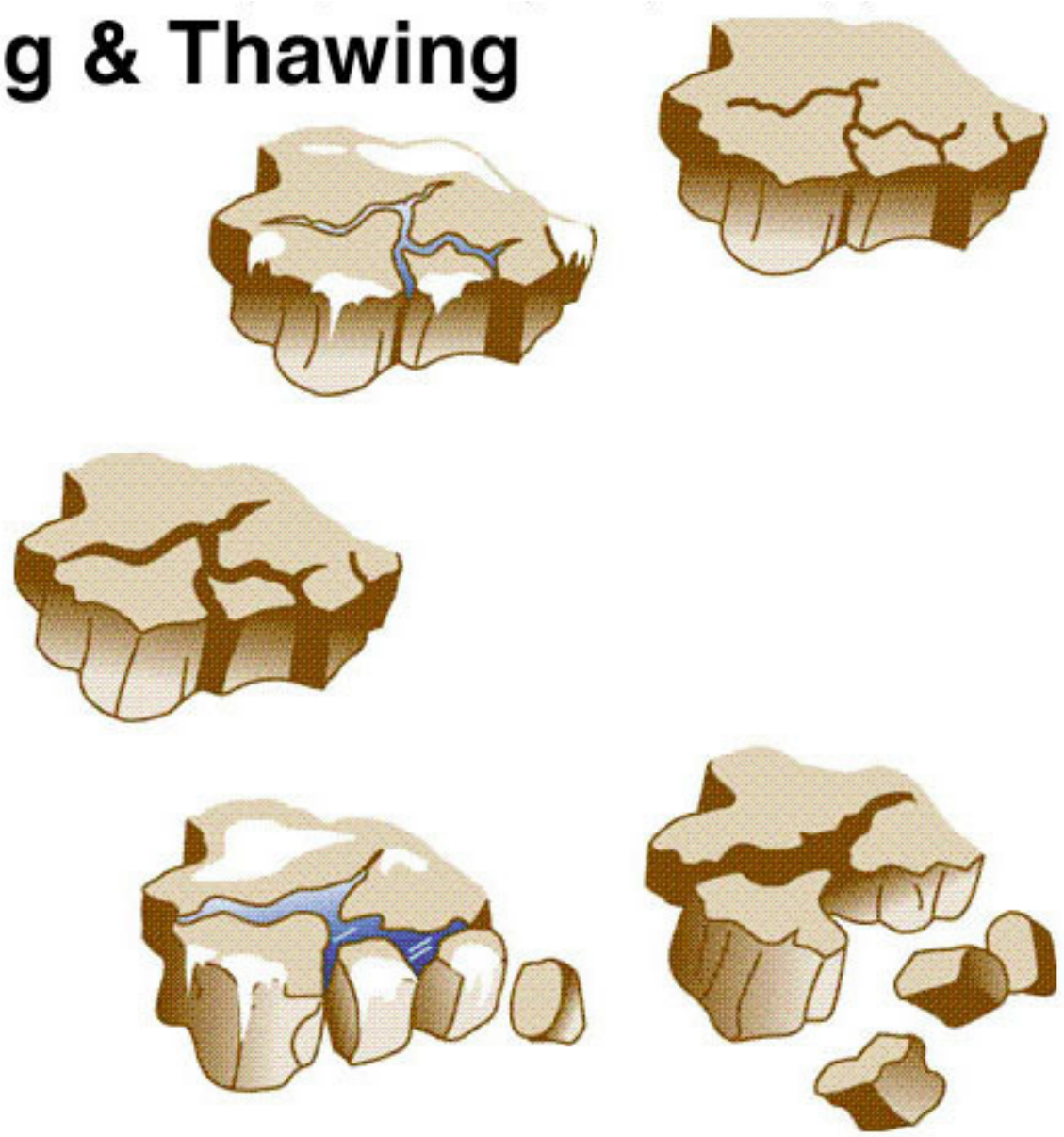
# Temperature

- Daytime heating and night cooling
- Differential heating
- Water freezing in cracks
  - Thermal expansion and contraction
  - Alternate wetting and drying
  - Crystal growth, including frost action

# Frost Action

- Unlike most liquids, water expands when it freezes.  The repeated freezing and melting of water, called frost action, is another cause of mechanical weathering. When water freezes in cracks in the rocks, it expands, making the crack larger.In time, this causes the rock to break into pieces.

