01. Soil – Pedological and Edaphological concepts

Soil science is the study of soil as a natural resource on the surface of the earth including soil formation, classification and mapping; physical, chemical, biological, and fertility properties of soils; and these properties in relation to the use and management of soils.

Sometimes terms which refer to branches of soil science, such as pedology (formation, chemistry, morphology and classification of soil) and edaphology (influence of soil on organisms, especially plants), are used as if synonymous with soil science. The diversity of names associated with this discipline is related to the various associations concerned. Indeed, engineers, agronomists, chemists, geologists, physical geographers, ecologists, biologists, microbiologists, sylviculturists, sanitarians, archaeologists, and specialists in regional planning, all contribute to further knowledge of soils and the advancement of the soil sciences.

Soil scientists have raised concerns about how to preserve soil and arable land in a world with a growing population, possible future water crisis, increasing per capita food consumption, and land degradation.

Soil occupies the pedosphere, one of Earth's spheres that the geosciences use to organize the Earth conceptually. This is the conceptual perspective of pedology and edaphology, the two main branches of soil science. Pedology is the study of soil in its natural setting. Edaphology is the study of soil in relation to soil-dependent uses. Both branches apply a combination of soil physics, soil chemistry, and soil biology. Due to the numerous interactions between the biosphere, atmosphere andhydrosphere that are hosted within the pedosphere, more integrated, less soil-centric concepts are also valuable. Many concepts essential to understanding soil come from individuals not identifiable strictly as soil scientists. This highlights theinterdisciplinary nature of soil concepts.

Soil Science

"The science dealing with soil as a natural resource on the surface of the earth, including Pedology (soil genesis, classification and mapping), physical, chemical, biological and fertility properties of soil and these properties in relation to their management for crop production."

Soil Science has six well defined and developed disciplines

Soil fertility   :   Nutrient supplying properties of soil

Soil chemistry	:	Chemical constituents, chemical properties and the chemical reactions
Soil physics	:	Involves the study of physical properties
Soil microbiology	:	Deals with micro organisms, its population, classification, its role in transformations
Soil conservation	:	Dealing with protection of soil against physical loss by erosion or against chemical deterioration i.e excessive loss of nutrients either natural or artificial means.
Soil Pedology	:	Dealing with the genesis, survey and classification

Views on Soil (Science)

The term SOIL was derived from the Latin Word "SOLUM" Means FLOOR

- For a Layman soil is dirt or debris
- For an Agriculturist soil is a habitat for plant growth (to grow crops)
- For a Mining Engineer soil is a debris covering the Rocks
- For a Civil Engineer soil is a material on which road bed or house bed is formed
- For a Home Owner soil is a mellow or loamy or hard material

Definitions

Generally soil refers to the loose surface of the earth as identified from the original rocks and minerals from which it is derived through weathering process.

Whitney (1892): Soil is a nutrient bin which supplies all the nutrients required for plant growth

Hilgard (1892): Soil is more or less a loose and friable material in which plants, by means of their roots, find a foothold for nourishment as well as for other conditions of growth"

Dokuchaiev (1900): Russian scientist - Father of soil science - Soil is a natural body composed of mineral and organic constituents, having a definite genesis and a distinct nature of its own.

Joffe (1936): "Soil is a natural body of mineral and organic constituents differentiated into horizons - usually unconsolidated - of variable depth which differs among themselves as well as from the underlying parent material in morphology, physical makeup, chemical properties and composition and biological characteristics".

Jenny (1941): Soil is a naturally occurring body that has been formed due to combined influence of climate and living organisms acting on parent material as conditioned by relief over a period of time.

Ruffin and Simonson (1968): Soil is a mixture of Earth's uppermost mantle of weathered rock and organic matter

Buckman and Brady (1969): Soil is a dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms

Soil Science Society of America (1970)

(i) Soil is the unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of parent material, climate (including moisture and temperature effects), macro and microorganisms and topography, all affecting over a period of time and producing a product, that is "SOIL" that differs from the material from which it is derived in many, physical, chemical, biological and morphological properties and characteristics.

(ii) The unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.

Dr. W.E.H. Blum

Soils not only serve for agriculture and forestry, but also for filtering, buffering and transformation activities between the atmosphere and the ground water, protecting the food chain and drinking water against pollution and biodiversity

As soil provides nutrients, water, air and anchorage and supports life on Earth, it can be called as Soul Of Infinite Life (SOIL)

List of International Soil Scientists

1. Van Helmont (1577 – 1644)
2. Theoder De Saussure
3. John Woodward
4. Boussingault (1802 – 1882)
5. J.V. Liebig (1803 – 1873)
6. J.B.Laws & J.H. Gilbert (1855)
7. J.T.Way (1856)
8. R.Warrington (1876)
9. E.W. Hilgard (1860)
10. V.V. Dokuchaiev (1846-1903)
11. K.D.Glinga (1914)
12. C.F.Marbut (1927)
13. Hens Jenny (1941)

Indian Scientists

1. J.W.Leather (1906)
2. Madam Scholasky (1932)

3. Wadia et al. (1935)
4. Viswanath & Ukil (1943)

Soil as a three dimensional body

Soil is a three dimensional body having length, breadth and depth. They form a continuation over the land surface and differ in properties from place to place. Its upper boundary is air or water and lower boundary is the rock lithosphere.

Composition of soil on volume basis (Soil components)

Mineral matter   : 45%

Organic matter   : 5%

Soil water   : 25%

Soil air   : 25%

Soil can be compared to various systems of animals

Digestive system   : Organic matter decomposition

Respiratory system   : Air circulation & exchange of gases

Circulatory system (blood) : Water movement within the soil

Excretory system   : Leaching out of excess salts

Brain   : Soil clay

Colour   : Soil colour

Height   : Soil depth

Approaches of Soil Study

Two Concepts: One treats soil as a natural body, weathered and synthesized product in nature (Pedology) while other treats soil as a medium for plant growth (Edaphology).

Pedological Approach: The origin of the soil, its classification and its description are examined in Pedology. (From Greek word *pedon*, means soil or earth). Pedology is the study of soil as a natural body and does not focus on the soil's immediate practical use. A pedologist studies, examines and classifies soil as they occur in their natural environment.

Edaphological Approach: Edophology (from Greek word *edaphos*, means soil or ground) is the study of soil from the stand point of higher plants. Edaphologists consider the various properties of soil in relation to plant production. They are practical and have the production of food and fibre as their ultimate goal. They must determine the reasons for variation in the productivity of soils and find means for improvement.

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Origin of the earth – Earth's crust – Composition

Origin of earth

Earth is one of the 9 planets (8 excluding Pluto) orbiting the SUN in the Solar System. The Universe is composed of several Galaxies. Our solar system is part of Milky way galaxy which is disk shaped with about 1, 00,000 million stars of varying sizes. Our solar system consists of 9 planets and 31 satellites, a belt of asteroids.
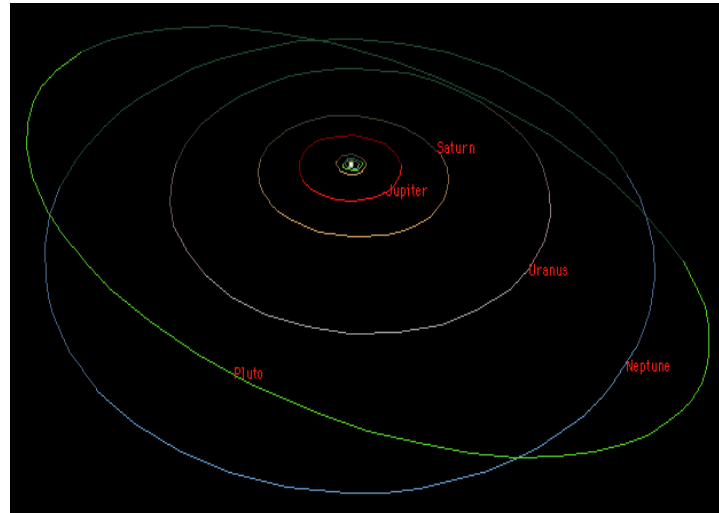

Theories about origin of Earth

Nebular hypothesis (Kant and Laplace, 1755)

This hypothesis suggests that the solar system formed through the condensation of a nebula which once encircled the Sun. The outer planets formed first, followed by Mars, the Earth, Venus, and Mercury. This hypothesis suggests a sequential origin from outermost planet to innermost. As per this hypothesis, Mars evolved earlier than the Earth. This hypothesis is widely accepted to explain origin of different planets.

During the past, the entire solar systems existed as a hot gaseous mass called nebula rotating in space. With time, the gaseous mass (nebula) cooled and contracted. Due to contraction, there developed a bulge at the equatorial region. This bulge subsequently separated into several rings. The ring coalesces in the form of a globe and continues to revolve around the nebula. In similar manner, ten rings were formed of which nine of them gave rise to nine planets.

One broke down into smaller fragments to form the group of planetoids, while the remnant of the pre-existing nebula formed the central incandescent mass of the solar system and is known as the **Sun**. The planets were originally gaseous but were subsequently cooled down into liquid and ultimately to the solid state.

Nebular Hypothesis
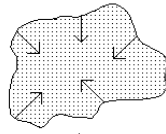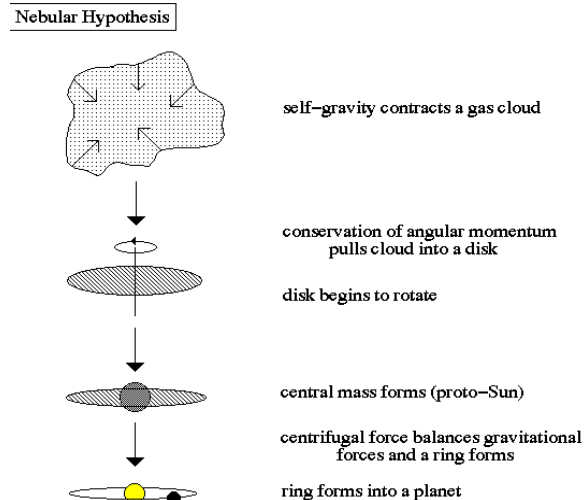
self–gravity contracts a gas cloud
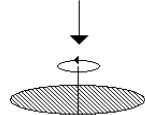
conservation of angular momentum pulls cloud into a disk

disk begins to rotate

central mass forms (proto–Sun)

centrifugal force balances gravitational forces and a ring forms

ring forms into a planet

Planetismal hypothesis (Chamberlain and Moulton, 1905)

Planets were formed as a result of mutual interaction between the sun and another star of suitable size. This is the theory of **biparental** origin of the solar system. This theory postulates that due to the near approach of a larger star, tidal distortions were raised upon the surface of the sun and these in conjunction with the eruptive force prevalent in the sun (known as the solar prominence) brought about a description of the mass of the sun and a number of gaseous bulbs were shot forth, in space, to great distances.

These gaseous solar materials thus ejected in space were subjected to immediate chilling, resulting in the formation of a number of minute solid particles known as **planetisimals**

These planetisimals continued to rotate round the sun in highly elliptical orbits. The orbits must have happened to intersect one another and at points of intersection, they must have collided whereby the small planetisimals continued to coalesce gradually giving rise to the planets. During collision and coalescence of the planetisimals, large quantities of heat must have been generated and were dissipated in space before the next collision could occur and accordingly the planets must have been solid all the time during the growth.