# Freezing & Thawing



# Organic Activity

## Plants and Animals

- Plants and animals can cause mechanical weathering. The roots of plants sometimes loosens rock material. A plant growing in a crack can make the crack larger as the root spread out. This is known as root-pry. It is organic since this activity is caused by living things.

- Animals move into and through soil/Rock and causes disintegration

# Gravity

- Gravity is another agent of mechanical weathering.  Sometimes gravity pulls loosened rocks down mountain cliffs in a landslide.  A landslide is a large movement of loose rocks and soil.  As the rocks fall, they collide with one another and break into smaller pieces. Falling rocks usually occur in areas where a road has been cut through, leaving cliffs on both sides.

# Abrasion

- Wind-blown sand causes mechanical weathering . Abrasion is the wearing away of rocks by solid particles carried by wind, water or other forces. In desert regions, the wind easily picks up and moves sand. The sharp edges of the sand particles scrape off pieces of exposed rocks. Running water also carries loose rocks which scrape against each other and break.

# Water, Ice and Wind

- Cutting power of water
- Water abrasion
- Glaciation
- Wind abrasion

- Factors affect weathering

  – Many factors can affect the weathering process such as
  – climate,
  – topography,
  – features of parent rocks,
  – biological reactions, and others.

# Rate of Weathering

- The rate of weathering depends on several factors, including:
- The composition of the rock
- The amount of time that the rock is exposed on the Earth's surface
- The amount of exposed surface on a rock

# Composition of Rocks

- Two different types of rocks in the same climate can weather differently, depending on the minerals that make up each rock type.  If the minerals in a rock resist chemical weathering, the rock is called a stable rock.  The stability of a rock can vary depending on the climate in which the rock is found. Limestone is stable in a dry climate but not in a wet climate.

# Amount of Time of Exposure

- The amount of time that rock is exposed on the Earth's surface also affects its rate of weathering. A very old rock that has not been exposed to the forces of weathering can remain almost unchanged. If a newly formed rock is deposited on the Earth's surface it will begin to weather right away.

# The Amount of Exposed Surface

- The amount of exposed surface area on a rock also affects its rate of weathering. As rocks are broken down into many small pieces, more rock surfaces are exposed and more weathering takes place. In rocks that contain many joints or cracks, various chemicals easily come into contact with the rock surfaces and break them down.

# Transportation of Weathering Products

- **Residual soils-**

- to remain at the original place

.

**The knowledge of "classical" geotechnical engineering is mostly based on behavior of transported soils. The understanding of residual soils is insufficient in general**

# Residual Soil

- Sometimes soil remains on top of its parent rock, or the rock from which it was formed.  This is called residual soil. Residual soil has a composition similar to that of the parent rock it covers.

# Transported Soil

- Some soil is removed from the parent rock by water, wind, glaciers and waves.soil that is moved away from its place of origin is called transported soil.  Transported soil can be very different in composition from the rock it covers.

## **Transported soils**-

- to be moved and deposited to other places.
  - The transported soils can be categorize based on the mode of transportation and deposition (six types).
  - The particle sizes of transported soils are selected by the transportation agents such as streams, wind, etc.

# Transported Soils (Cont.)

(1) **Glacial soils**: formed by transportation and deposition of glaciers.

(2) **Alluvial soils**: transported by running water and deposited along streams.

(3) **Lacustrine soils**: formed by deposition in quiet lakes.

(4) **Marine soils**: formed by deposition in the seas.