This theory accepts that the collision must have taken place in quick succession and accumulation of heat might have caused a melting of the masses of the planets.

Gaseous tidal hypothesis (Jeans and Jeffreys, 1925)

This also accepts the idea of biparental origin like that of planetisimal hypothesis but refuses to consider the disruptive forces in the sun (i.e. the solar prominence) had anything to do with the formation of the planets.

According to Jeans and Jeffreys, during the ancient past, an extremely large star, while moving in space chanced to approach the sun. Due to progressive and nearer approach of the star, a tidal pull was raised on the surface of the sun and this increased in size with the

nearer approach of the passing star. At the stage, where the passing star began to recede, the tidal pull on the surface of the sun, thus formed, was detached from the body of the sun in the shape of a spindle bulging near the centre and tapering at both ends. This very large mass of gas, thus ejected in space, was naturally extremely unstable and was immediately broken down into a number of small fragments. In all, ten such pieces were formed, nine giving rise to the planets and one, which was broken down into pieces, to the group of planetoid. These fragments formed into globular masses revolving round the sun along definite orbits and cooled down gradually from the gaseous to the liquid and ultimately to the solid state.

This hypothesis is the most popular one due to do simplicity and capability of explaining the co-planar placement of the planets and the features relating to the distribution of mass and density in them and the density stratification that exists within the earth.

Tectonic plate theory

Tectonic plates are layers of rock inside the earth. This crust and upper mantle form lithosphere. Under the lithosphere lies a fluid rock layer called asthenosphere. The rocks in Tectonic plates are able to float upon the asthenosphere. There are seven large and several small plates. The largest plates include the pacific, North American, Eurasian, Antarctic and African plates.
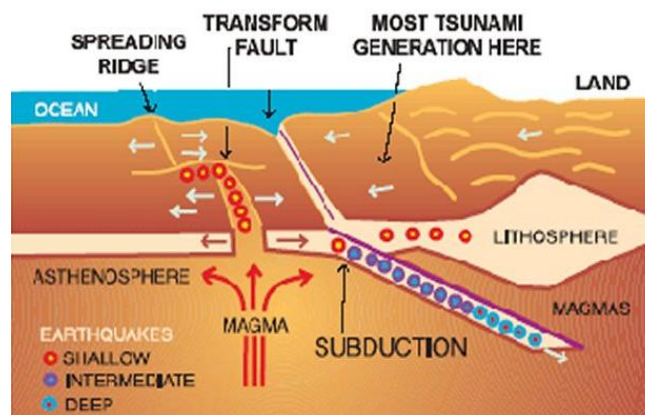

Continental drift theory

The huge land masses of the earth are in constant movement. The continents and the oceans rest upon rock plates. They move relative to each other at rates of few centimeters a year. Until 200 million years ago, the continents were connected into one single land mass called Pangaea. This Pangaea splits and pieces drifted apart creating 2 new continents160 million years ago. The land mass that was to become India separated and

moved north ward (140 million years ago) and hit another landmass leading to the eruption of the Himalayas. Australia separated from Antarctica (100 million years ago). The two super continents then pulled apart east and west opening the Atlantic oceans.

The continents are still moving even today. The continental drift makes the Pacific Ocean smaller, the Atlantic Ocean larger and the Himalayan Mountains taller. The Atlantic oceans become wider, Mediterranean Sea collapses and Australia reaches equator in 60 million years.
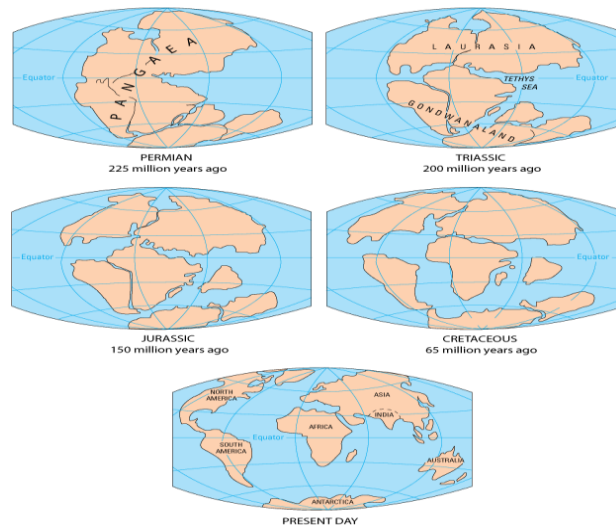
Age of the earth

So far scientists have not found a way to determine the exact age of the Earth directly from Earth rocks because Earth's oldest rocks have been recycled and destroyed. Nevertheless, scientists have been able to determine the probable age of the Solar System and to calculate an age for the Earth by assuming that the Earth and the rest of the solid bodies in the Solar System formed at the same time and are, therefore, of the same age.

The ages of Earth and Moon rocks and of meteorites are measured by the decay of long-lived radioactive isotopes of elements that occur naturally in rocks and minerals and that decay with half lives of 700 million to more than 100 billion years to stable isotopes of other elements. These dating techniques, which are firmly grounded in physics and are known collectively as radiometric dating, are used to measure the last time that the rock being dated was either melted or disturbed sufficiently to rehomogenize its radioactive elements.

These ancient rocks have been dated by a number of radiometric dating methods and the consistency of the results give scientists confidence that the ages are correct to within a few percent. An interesting feature of these ancient rocks is that they are not from

any sort of 'primordial crust' but are lava flows and sediments deposited in shallow water, an indication that Earth history began well before these rocks were deposited.

In Western Australia, single zircon crystals found in younger sedimentary rocks have radiometric ages of as much as 4.3 billion years, making these tiny crystals the oldest materials to be found on Earth so far. The source rocks for these zircon crystals have not yet been found. The ages measured for Earth's oldest rocks and oldest crystals show that the Earth is at least 4.3 billion years in age but do not reveal the exact age of Earth's formation.

The best age for the Earth (4.54 Ga) is based on old mineral grains (zircon) with U-Pb ages of 4.4 Ga have recently been reported from sedimentary rocks in west-central Australia. The oldest dated moon rocks, however, have ages between 4.4 and 4.5 billion years and provide a minimum age for the formation of our nearest planetary neighbour. The age of 4.54 billion years found for the Solar System and Earth is consistent with current calculations of 11 to 13 billion years for the age of the Milky Way Galaxy (based on the stage of evolution of globular cluster stars) and the age of 10 to 15 billion years for the age of the Universe.

Geological Time Scale of Earth – Development of Life

Era	Period	Age (m.Yr)	Organism
Archean	Archean	> 3500	Lifeless
Precambrian	Precambrian	-do-	Soft bodied plant & animals
Palaeozoic	Cambrian	500	Algae and shell bearing molluscus
	Ordovician	400	Molluscus & sea weeds
	Silurian	360	Land plants & breathing land animals
	Devonian	320	True fishes and ampibians
	Carboniferous	280	Coal forming materials , non flowering plants
	Permian	246	Reptiles
Mesozoic	Triassic	235	Marine life & reptiles
	Jurassic	185	Dinosours
	Cretaceous	139	Many plants & fishes
Cenozoic	Tertiary Eocine	20	Mammals

	Myocine	29	Mammals
	Pliocine	10	Mammals
	Quartanary		
	Plistocine	01	Mammals
	Recent time		Mammals

Radius, distance from sun and revolution period

S.No	Planet	Radius (km)	Distance from sun(m.k)	Revolution period (day)
1	Mercury	2439	57.9	88
2	Venus	6052	108.2	245
3	Earth	6378	149.4	365.25
4	Mars	3397	227.9	687
5	Jupiter	71398	778.3	4333
6	Saturn	60000	1427	10743
7	Uranus	23620	2870	30700
8	Neptune	24300	4496.5	60280
9	Pluto	1150	5970	90130

Present condition of the earth

Our earth is supposed to have been formed in similar manner. It must have been hot and plastic when it was first formed. At present the outside of the earth is quite cool and solid but the interior is very hot and in a fluid condition. The outer cool layer, which we know as the earth's crust rests upon a denser molten substratum in which various gases are dissolved at high pressure

Interior of Earth

The Earth Ball consists of 3 concentric rings namely Crust, Mantle and Core.

Crust: 5 to 56 km on the surface of Earth. Density of rocks is 2.6 to 3.0 g cc^{-1}. **Distance:** 5 to 11 km in oceans and 35 to 56 km in the continents. The crust has been divided into two sub-zones called Sial and Sima. The Sial is a heterogeneous mixture of rocks. The Sima is a homogenous plastic or semi-plastic concentric layer that behaves like a solid. The Sial floats on the Sima, which in turn floats on the lower concentric layer called the Mantle.

Sial contains about 65-75 % silica. Aluminium is the next important element in the Sial, represented by the most common rocks like granite, and rhyolite. Silica decreases to about 50-60 percent in the Sima where aluminium has largely been replaced by magnesium

with minor quantities of iron. Sima is represented by the most common rocks like basalt and gabbro at the upper level and by olivine rich rocks at the lower level.

Mantle

A massive solid to semi solid layer below the crust; 2900 km in thickness; comprises mixed metals and silicate and basic rocks with density of 3.0 to 4.5 g cc^{-1}.
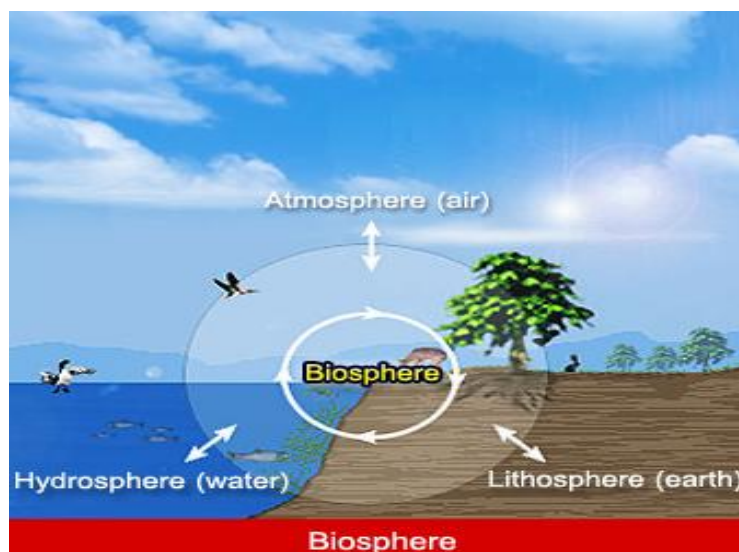
Core

Innermost portion of Earth, 3500 km in thickness, contains molten metals like Nickel, iron; average density: 9.0 to 12.0 g cc^{-1}.
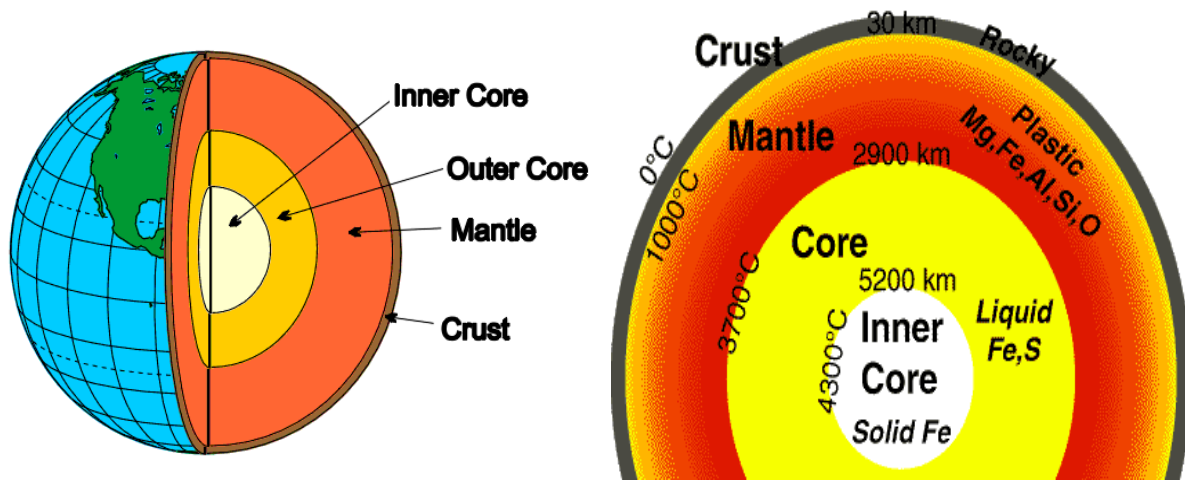

Exterior of Earth

Solid lithosphere, Liquid hydrosphere and gaseous atmosphere. The atmosphere is of 320 km above the lithosphere / hydrosphere. (70% of Earths surface is covered by water (**Hydrosphere**).

Composition of atmospheric air

	By volume (%)	By weight (%)
N_2	78.08	76.5
O_2	20.9	23.1
CO_2	0.033	0.04
Other gases	0.93	1.36

(H, NH_3, H_2S, SO_2, O_3, He, Argon, Neon, Krypton, Xenon)

Proportional Volume of Gases Composing Dry Air
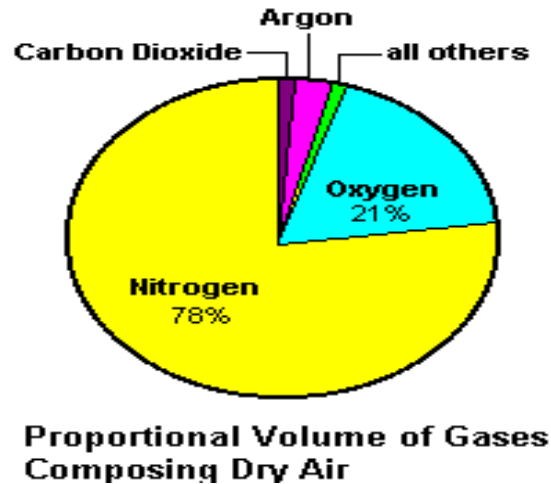
Hydrosphere

It is the layer of water surrounding the lithosphere. It is present in the form of seas and oceans. It covers 70% of the earth leaving only about 30% above sea level.   The surface of the waters of the various seas is in one level in contrast with the surface of the land. This surface is known as the sea level.

The seawater has a higher specific gravity than terrestrial water due to the salts it contains in solution. The average density is 1.026, but it varies slightly from place to place. Sea water contains 3.5% salts (minerals) It is least dense at the places where river enters the sea and very heavy at places where evaporation is high.

Lithosphere

It is the inner most body within the gaseous and watery envelops. That portion of the lithosphere, which rises above the seawater, is visible to us and is known as land. The land is only about ¼th of the total surface of the earth. Most of this land is situated in the northern hemisphere. The lithosphere consists of two portions, viz.,

1. The upper or outer cool solid surface.
2. The inner hot and molten mass.

It is the heaviest of the three spheres. Its mean density is 5.5 compared to that of water as one. The outer crust has a density of about 2.5 to 3.0, while the inside core, consists of much heavier materials.

The outer solid layer, called as the earth's crust is estimated to be about 10 to 20 miles thick. It consists of the various rocks together with a more or less thin mantle of soil enveloping them. It is on this crust that life, both animal and plant sustains. The inner mass, which forms the interior of the earth, is in molten condition. According to one belief, the whole of the inner core is a molten mass of materials, upto the centre. According to another view, the interior of the earth consists of a molten magma, about 50 to 100 miles thick, surrounding a gaseous centre. A gradation exists from the central gaseous nucleus, through the intermediate molten mass, to the outer solid crust.

The interior of the earth is intensely hot and is at the same time under enormous pressure. There is progressive increase in temperature with depth. Though, the increase is not uniform at all depths and all places, there is a rise of 1^oF for every 64 feet on an average. Assuming the temperature to increase at this rate, at a depth of 25 to 50 miles, it should be sufficiently high to melt all substances known to us. This indicates that the interior of the earth is in molten condition.

Composition of the earth's crust

The Earth's crust is principally compassed of mineral matter. This mineral matter is made up of various elements combined together to form compounds. Some elements exist as such without forming compounds. Almost all the elements known to us at present, except the inert gases, are present in the earth's crust. The elements do not exist in the earth's crust as such. Each element is in combination with one or more other elements to form definite chemical compounds known as **minerals**. Many of these minerals in turn combine together to form aggregates, which we know as **rocks**. Almost all the mineral mater is present in the form of rocks in the earth's crust. Rock is composed of elements, which in turn are made up of atoms. Out of 106 elements knows, 8 are sufficiently abundant as to constitute about 99 percent by weight of the Earth's Crust (upto 16 Km). The elements are geochemically distributed into five main groups based on their bonding characters.
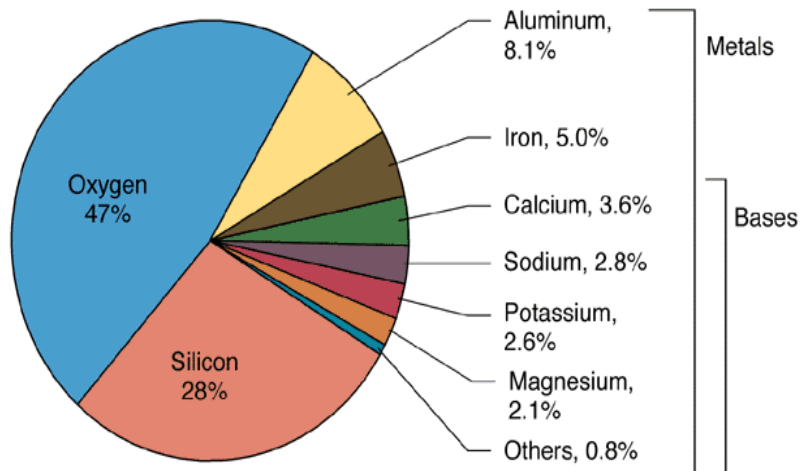
➢ **Lithophile elements**- which ionize readily or form stable oxyanions, viz. O,Si, Ti, Fe, Mn, A1, H, Li, Na, K, Rb, Cs, Be, Mg, Ca, Sr, Ba, B, Ga, Ge, Sn, Sc, Y, F,C1, Br, I, C, HF,Th, P,V, Nb, Ta, Cr,W, U, Zr, (Mo), (Cu), (Zn), (Pb), (T1), (As), (Sb), (Bi), (S), (Se), (Te), (Ni), (Co) and rare earths.

➤ **Chalcophile element** – which tend to form covalent bonds with sulphide, viz, S,Se, Te, (Fe), Ni, Co, Cu,Zn, Pb, Mo, Ag,Sb,(Sn), Cd, In,T1,Pb, As,Bi, Re, (Mn), (Ga) and Ge).

➤ **Siderophile elements** – which readily form metallic bonds, viz, Fe, Ni, Co,Ru, Rh,Pd, Ir, Os and Au.

➤ **Atmosphile elements**- which tend to remain in atmospheric gases, viz. N, (O) He, Ne, Ar, Kr, Xe.

➤ **Biophile elements**- which tend to be associated with living organisms, viz. C,H,O,N, P,S,C1, I, B, Ca, Mg, K, Na, Mn, Fe, Zn, Cu, Ag, Mo, Co, Ni, Au, Be, Cd, Se, T1,Sn, Pb, As and V.

Composition of Earth crust (% by weight)

Non - metallic	Oxygen	O_2^-	46.60%	74.32% (¾th)
	Silica	Si^{4+}	27.72%	
Metallic	Aluminium	Al^{3+}	8.13%	¼th of the total
	Iron	Fe^{2+}	5.00%	
	Calcium	Ca^{2+}	3.63%	
	Sodium	Na^+	2.83%	
	Potassium	K^+	2.59%	
	Magnesium	Mg^{2+}	2.09%	
	Others	-	1.41%	