(5) **Aeolian soils**: transported and deposited by the wind .

(6) **Colluvial soils**: formed by movement of soil from its original place by gravity, such as during landslide

# Glacial

- An accumulation of earth, usually with stones, carried and deposited by a glacier
- heterogeneous
- unsorted and unstratified

# Glacial material

# ALLUVIAL

- Deposited by flowing water
- Gravel, sand, and/or silts
- Rounded grains, sorted and stratified

# Alluvial Soils

# Lacustrine deposits

- Deposited in lakes
- Stratified
- Sorted
- Absence of stones - usually

# Lacustrine parent material

# Aeolian deposits

- Transported and deposited by wind
- Medium to fine sized sand
- Medium to fine sized silt
- or both sand and  silt
- Sorted

# Aolian parent material

# Colluvial

- Moved by gravity
- Heterogeneous mix of sizes
- Unsorted
- Unstratified
- Rock fall

# Colluvial parent material

# Soil Formation

Soils can take 100’s to 1000’s of years to fully develop.

# Factors affecting soil formation

Climate (precipitation, temperature)

Vegetation (plants)

Parent material/Type of Rock (geological/organic)

Organisms (soil microbes/fauna)/ Living Things

Relief (configuration of surface)/ (Topography)

Time

Human Impacts

# Climate

- Climate is an important factor in the formation of soil.  In areas with heavy rainfall and warm temperatures, weathering takes place more rapidly. Heavy rainfall may wash much of the topsoil away. Since Organisms are more plentiful these areas, the soil is quickly replaced.  They speed up the chemical and mechanical weathering of rocks.

# Climate

- Temperature
- Precipitation
- Control the rate of weathering processes

# Climate

- Length of growing season
- Length of frost free season
- Amount and intensity of rainfall

# Vegetation

- Type and amount
- pH of the plant material
- Natural or disturbed

# Parent material

- Type
- Resistance to weathering
- Weathering products

# Type of Rock

- The type of rock in an area also affects soil formation. Some rocks do not weather as rapidly as other do. Rocks that do not break down easily do not form soil rapidly. In some climates it takes along time for granite to break down. So soil formation from granite is slow. But sandstone breaks easily and forms soil quickly.

# Living Things

- Living things such as moles, earthworms, ants and beetles help to break apart large pieces of soil as they burrow through the ground. The burrows allow water to move rapidly through the soil. The water speeds up the weathering of the underlying rock.

# Soil Organisms

Different sizes

- Bacteria
- Fungi
- Microfauna
- Earthworms
- Gophers

# Soil organisms

- Need food
- Need water and air
- Like it warm
- Types and amounts

# Topography

- The shape of the landscape
- Water moves downslope
- Wind moves material
- Gravity moves material downward
- Controls where materials come from and where they are deposited

# Time

- Time is one of the most important factors in soil formation.  The longer a rock is exposed to the forces of weathering, the more it is broken down.  Mature soil is formed if all three layers have had time to develop.

# Human Impacts

- Alteration of natural vegetation
- Tillage
- Irrigation
- Addition of wastes and fertilizers
- Addition of pollutants

# Soil forming formula

$$S = f\,(cl, v, pm, r, o)_t$$

where s is soil property, cl is climate,
v is vegetation, pm is parent material,
r is relief (topography), and
o is soil organisms.

# Different Compositions of Soil

- The composition of soil varies from place to place. The type of rock broken down by weathering determines the kinds of minerals in the soil. The type of weathering also affects the composition of soil. Mechanical weathering produces soil with a composition similar to the rock being weathered. Chemical weathering produces soil with a different composition.