Eight elements are abundant – 98.6%

Aluminum, 8.1% — Metals

Iron, 5.0%

Calcium, 3.6% — Bases

Sodium, 2.8%

Potassium, 2.6%

Magnesium, 2.1%

Others, 0.8%

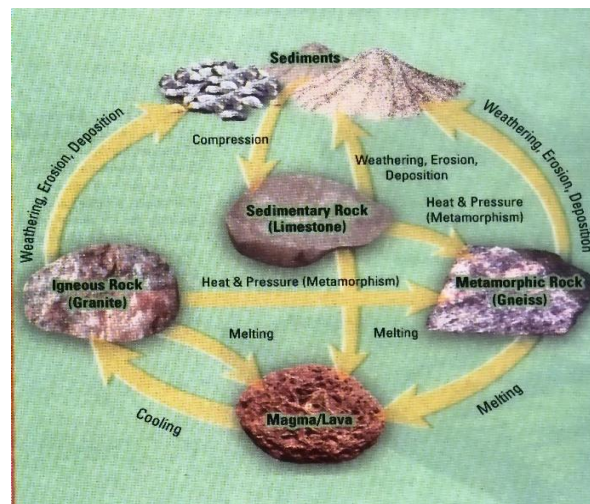Oxygen 47%

Silicon 28%

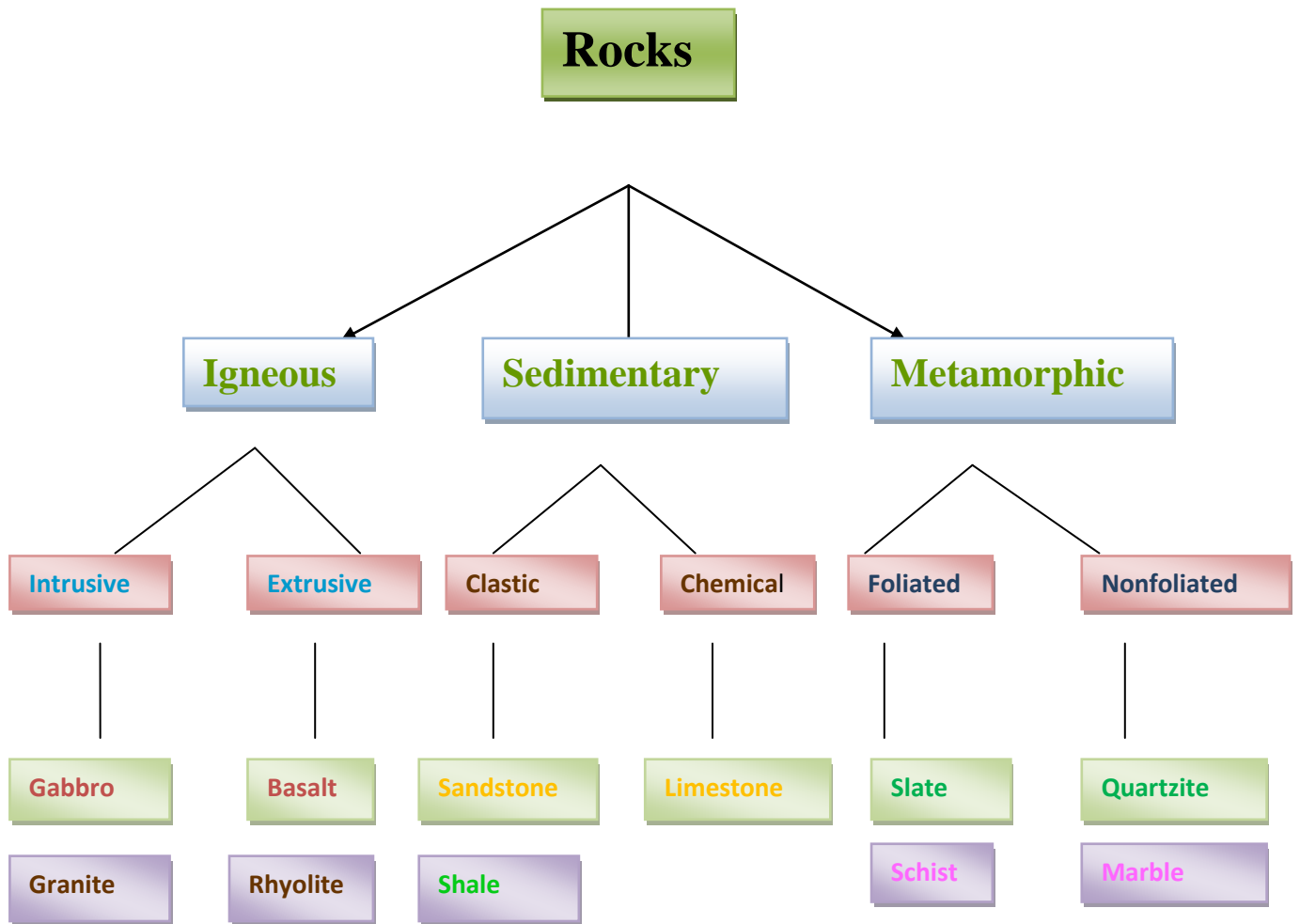**************

Rocks and minerals

What is Rocks?

Rocks are the materials that form the essential part of the Earth's solid crust. "Rocks are hard mass of mineral matter comprising one or more rock forming minerals". Rocks are formed from the molten material known as **magma**. The study of rocks is called **Petrology** (in Greek, petra means rock, logos means science). Petrology deals with the description of rocks; petrogenesis is the study of the origin of rocks.

Formation of rocks

1. Cooling and consolidation of molten magma within or on the surface of earth = Igneous or **Primary rocks**

2. Transportation and cementation of primary rocks = **Sedimentary or Secondary rocks**

3. Alteration of the existing primary and secondary rocks = **Metamorphic rocks**

Rocks

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                          Rocks


     Igneous          Sedimentary        Metamorphic


 Intrusive  Extrusive  Clastic  Chemical  Foliated  Nonfoliated


 Gabbro     Basalt    Sandstone Limestone  Slate    Quartzite

 Granite    Rhyolite  Shale                Schist    Marble
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1. Igneous rocks (primary or massive rocks)

These are first formed in the earth crust due to the solidification of molten magma.

Based on the mode of formation, they are further classified as extrusive and intrusive rocks
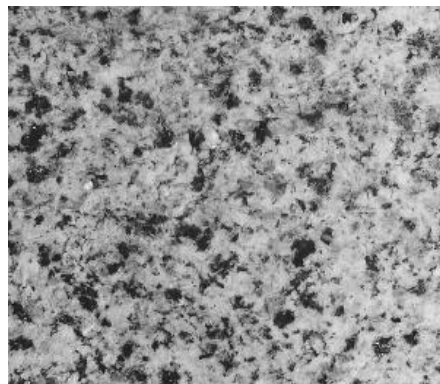
Extrusive rocks or volcanic rocks

These rocks are formed due to the consolidation of magma on the surface of the earth. The magma, when it flows on the Earth surface is called LAVA. E.g. Basalt.

Intrusive rocks or plutonic rocks

These rocks are produced due to solidification of magma below the surface of the earth. Plutonic – intrusive rocks solidifies at greater depth and Hypabassal rocks solidifies at shallow depth from the surface. E.g. Granite, syenite, diorite, Gabbro *etc.* Rocks formed in vertical cracks are called dykes and in horizontal cracks are called sills.

Vesicular rocks: Molten magma cools on the surface. Steam of water is entrapped into rocks and forms vesicles.

Based on the silica content, rocks are also classified as

1. Acid rocks : >65% SiO_2 (Granite, Rhyolite)

2. Intermediate   : 56 to 65% SiO_2

(Sub acid rocks 60 to 65% SiO_2 (Syenite and Trachyte))

(Sub basic rocks 56 to 60 % SiO_2 (Diorite and Andesite))

3. Basic rocks : 40 to 55% (Gabbro, basalt)

Igneous rocks

S.No	Rocks	Origin	Essential minerals	Common minerals	Average specific gravity	Remarks
i.	Granite	Plutonic holocrystalline	Quartz (20 to 30%)	Hornblende, magnetite, mica	2.64	Light coloured white or reddish
ii.	Syenite	Plutonic Holocrystalline	Quartz, orthoclase	Hornblende, magnetite, biotite	2.80	Light coloured white or reddish
iii.	Diorite	Plutonic Holocrystalline	Quartz	Hornblende, magnetite, biotite	2.85	Darker
iv	Gabbro	Plutonic Holocrystalline	Labradorite, augite, olivine	Hornblende, ilmenite	3.0	Blakish

v.	Dolerite	Hypabasal	Labradorite, augite, olivine	Hornblende, ilmenite	3.0	Blakish
vi.	Basalt	Volcanic crystalline with glassy mass	Labradorite, augite, olivine	Hornblende, ilmenite	3.0	

2. Sedimentary rocks

These rocks are formed from the consolidation of sediments accumulated through wind or water action at the surface of the earth. Many are deposited in layer or formed through chemical reactions as precipitates from aqueous solutions. Sediments may contain various size particles cemented together by substances like SiO_2, Fe_2O_3 or lime. These rocks are also called as clastic rocks.

Based on the origin, the sedimentary rocks are classified as

1. Residual   : Laterite

2. Transported

         a. Deposited as solids in suspension   : Sandstone, shale

         b. Deposited by chemical precipitation   : Limestone, ironstone

         c. Deposited through agency of organic matter: Peat, Phosphatic deposits

Based on the grain size, sedimentary rocks are classified as

1.   Rocks with boulder pebbles sized minerals (Rudaceous)   : Conglomerate
2.   Rocks with sand size particles (Arenaceous)   : Sandstone
3.   Rocks with silt size particles (silt rocks)   : Siltstone
4.   Rocks with clay size particles (Argillaceous)   : Shale

Sedimentary rocks

S.No	Rock	Mineral composition	Colour and structure
1.	Sandstone	Mainly quartz with some $CaCO_3$, iron oxides and clay	Light to red, granular
2.	Shale	Clay minerals, quartz and some organic matter	Light to dark thinly laminated
3.	Limestone	Mainly calcite with some dolomite, iron oxides, clay, phosphate and organic matter	Light grey to yellow, fine grained and compact

3. Metamorphic rocks

These are formed from igneous and sedimentary rocks under the influence of heat, pressure, chemically active liquids and gases. Change may occur in mineral composition or texture or both. The changes due to water is called **hydro metamorphosis** and due to pressure is called **dynamo metamorphosis**

Sand stone	: Quartizite
Shale	: Slate/mica, schist
Lime stone	: Marble
Granite	: granite gneiss
Dolerite	: Hornblende gneiss
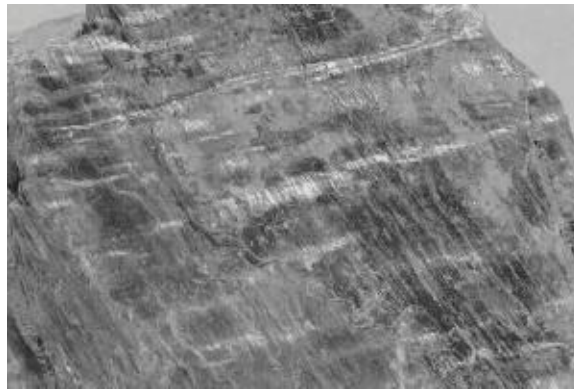
Metamorphic rocks

S.No.	Rock	Mineral composition	Colour and structure
1.	Gneiss	Formed from granite	Alternating light and dark colours, banded and foliated
2.	Schist	Formed from basalt or shale	As original rock, foliated
3.	Quartzite	Formed from	Light or brown, compact and uniform texture,

		sandstone	foliated structure
4.	Slate	Formed from shale	Grey to black, compact and uniform texture, foliated structure
5.	Marble	Formed from lime stone	Light red, green, black, compact fine to coarse texture, foliated structure

Brief description of important rocks-Mineralogical composition

Sedimentary rocks

Formed through the agency of water. Also called as **aqueous rocks**. Formed from sediments brought by water. The sediment may contain various types of substances and sizes of particles. The particles are cemented by silica, iron oxide or lime to give a consolidated form. The rocks are mostly deposited in layers or strata – so called as **stratified rocks**. Sometimes they are formed by cooling, evaporation or by direct chemical precipitation. Anyway they are of secondary origin.

Sedimentary rocks divided into six groups as follows

1. **Arenaceous**: Formed of the deposits of coarse grained particles. They are composed of siliceous material derived from the disintegration of older rocks. The fragmental material so derived is deposited in beds of varying thickness through the agency of water. Depending upon the nature of cementing material present, some arenaceous rocks are hard and refractory, but most are loose and fall away very easily. E.g. Sandstone, grit, conglomerate and breccia.

2. **Argillaceous rocks**: Consist of small sized particles known as clay. They are composed of hydrated silica of alumina in admixture with sand, various other silicates and calcareous matter. When clay is deposited mainly of silicate of alumina, it is known as kaolin or China clay. E.g. clay, mudstone, shale and fuller's earth.

3.   **Calcareous rocks**: Consists of carbonate of lime or lime and magnesia. They may be of sedimentary origin or formed by chemical precipitation or by organic agency. When, they are of organic agency, they are composed mainly of debris from plant and animal life. They are formed either by growth and decay of organisms in situ or by the transport and subsequent accumulation of their remains. The rocks so formed are found in layers, which vary considerably in depth of thickness.