# Characteristics of Soil:

- Physical Characteristics
  - **Soil Texture, Consistency, & Structure**
  - **Soil Compaction (Bulk Density)**
  - **Soil Moisture**

- Chemical Characteristics

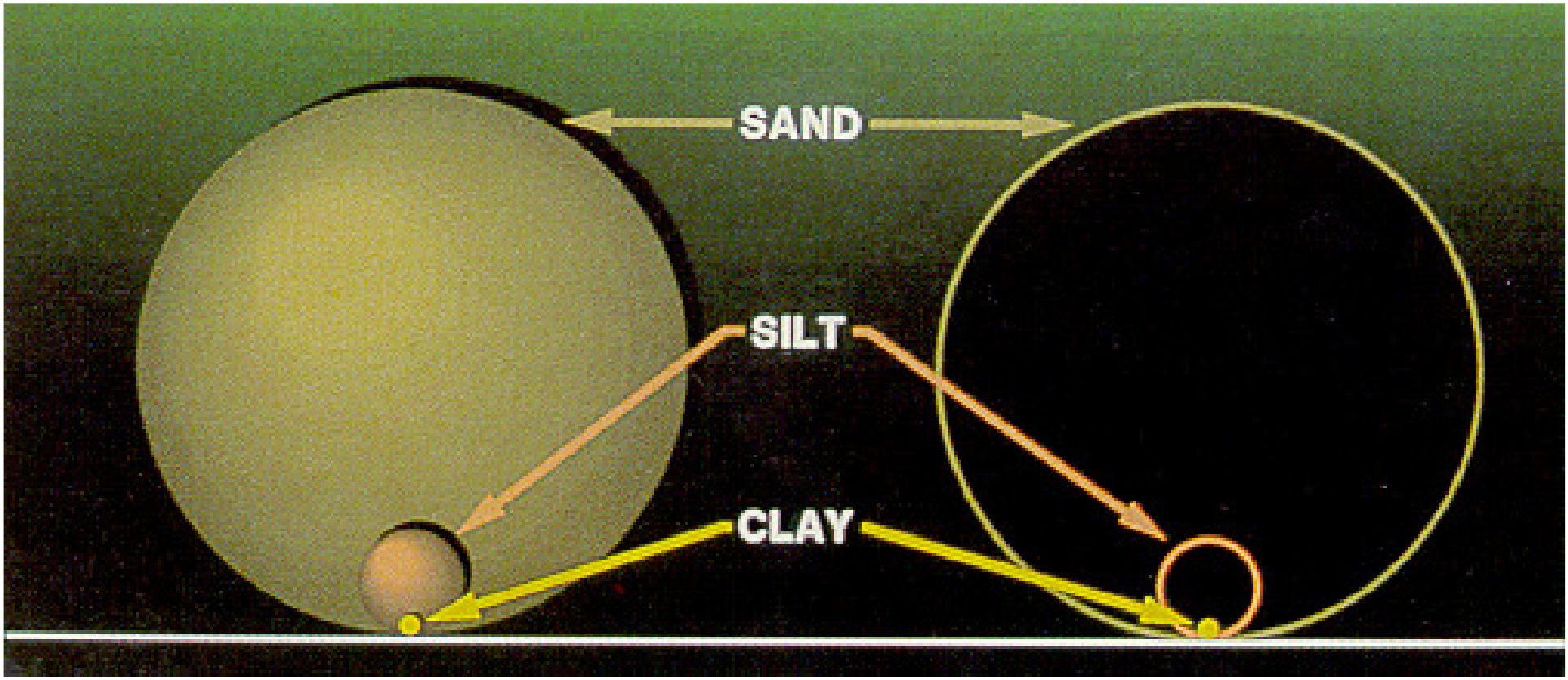
  **-Chemical bonding**
  - **pH**
  - **Cation Exchange Capacity (CEC)**
  - **Nutrient Availability**

# Physical Characteristics of Soil:

- **Texture:** the mineral components
- **Consistency & Structure:** How the mineral components are put together
- Bulk Density
- Soil Moisture