When formed by chemical precipitation, the calcareous material is deposited in the form of layers/sheets from waters containing calcium carbonate in solution. The precipitate when first formed is usually soft and chalky, but soon acquires a hard, compact structure and crystalline texture. The important calcareous rocks of aqueous origin are limestone, chalk, magnesian, ferruginous limestones, dolomite, marks of various varieties and coral.

4.   **Carbonaceous rocks:** Formed from decomposing vegetation under anaerobic conditions. When plants undergo decomposition under restricted air supply, is greater portion of the carbonaceous matter is retained and the material is slowly converted into coal. E.g. peat, lignite, coal, anthracite.

5.   **Siliceous rocks:** Siliceous rocks of organic origin formed from parts of minute plants and animals like diatoms, radiolaria etc, some are soft and friable and crumble to powder very easily. Others like flint and chert are hard and compact.

6.   **Precipitated salts:** Consist mainly of deposits formed as rock masses either by cooling, evaporation or by chemical precipitation. Water charged with acid or alkaline material, acting under pressure as it does under subterranean regions, dissolves various mineral substances from rocks with which it comes in contact. The salts thus formed deposit as rocks and such rocks vary in composition. They are

   i.   Oxides: e.g. hematite, limonite, bauxite and quartz.
   ii.   Carbonates: e.g. stalactite, stalagmite, magnetite and limestone.
   iii. Sulphates: e.g. gypsum and anhydrite
   iv.   Phosphates: e.g. phosphorite
   v.   Chlorides: e.g. rock salt.

Metamorphic rocks

The igneous and sedimentary rocks after they were first formed sometimes undergo a change. When the change is considerable, the rock is said to have undergone metamorphosis and the new rock is known as a metamorphic rock. The metamorphism is brought about by the action of water, heat or pressure or by the combined action of any one of these or all. The change brought about by water is hydro-metamorphism. The change brought about by heat is thermo-metamorphism. The change brought about by pressure is

dynamo- metamorphism. The changes that are brought about are both physical and chemical in character. In some cases the metamorphism is so pronounced that the new rock looks quite different from the original.

The action of water tends to remove some material or introduce new materials. By the introduction of a cementing material like silica, lime or iron oxide, loose sand may be turned into sandstone or sandstone into a quartzite. By the removal of certain constituents by percolating waters, basalt or granite may be converted into a laterite.

The action of heat hardens the rock and develops new crystals in it. Crystalline marble is produced this way from amorphous limestone by the action of heat and pressure. Due to pressure, the crystals of the original rock get pressed or flattened and the new rock is foliated. When foliation is slight, the layers are inseparable and it is called as gneiss. It foliation is complete with distinct and separable layers it is called as schist.

Mineralogical composition of important rocks

SI. No	Rocks	Grain size	Essential minerals	Most common accessory minerals	Average specific gravity	Remarks
(i)	Igneous rocks					
1.	Granite	Plutonic Holocrystalline	Predominant quartz 20-35 orthoclase	Hornblende mica, magnetite	2.64	Light coloured, White or reddish
2.	Syenite	- do -	Predominance quartz 100% plus of orthoclase, nepheline and albite	Hornblende, biotite, magnetite	2.08	- do -
3.	Granodiorite	- do -	Intermediate quartz plagioclase exceeds orthoclase	- do -	2.07	Medium coloured reddish
4.	Diorite	- do -	Intermediate quartz absent plagioclase	- do -	2.85	Darker
5.	Gabbro	- do -	Labradorite augite + olivine	Hornblende, ilmenite	3.00	Blackish
6.	Dolerite	Hypabyssal ophitic texture	- do -	- do -	3.00	- do --

7.	Basalt	Volcanic micro crystalline with glassy mass	- do -	- do -	3.00	- do -

| SI.No	Name of the type	Mineral composition	Colour and structure
(ii)	**Sedimentary rocks**		
1.	Sandstone	Mainly quartz with same contents, such as calcium carbonate, iron oxides and clays	Light to red, usually granular in structure
2.	Shale	Clay minerals, quartz and some organic matter	Light to dark thinly laminated structure
3.	Limestone	Mainly calcite or calcite and dolomite with some iron oxides, clay, phosphate and organic matter	Usually light grey to yellow usually fine grained and compact
(iii)	**Metamorphic rocks**		
1.	Gneiss	Formed from granite, mineral composition like that of granite	Alternating light and dark colours. Banded and foliated structure
2.	Sehist	Formed from basalt or shales. Mineral composition much as that of original rock	Much as original rock, foliated structure
3.	Quartzite	Formed from sandstone and of same composition	Light to brown. Compact and uniform texture, foliated structure
4.	Slate	Formed from shale and of same composition	Grey to black, compact, and uniform texture

5.	Marble	Formed from limestone	Light red, green, black, compact, fine to coarse texture, non-foliated structure
			foliated structure

(Note: "foliated structure" appears at top continued from previous row)

Minerals

Minerals are naturally occurring solids with a definite chemical composition and crystal structure. "Solid substances composed of atoms having an orderly and regular arrangement"

When molten magma solidifies, different elements present in them freely arrange in accordance with the attractive forces and geometric form. Silica tetrahedron is the fundamental building blocks for the formation of different minerals. (SiO_2). Different silicate minerals are ortho silicates, ino-silicates, phyllosilicates and tectosilicates. There are non-silicate minerals also. These are different oxides, carbonates, sulphates, phosphates *etc*.

Minerals that are original components of rocks are called **primary minerals.** (feldspar, mica, *etc*.). Minerals that are formed from changes in primary minerals and rocks are called **secondary minerals** (clay minerals). Those minerals that are chief constituents of rocks are called as **essential minerals** (Feldspars, pyroxenes micas *etc*) and those which are present in small quantities, whose presence or absence will not alter the properties of rocks are called **accessory minerals** (tourmaline, magnetite *etc*).
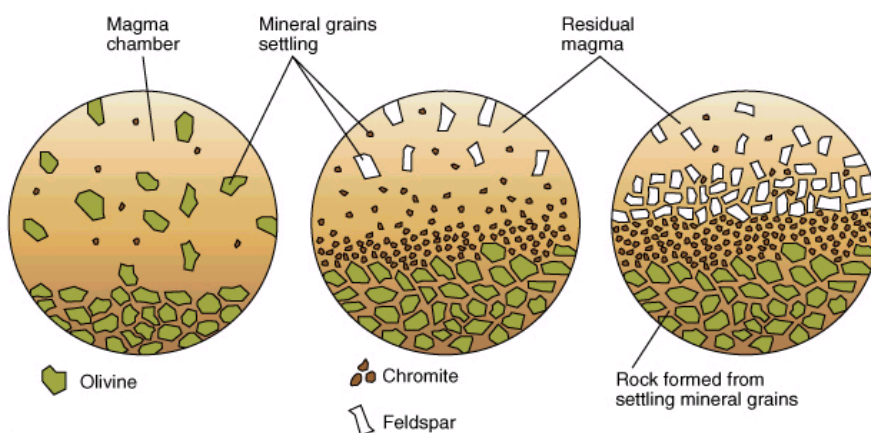
Of the >2000 known minerals, only few occur in abundance in the Earth crust.

Minerals (arranged in the order of their crystallization)	Important constituents	Percent distribution
Primary minerals		
Ferro magnesium minerals		
Ortho-ino silicates		16.8
Olivine	Fe, Mg	
Pyroxenes	Ca, Na, Fe, Mg	
Amphiboles	Ca, Na, Fe, Mg, Al, OH	
Phyllo Silicates		3.6
Biotite	K, Fe, Mg, Al, OH	
Muscovite	K, Al, OH	
Non-Ferro Magnesium		
Tecto Silicates		
Feldspars		61.0
Anorthite	Ca, Al	
Albite	Na, Al	
Orthoclase	K, Al	
Quartz		
Secondary clay minerals		
Minerals	Na, K, Ca	11.6
Others	Mg, Fe, Al, OH	6.0

Ferro magnesium minerals

Pyroxenes and amphiboles: The pyroxenes and amphiboles are two groups of ferromagnesian minerals (heavy group) the structure of which consists of long chains of linked silica tetrahedral. The pyroxenes consist of a single chain (2 oxygen shared in each tetrahedron) whereas amphiboles consist of a double chains (alternately 2 and 3 oxygen atoms shared successive tetrahedral). These chain silicates are sometimes referred to inosilicates. The pyroxene group of minerals comprised of different minerals namely enstatite, hypersthene, diopside and augite, of which **augite** is the most important minerals in soils and it is found in basic rocks. The amphibole group of minerals are common in acidic rocks and it can be represented by the isomorphous series between tremolite actinolite olivine and hornblende. Hornblende weathers fairly rapidly. Olivine (olive-green) minerals from an isomorphous series between foresterite ($Mg_2 SiO_4$) and fayalite (Fe_2SiO_4).

Pyroxenes are more basic in character and therefore it weathers more rapidly than amphiboles.

Micas: Micas occur extensively in soils. They are primarily originated from the parent rock from which the soil is derived. Generally soils are inherited from well-ordered and imperfectly ordered micas. Well-ordered micas are derived from sedimentary rocks. The most common well ordered micas are muscovite, paragonite, biotite and phlogopite (trioctahedral). The imperfectly ordered micas contain less potassium and more water as compared to well-ordered micas and this type of micas are most abundant in the clay fraction of soils. Among the ordered micas, biotite weathers more rapidly than muscovite. In imperfectly ordered micas, many of the illite-type specimens as well as the disordered micas of soils exhibits some mixed-layering with phases of vermiculite, smectite group of minerals, chlorite and intergrades of several of these species.

Non-ferromagnesium minerals

Feldspars: Feldspars are anhydrous aluminosilicates of K, Na and Ca and occasionally of other large cations such as Ba. The feldspar structure consists of tetrahedral which are attracted by sharing each oxygen atom between neighbouring tetrahedran. The tetrahedral contain mainly Silicons with sufficient Al substitution. It belongs to the group of minerals that are light in weight. There are two groups of feldspars: **(i) potassium feldspars** ($KA1Si_3O_8$) include orthoclase, microcline, adularia and sanidine. **Orthoclase and microcline are more common in the plutonic and metamorphic rocks.** The potassium feldspars occur commonly in the silts and sands of soils and also abundant in clay-size, **(ii) plagioclase feldspars**- a series consisting of a solid solution of albite ($NaA1Si_3O_8$) high in sodium and anorthite ($CaA1_2Si_2O_8$) high in calcium. Plagioclase weathers more rapidly than orthoclase.

Quartz: It is very densely packed and occurs in a high degree of purity. It is strongly resistant to weathering as the structure is densely packed, electrically neutral and free from any substitution. It is the most abundant mineral next to feldspars. Serpentine, a hydrous magnesium silicate occurs more commonly as a secondary product. Garnets are characteristic of metamorphic rocks and are very hard and most resistant to weathering.