# Soil Texture:

- The way the soil "feels" is called the soil texture.
- Soil texture depends on the amount of each size of mineral particles in the soil.
- Sand, silt, and clay are names that describe the size of individual mineral particles in the soil.
  - ➔**Sand** are the largest particles and they fell "gritty"
  - ➔**Silt** are medium sized, and they feel soft, silky or "floury"
  - ➔**Clay** are the smallest sized particles, and they feel "sticky"




# Soil Particles

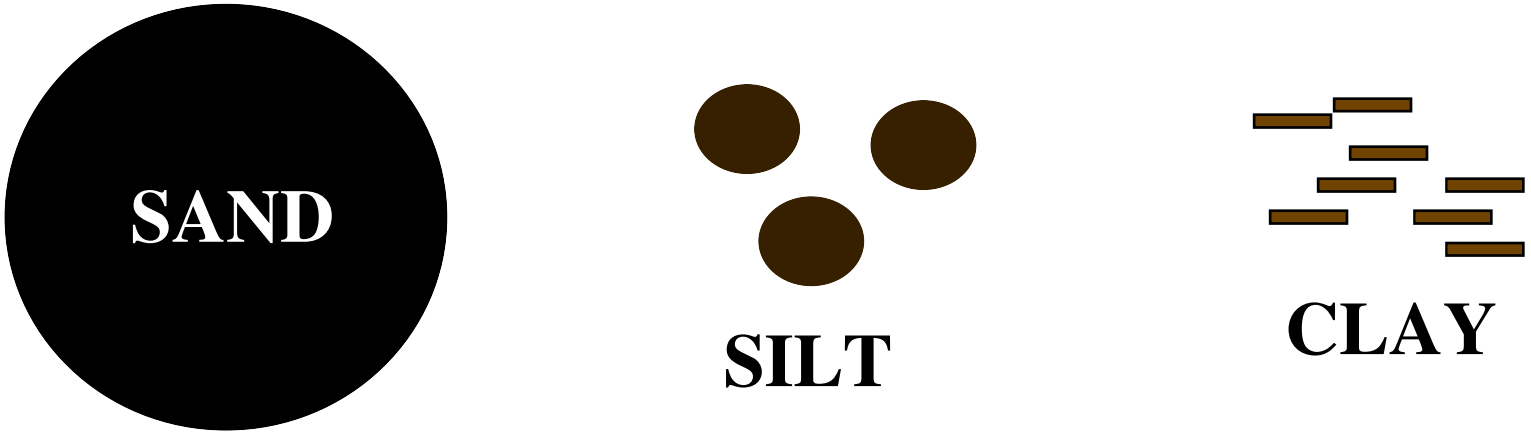
Note: clays are microscopic in size !

# Soil separate particle diameter (mm)

**Sand . . . . . 2.0 - 0.05**

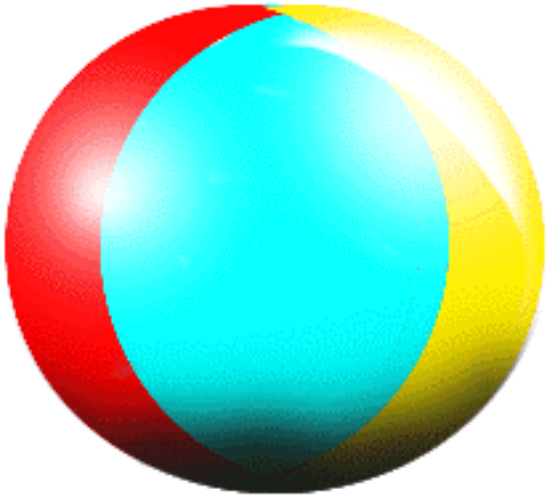
**Silt . . . . . 0.05 - 0.002**

**Clay . . . . . <0.002**



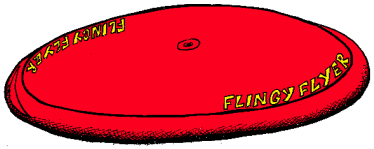
# Soil Texture: Relative Size Comparison of Soil Particles