Silicate minerals

Ortho/ Neosilicates

The minerals in this group are composed of single tetrahedral linked together by Mg or Fe. To effect a break down, it is considered sufficient to sever the weaker Mg-O or Fe-O bonds. Non-withstanding the bond energy considerations susceptibility of the minerals in this group to breakdown by weathering appears to vary considerably from one mineral to another,

e.g., zircon makes the mineral comparatively hard. On the other hand, the looser packing of oxygens in olivine makes the mineral weather faster.

Inosilicates

The inosilicate group has in its structure single-chain (pyroxenes) and double chain (amphiboles) silica tetrahedral linked together by Ca, Mg, or Fe. Because of the presence of many weak spots provided by the Ca-O, Mg-O, or Fe-O bonds, these minerals tend to weather rapidly

Phyllosilicates

Linkages of silica tetrahedral and Alumina octahedral sheets by mutually shared oxygen atoms from the basis for the structure of this group. Some of the minerals, e.g., biotite and muscovite, are relatively susceptible to weathering, whereas others, like clay minerals, are resistant weathering products and further breakdown of clays is difficult. Disruption of interlayer ions, or through cleavage of A1-O bonds in tetrahedral and octahedral positions.

Tectosilicates

The minerals are considered solid solution minerals with a framework of silica tetrahedral, in which the cavities are occupied by Na, Ca, and so on. The minerals in this group may also vary considerably in their resistance to weathering, e.g., leucite and plagioclase versus potash fertilizers. The relative degree of close packing of atoms in their structural frame work may be the reason for such variability in weathering. Increased substitution of A1 and Si in tetrahedral of plagioclase mineral is also considered a factor that makes these minerals weaker than potash feldspars.

Non-silicate minerals

Oxides: Hematite (Fe_2O_3)

Limonite ($Fe_2O_3, 3H_2O$)

Goethite ($FeO (OH) H_2O$)

Gibbsite ($Al_2O_3H_2O$)

The red, yellow or brown colours in soils are due to the presence of goethite and hematite, which occur as coatings on the surface of soil particles.

Carbonates: Calcite ($CaCO_3$)

Dolomite ($CaMgCO_3$)

Sulphates: Gypsum ($CaSO_4.2H_2O$)

Phosphates: Apatite (Rock phosphate $Ca_3 (PO_4)_2$ - primary source of phosphorus

Physical properties of minerals

1. Color
2. Streak
3. Fracture/ cleavage
4. Hardness
5. Luster
6. Crystal form
7. Taste
8. Specific gravity
9. Magnetism
10. Effervescence (fizz)
11. Birefringence
12. Fluorescence

Additional reading

Color

➢ Denotes the natural colour of the mineral
➢ The most obvious, but least reliable.
➢ Calcite has more colours
➢ Sulfur and Pyrite have same colour
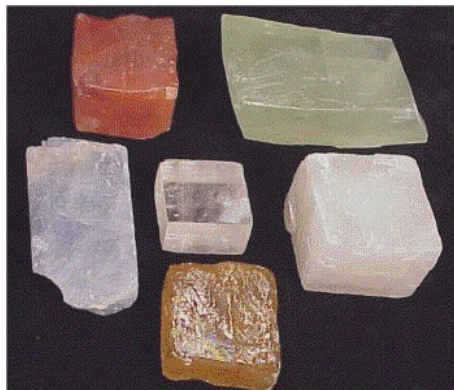
Streak

➢ Refers to the colour of the powder form of the mineral When an unknown mineral is rubbed against a piece of unglazed porcelain (streak plate) it produces a colored line.
➢ Hematite   - red
➢ Magnetite   - Black
➢ Talc   - white

Fracture and Cleavage

These terms describe the way a mineral breaks Fracture is the nature of the surface produced as a result of its breakage

Conchoidal   -   curved surface

Uneven   -   Uneven surface

Hackly   -   Jagged surface

Earthy   -   Like chalk

Even   -   Smooth

Cleavage

Some minerals break along certain well defined planes called cleavage planes.

Gypsum   -   1 set

Calcite   -   2 sets

Flourite   -   3 sets

Hardness

This is how resistant a mineral is to being scratched. We use the Mohs scale to classify a given minerals hardness. Try to scratch the unknown mineral with various items, such as a fingernail (hardness of about 2.5), a coin (3), a steel nail (5.5) and a steel file (7)

MOHS SCALE OF HARDNESS

Mineral	Hardness	Mineral	Hardness
Talc	1	Feldspar	6
Gypsum	2	Quartz	7
Calcite	3	Topaz	8
Fluorite	4	Corundum	9
Apatite	5	Diamond	10

Luster

The way a mineral reflects light Metallic (Magnetite); sub-metallic, Vitreous (Opal), Resinous (Pyrite), Pearly, Adamentine (Diamond), silky (Asbestos) and greasy.

Crystal form

Crystal structure is the result of regular grouping of atoms that are homogeneous. A crystal is a polyhedral form, which means it is a geometric solid. It has a specific set of faces, corners and edges, which is consistent with the geometric packing of the atoms

There are 6 basic crystal forms

1. Isometric
2. Tetragonal
3. Hexagonal
4. Orthorhombic
5. Monoclinic
6. Triclinic

Taste

This property is used to identify the mineral halite (salt)

Specific Gravity

This characteristic relates to the minerals density. If the mineral is heavy for its size, then it has a high specific gravity

Magnetism

Is the mineral magnetic (try using a compass), or is it attracted by a magnet? This property is characteristic of Magnetite.
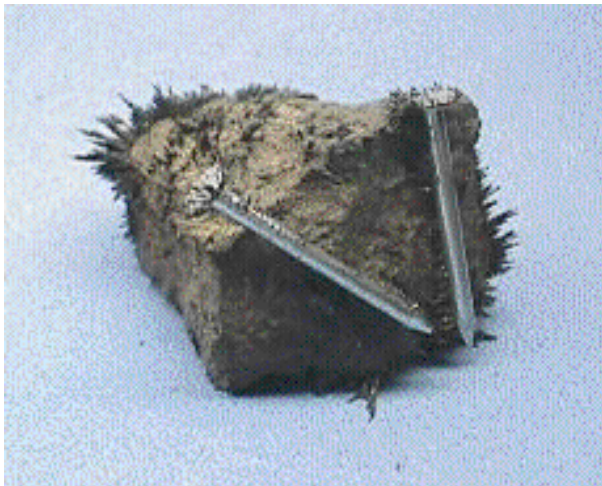
Effervescence

When some minerals are exposed to acids, they begin to fizz (calcite).

Birefringence

This is also known as double refraction. Birefringent minerals split the light into two different rays which gives the illusion of double vision in this Iceland Spar Calcite

Fluorescence

Some minerals display the phenomenon of photoluminescence.

They "glow" when exposed to UV light.

Opal and Fluorite.

Formation of secondary minerals, Clay minerals & Amorphous minerals

The secondary minerals are formed at the Earth's surface by weathering of the preexisting primary minerals under variable conditions of temperature and pressure. During weathering, water accompanied by CO_2, from the atmosphere plays an important role in processes, such as hydrolysis, hydration and solution. As a result the primary minerals are altered or decomposed.

Feldspar + water — clay mineral + cations + anions + soluble silica

Because of weathering, many elements are released into solution; a part of which may be used as a source of plant nutrients, a part may be leased out into the groundwater; still another part together with other constituents of the environment (like CO_2, H_2O) may recombine to form secondary minerals. The most commonly formed secondary minerals are clay minerals (e.g. illite, montmorillonite, kaolinite, etc.) and iron and aluminium oxides. Other secondary minerals observed in soils, especially in arid and semi-arid (dry) regions are gypsum, calcite, attapugite and apatite.

SILICATES

- Clay minerals: hydrous aluminosilicates, with layer structure similar to micas, e.g. illite, montomorillonite, kaolinite, etc.

NON-SILICATES

--Oxides, hydroxides or oxyhydrates of Si, A1 and Fe

Haematite	Fe_2O_3
Goethite; Limonite	$FeO(OH)n\ H_2O$
Gibbsite	$A1\ (OH)_3,$

Clay Minerals

Clay minerals in soils are formed from primary minerals due to weathering processes. These clay minerals are of size <0.002 mm and are considered to be the most reactive part of soil. Important soil properties like nutrient and water holding capacity are controlled by clay minerals. These minerals are layered silicates consisting of silica tetrahedron and aluminium octahedron.

1) 1 silicon tetrahedron + 1 aluminium octahedron = 1:1 clay mineral (Kaolinite)

2) 2: 1 non-expanding clay mineral   i. Black mica (Biotite)

                                               ii. White mica (Muscovite)

                                               iii. Weathered mica (illite)

3) 2: 1 expanding clay mineral   i.Partially expanding (Vermiculite)

ii.Fullyexpanding (Montmorillonite)

    4) 2: 2 clay mineral   (chlorite)

Of the naturally-occuring inorganic crystalline minerals found in the clay fraction of soils, the most commonly observed are layer silicates (illite, montmorillonite, chlorite, vermiculite, kaolinite). Besides, O, OH, A1 and Si, they contain Mg, Fe and K in large amounts. They are variable in colour (white, grey, light yellow) depending on their chemical composition. In soils, the clays and oxihydrates of iron which form coatings on mineral grains impart shades of yellow, brown or red colour to soils.

The clay minerals carry a significant negative electrical charge on their surfaces and have a structure like that of mica .In some cases, the groups of sheets are not firmly bounded together and water molecules can enter in their crystal lattice. This can cause considerable swelling due to change in soil moisture content. This is case in Vertisols (black cotton Soils) of India and NE Iraq, where deep and wide cracks on the surfaces are suggestive of the shrink-swell characteristics of soil clays.

Owing to the negative electrical charge on the clay surfaces, the cations are attracted to regions of electrical charge around the clay minerals these cations do not get bounded permanently and can be exchanged for other cations. The amount of charge varies depending upon the type of clay mineral and it is referred to as the cation exchange capacity. Because of this exchange, there is always a balance between the concentration of cations in soil water and those adsorbed on the surfaces of the particles. Rain water percolating through the soil leaches out many meta cations (K, Na, Ca, Mg) together with the existing soil-water and replaces it with new water containing H^+ ions and may render the soils acidic in reaction. The H^+ concentration is expressed in terms of pH*. A soil with high pH (>7) is alkaline while a soil with low pH (7) is acidic in nature.

-     pH is expressed in terms of negative log to the base 10 of H^+ ion concentration.

Distribution

-     While primary minerals are observed in all rocks and in sand and silt fractions of soils, the secondary minerals dominantly occur in the clay fractions of almost all soils and in sedimentary rocks, especially shales. The kind and proportion of mineral(s) observed in a soil depend on the kind of parent material and weathering intensity (to which it has been exposede.) The most common clay mineral observed is illite. Apart from illite, smectite predominates in the cracking-clay soils (of Australia, northern Iraq and central India north-east Africa), kaolinite in the highly-weathered soils of the inter tropical zones (of southern India, South America, S.E. Asia) and southern Iraq, western India). In view of their high

surface area and negative charge on them, they are considered as a source of cation adsorption and cation release which are so important in acidic soil fertility.

Non-Silicates

Oxides, Hydroxides or Hydrous-oxides group

We have already seen that oxygen is present in great abundance (46.7%) in the Earth's crust. The oxide minerals are found by the direct combination of elements (present in the Earth's crust) with oxygen.