**Beach ball**



Sand
(feels gritty)
(2.00 - 0.05 mm, USDA)
(2.00 - 0.02 mm, ISSS)

**frisbee**




Silt
(feels floury)
(0.05 - 0.002 mm, USDA)
(0.02 - 0.002 mm, ISSS)

**dime**

Clay
(feels sticky)
(< 0.002 mm, USDA)
(< 0.002 mm, ISSS)

# Effects of Soil Texture:

- Soils are more cohesive when they have more fine particles (Clays).
- Soils are more loose when the have more coarse particles (Sand).
- Different combinations of coarse and fine contents produce different soil textures.
- A loam is a mixture of sand, silt and clay:  sandy clay loam is best in landscapes.
- Many other inclusions, such as cobbles, boulders.

- **Soil Consistency**

  – Describes the general organization of the soil

  – Hold a moist sample between the thumb and forefinger, and gently squeeze it until it falls apart.

- **Soil Consistency**

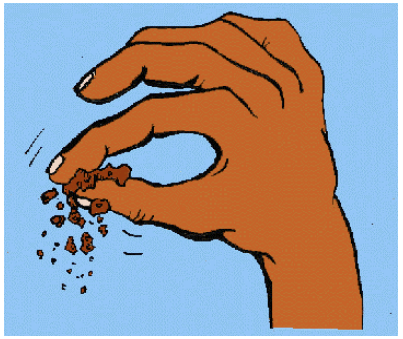
The soil is classified by the following categories

- **Loose:** You have trouble picking out a single sample and the structure falls apart before you handle it.
- **Friable:** The sample breaks with a small amount of pressure.
- **Firm:** The sample breaks when you apply a good amount of pressure and dents your fingers before it breaks.
- **Extremely Firm:** The sample can't be crushed with your fingers (you need a hammer!).

# Soil Consistence

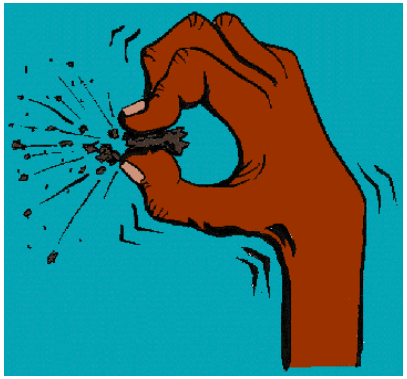
## Loose*

## Friable



* Soils with “single grained” structure **always** have **loose** consistence.