The oxides are usually harder than any other mineral, except the silicates. The most important soils-forming oxide minerals are:

Haematite : Fe_2O_3

Limonite : Fe_2O_3 $3H_2O$

Goethite : $FeO (OH).nH_2O$

Gibbsite : $Al_2O_3.H_2O$

Haematite, Fe$_2$O$_3$

It varies in colour from red to blackish and has reddish streak. It has a metallic luster and hardness (H) of about 5. Its presence in rocks is indicative of quick chemical change. Haematite alters to limonite, magnetite, pyrite and siderite. It occurs as coatings on sand grains and acts as a cementing agent. It swells on absorbing water to form hydrated iron oxide, i.e. limonite, $2Fe_2O_3$ $3H_2O$ and goethite, $FeO (OH).nH_2O$.

Limonite or Bog Iron, 2Fe$_2$O$_3$,3H$_2$O

It is hydrated ferric oxide, yellow to brown in colour and is of wide occurrence. It is the final product of most iron minerals and hence is resistant any further change, except for absorption of water. It is an important colouring and cementing agent in soils, iron. Limonite is a common alteration product of pyrite, magnetite, hornblende and pyroxene. It may be present in the form of iron concentration.

Goethite, FeO(OH)nH$_2$O

Most materials, called limonite, are goethite with some adsorbed water. It is usually white but may pink or grey in colour. Its hardness is 5.3

Gibbsite (Hydragillite), Al$_2$O3H$_2$O

It is the most common aluminium compound in soils. Its natural colour is white. It is abundantly observed in highly-weathered soils of the tropical environment, supporting Laterites (Oxisols). It's present in soils suggests extreme degree of weathering and leaching under well drained conditions.

The red, yellow or brown colour in soils is due to the presence of goethite and hematite which occur as coating on the surfaces of soil particles, especially clay.

Carbonate Group

The basic compounds, like Mg $(OH)_2$, and Ca(OH) combine with CO_2 or carbonic acid to form carbonates as under:

Calcite, $CaCO_3$

A white mineral, with hardness of 3, is widely distributed in sedimentary rocks, like limestone and decomposes easily to calcium bicarbonate as:

$$CaCO_3 + CO_2 + H_2O \text{ --- } Ca (HCO_3)_2 \text{ (soluble in water)}$$

Dolomite, Ca Mg $(CO_3)_2$

Dolomite is less-readily decomposed than calcite; it is the chief source of Mg in soils.

Siderite, $FeCO_3$

It is an alteration product of other iron-bearing minerals, having hardness of 4 and may itself alter to hematite or limonite. It is an important mineral in waterlogged soils.

Sulphate Group

Sulphate is a complex group formed by the combination of 1 sulphur and 4 oxygen ions, which further reacts with Ca to form calcium sulphate (anhydrite, $CaSO_4$) On hydration it forms gypsum ($CaSO_4 2H_2O$)

Gypsum, $CaSO_4$ $2H_2O$

It is a common mineral in desert soils and in sedimentary rocks having a hardness of 2. It is slightly soluble in water and gets most-easily leached. It precipitates as very fine, powdery mycelium from ground waters rich in Ca and SO_4 ions (as observed in the Mesopotamian Plain of Iraq where hyper aridic prevail). In India, it is used as an amendment to reclaim sodic soils and also acts as a source of Ca and S for plants. Under the hot, aridic climatic environments of Iraq, the presence of gypsum in high amounts is a problem, as it causes civil structures to collapse and makes sink-holes in soils, resulting in loss of irrigation water.

Phosphate Group

Apatite, Rock Phosphate

It is a primary source of phosphorus in soils. Its hardness is 5 in mho's scale. It decomposes readily under the influence of carbonic acid. It becomes immobile in calcareous soils as it readily combines with clays, with clays, Fe-A1 hydrous oxides, calcium carbonate to form rock phosphate. It also precipitates under acidic environment, as Fe and/or A1-phosphate.

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Weathering – Soil formation factors and processes – Components of soils

Weathering

A process of disintegration and decomposition of rocks and minerals which are brought about by physical agents and chemical processes, leading to the formation of Regolith (unconsolidated residues of the weathering rock on the earth's surface or above the solid rocks).

(OR)

The process by which the earth's crust or lithosphere is broken down by the activities of the atmosphere, with the aid of the hydrosphere and biosphere.

(OR)

The process of transformation of solid rocks into parent material or Regolith.

Parent material

It is the regolith or at least it's upper portion. May be defined as the unconsolidated and more or less chemically weathered mineral material from which soil are developed.

Weathering

Two basic processes

Physical /mechanical   **Chemical**

(disintegration)   (decomposition)
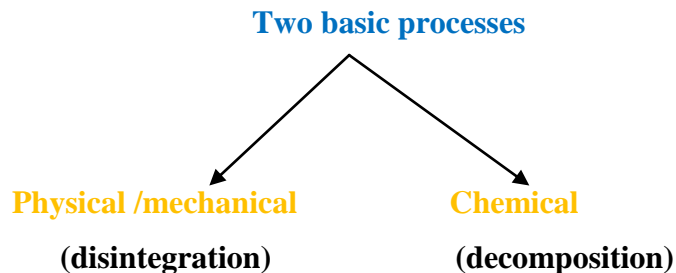
In addition, another process: **Biological** and all these processes are work hand in hand. Depending up on the agents taking part in weathering processes, it is classified into three types.
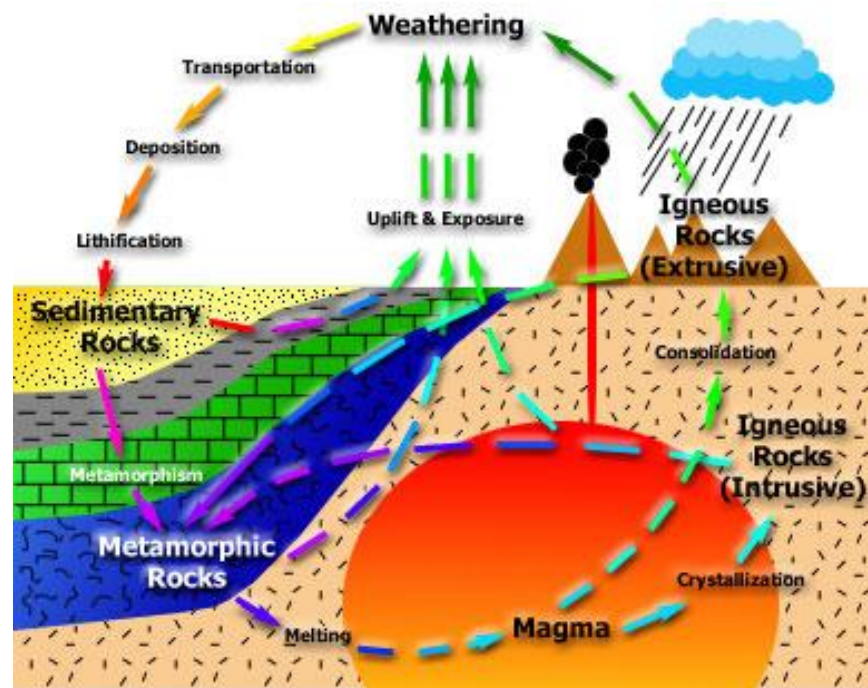
Different agents of weathering

Physical/ Mechanical (disintegration)	Chemical (decomposition)	Biological (disint + decomp)
1.Physical condition of rock	1.Hydration	1.Man & animals
2.Change in temperature	2.Hydrolysis	2. higher plants & their roots
3.Action of H_2O	3.Solution	3.Micro organisms
-fragment&transport	4.Carbonation	
- action of freezing	5.Oxidation	
- alter. Wet & drying	6.Reduction	
- action of glaciers		
4.Action of wind		
5.Atmosp.electric pheno		

Physical weathering

The rocks are disintegrated and are broken down to comparatively smaller pieces, without producing any new substances

1. Physical condition of rocks

The permeability of rocks is the most important single factor. Coarse textured (porous) sand stone weather more readily than a fine textured (almost solid) basalt. Unconsolidated volcanic ash weather quickly as compared to unconsolidated coarse deposits such as gravels.

2. Action of Temperature

The variations in temperature exert great influence on the disintegration of rocks.

➢ During day time, the rocks get heated up by the sun and expand. At night, the temperature falls and the rocks get cooled and contract.

➢ This alternate expansion and contraction weakens the surface of the rock and crumbles it because the rocks do not conduct heat easily.

➢ The minerals within the rock also vary in their rate of expansion and contraction

- The cubical expansion of quartz is twice as feldspar
- Dark coloured rocks are subjected to fast changes in temperature as compared to light coloured rocks

➢ The differential expansion of minerals in a rock surface generates stress between the heated surface and cooled un expanded parts resulting in fragmentation of rocks.

➢ This process causes the surface layer to peel off from the parent mass and the rock ultimately disintegrates. This process is called Exfoliation

3. Action of Water

Water acts as a disintegrating, transporting and depositing agent.

i) Fragmentation and transport

Water beats over the surface of the rock when the rain occurs and starts flowing towards the ocean

➢ Moving water has the great cutting and carrying force.

➢ It forms gullies and ravines and carries with the suspended soil material of variable sizes.

➢ Transporting power of water varies. It is estimated that the transporting power of stream varies as the sixth power of its velocity i.e the greater the speed of water, more is the transporting power and carrying capacity.

Speed/Sec	Carrying capacity
15 cm	Fine sand
30 cm	Gravel
1.2 m	Stones (1kg)
9.0 m	Boulders (several tons)

The disintegration is greater near the source of river than its mouth

ii) Action of freezing

Frost is much more effective than heat in producing physical weathering

➢ In cold regions, the water in the cracks and crevices freezes into ice and the volume increases to one tenth

➢ As the freezing starts from the top there is no possibility of its upward expansion. Hence, the increase in volume creates enormous out ward pressure which breaks apart the rocks

iii) Alternate wetting and Drying

Some natural substances increase considerably in volume on wetting and shrink on drying. (e.g.) smectite, montmorilonite

➢ During dry summer/ dry weather – these clays shrink considerably forming deep cracks or wide cracks.

➢ On subsequent wetting, it swells.

➢ This alternate swelling and shrinking/ wetting or drying of clay enriched rocks make them loose and eventually breaks

iv). Action of glaciers

➢ In cold regions, when snow falls, it accumulates and change into a ice sheet.

➢ These big glaciers start moving owing to the change in temperature and/or gradient.

➢ On moving, these exert tremendous pressure over the rock on which they pass and carry the loose materials

➢ These materials get deposited on reaching the warmer regions, where its movement stops with the melting of ice

4. Action of wind

➢ Wind has an erosive and transporting effect. Often when the wind is laden with fine material viz., fine sand, silt or clay particles, it has a serious abrasive effect and the sand laden winds itch the rocks and ultimately breaks down under its force

➢ The dust storm may transport tons of material from one place to another. The shifting of soil causes serious wind erosion problem and may render cultivated land as degraded (e.g) Rajasthan deserts

5. Atmospheric electrical phenomenon

It is an important factor causing break down during rainy season and lightning breaks up rocks and or widens cracks

Chemical Weathering

Decomposition of rocks and minerals by various chemical processes is called chemical weathering. It is the most important process for soil formation.