## Firm



## Extremely Firm

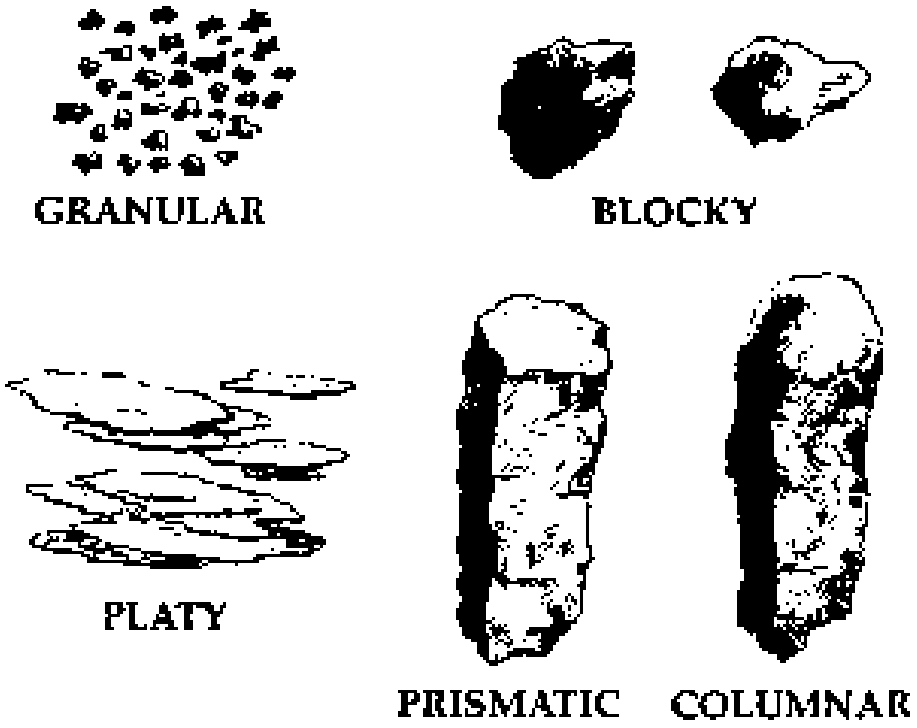
# Soil Structure

the shape that the soil takes based on its physical and chemical properties. Possible choices of soil structure are:

- With Structure:
  - **Granular**
  - **Blocky**
  - **Platy**
  - **Prismatic**
  - **Columnar**
- Without Structure
  - **Single Grained**
  - **Massive**

# Soil Structure:

- With Structure:



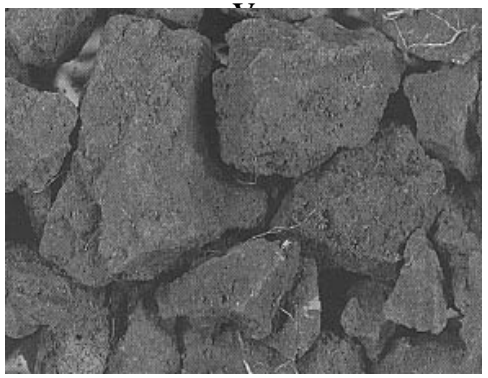

*Choices of Soil Structure*

- Without Structure
  - **Single Grained:**
    - **beach sand**
  - **Massive**
    - **solid mass with no shape**

# Soil Structure:  with Structure

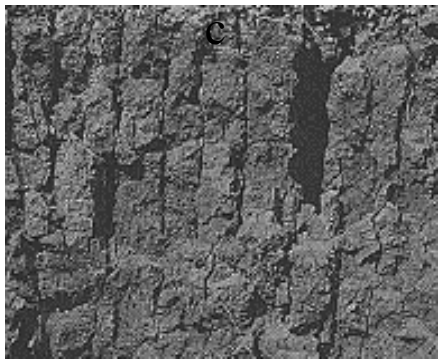
Granular

Block



Columna

Prismati

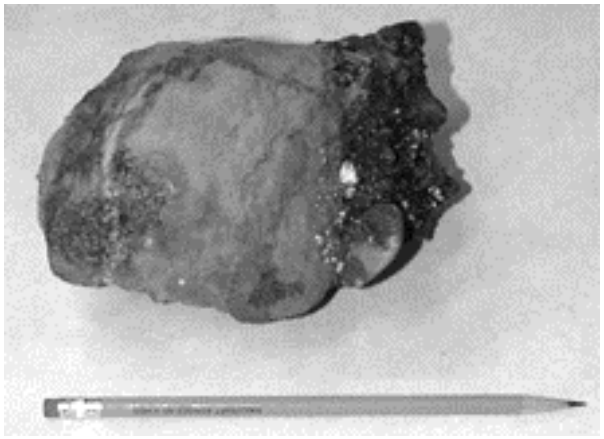


Platy

# Soil Structure: without Structure

Single Grained

Massive



# Soil Structure

- Physical property
- Combination of primary soil particles into secondary particles
- Different shapes and sizes

# Soil Structure

- Grade, size, shape of the arrangements
- Example: Strong, coarse, angular blocky
- Structure affects the size and shape of pores
- Aggregation very important

# Soil Colour

Tells us something about:

- the air and water regimes in the soil
- the amount of organic matter
- the types of minerals that make up the soil