Chemical weathering takes place mainly at the surface of rocks and minerals with disappearance of certain minerals and the formation of secondary products (new materials). This is called chemical transformation.

Feldspar + water ⟶ clay mineral + soluble cations and anions

Chemical weathering becomes more effective as the surface area of the rock increases.

Since the chemical reactions occur largely on the surface of the rocks, therefore the smaller the fragments, the greater the surface area per unit volume available for reaction.

The effectiveness of chemical weathering is closely related to the mineral composition of rocks. (e.g) quartz responds far slowly to the chemical attack than olivine or pyroxene.

Average mineralogical composition (%)

Composition	Granite	Basalt	Shale	S. Stone	L.Stone
Feldspar	52.4	46.2	30.0	11.5	-
Quartz	31.3	-	2.3	66.8	-
Pyrox-amphi	-	44.5	-	-	-

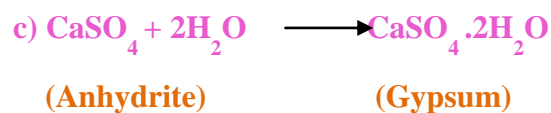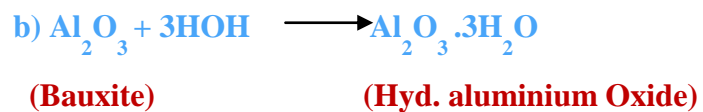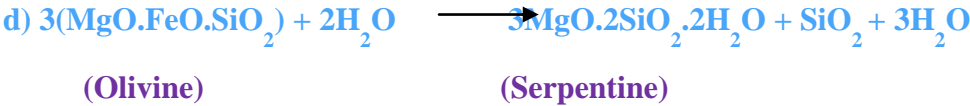| FeO mineral	2.0	9.3	10.5	2.0	-
Clay mineral	14.3	-	25.0	6.6	24.0
Carbonates	-	-	5.7	11.1	76.0

Chemical Processes of weathering:

1. Hydration

Chemical combination of water molecules with a particular substance or mineral leading to a change in structure. Soil forming minerals in rocks do not contain any water and they under go hydration when exposed to humid conditions. Up on hydration there is swelling and increase in volume of minerals. The minerals loose their luster and become soft. It is one of the most common processes in nature and works with secondary minerals, such as aluminium oxide and iron oxide minerals and gypsum.
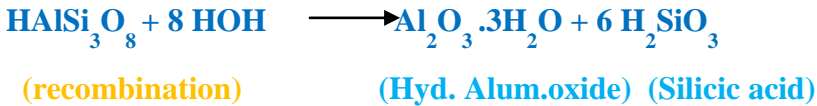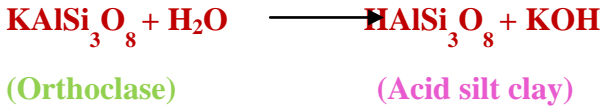
Example:

a) $2Fe_2O_3 + 3HOH \longrightarrow 2Fe_2O_3.3H_2O$

    (Haematite) (red)   (Limonite) (yellow)

b) $Al_2O_3 + 3HOH \longrightarrow Al_2O_3.3H_2O$

    (Bauxite)   (Hyd. aluminium Oxide)

c) $CaSO_4 + 2H_2O \longrightarrow CaSO_4.2H_2O$

    (Anhydrite)   (Gypsum)

d) $3(MgO.FeO.SiO_2) + 2H_2O \longrightarrow 3MgO.2SiO_2.2H_2O + SiO_2 + 3H_2O$

(Olivine)   (Serpentine)

2. Hydrolysis

Most important process in chemical weathering. It is due to the dissociation of H_2O into H^+ and OH^- ions which chemically combine with minerals and bring about changes, such as exchange, decomposition of crystalline structure and formation of new compounds. Water acts as a weak acid on silicate minerals.

$$KAlSi_3O_8 + H_2O \longrightarrow HAlSi_3O_8 + KOH$$

(Orthoclase)   (Acid silt clay)

$$HAlSi_3O_8 + 8\ HOH \longrightarrow Al_2O_3.3H_2O + 6\ H_2SiO_3$$

(recombination)   (Hyd. Alum.oxide) (Silicic acid)

This reaction is important because of two reasons

➢ clay, bases and silicic acid - the substances formed in these reactions - are available to plants

➢ water often containing CO_2 (absorbed from atmosphere), reacts with the minerals directly to produce insoluble clay minerals, positively charged metal ions (Ca^{++}, Mg^{++}, Na^+, K^+) and negatively charged ions (OH^-, HCO_3^-) and some soluble silica – all these ions are made available for plant growth.

3. Solution

Some substances present in the rocks are directly soluble in water. The soluble substances are removed by the continuous action of water and the rock no longer remains solid and form holes, rills or rough surface and ultimately falls into pieces or decomposes. The action is considerably increased when the water is acidified by the dissolution of organic and inorganic acids. (e.g) halites, NaCl

$$NaCl + H_2O \longrightarrow Na^+, Cl^-, H_2O \text{ (dissolved ions with water)}$$

4. Carbonation: Carbon di oxide when dissolved in water it forms carbonic acid.

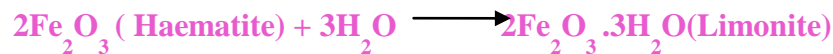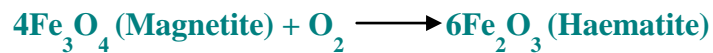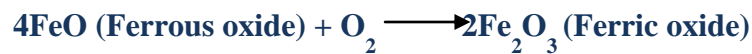$$2H_2O + CO_2 \longrightarrow H_2CO_3$$

This carbonic acid attacks many rocks and minerals and brings them into solution. The carbonated water has an etching effect up on some rocks, especially lime stone. The removal of cement that holds sand particles together leads to their disintegration.

$$CaCO_3 + H_2CO_3 \longrightarrow Ca(HCO_3)_2$$

(Calcite)   (Ca bi carbonate)

slightly soluble   readily soluble
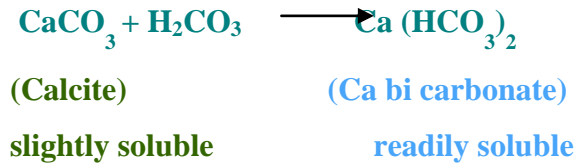
5. Oxidation

The process of addition and combination of oxygen to minerals. The absorption is usually from O_2 dissolved in soil water and that present in atmosphere. The oxidation is more active in the presence of moisture and results in hydrated oxides. (e.g) minerals containing Fe and Mg.

$$4FeO \text{ (Ferrous oxide)} + O_2 \longrightarrow 2Fe_2O_3 \text{ (Ferric oxide)}$$

$$4Fe_3O_4 \text{ (Magnetite)} + O_2 \longrightarrow 6Fe_2O_3 \text{ (Haematite)}$$

$$2Fe_2O_3 \text{ (Haematite)} + 3H_2O \longrightarrow 2Fe_2O_3.3H_2O \text{(Limonite)}$$

6. Reduction

The process of removal of oxygen and is the reverse of oxidation and is equally important in changing soil colour to grey, blue or green as ferric iron is converted to ferrous iron compounds. Under the conditions of excess water or water logged condition (less or no oxygen), reduction takes place.

$$2Fe_2O_3 \text{ (Haematite)} - O_2 \longrightarrow 4FeO \text{ (Ferrous oxide) - reduced form}$$

In conclusion, during chemical weathering igneous and metamorphic rocks can be regarded as involving destruction of primary minerals and the production of secondary minerals.

In sedimentary rocks, which is made up of primary and secondary minerals, weathering acts initially to destroy any relatively weak bonding agents (FeO) and the particles are freed and can be individually subjected to weathering.

Biological Weathering

Unlike physical and chemical weathering, the biological or living agents are responsible for both decomposition and disintegration of rocks and minerals. The biological life is mainly controlled largely by the prevailing environment.

1. Man and Animals

> The action of man in disintegration of rocks is well known as he cuts rocks to build dams, channels and construct roads and buildings. All these activities result in increasing the surface area of the rocks for attack of chemical agents and accelerate the process of rock decomposition.

> A large number of animals, birds, insects and worms, by their activities they make holes in them and thus aid for weathering.

> In tropical and sub tropical regions, ants and termites build galleries and passages and carry materials from lower to upper surface and excrete acids. The oxygen and water with many dissolved substances, reach every part of the rock through the cracks, holes and galleries, and thus brings about speedy disintegration.

> Rabbits, by burrowing in to the ground, destroy soft rocks. Moles, ants and bodies of the dead animals, provides substances which react with minerals and aid in decaying process.

> The earthworms pass the soil through the alimentary canal and thus brings about physical and chemical changes in soil material.

2. Higher Plants and Roots

The roots of trees and other plants penetrates into the joints and crevices of the rocks. As they grew, they exert a great disruptive force and the hard rock may broken apart. (e.g) pipal tree growing on walls/ rocks.

The grass roots form a sponge like mass, prevents erosion and conserve moisture and thus allowing moisture and air to enter in to the rock for further action.

Some roots penetrate deep into the soil and may open some sort of drainage channel. The roots running in crevices in lime stone and marble produces acids . These acids have a solvent action on carbonates.

The dead roots and plant residues decompose and produce carbon dioxide which is of great importance in weathering.

3. Micro- organisms

In early stages of mineral decomposition and soil formation, the lower forms of plants and animals like, mosses, bacteria and fungi and actinomycetes play an important role. They

extract nutrients from the rock and N from air and live with a small quantity of water. In due course of time, the soil develops under the cluster of these micro-organisms.

These organisms closely associated with the decay of plant and animal remains and thus liberate nutrients for the use of next generation plants and also produces CO_2 and organic compounds which aid in mineral decomposition.

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Soil formation factors and processes

The soil formation is the process of **two consecutive stages**.

      1. The weathering of rock (R) into Regolith

      2. The formation of true soil from Regolith

The evolution of true soil from regolith takes place by the combined action of soil forming factors and processes.

    ➢ The first step is accomplished by weathering (disintegration & decomposition)

    ➢ The second step is associated with the action of Soil Forming Factors

Weathering
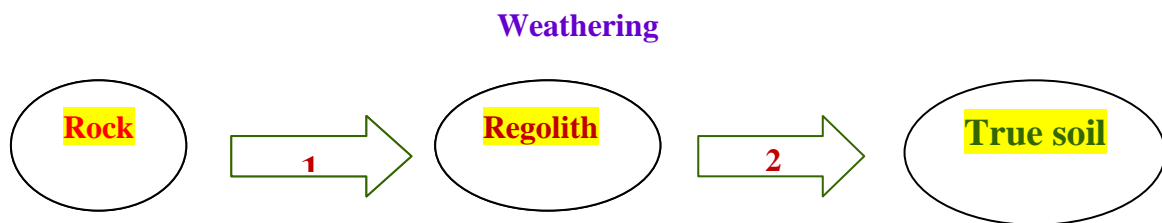
Factors

      Dokuchaiev (1889) established that the soils develop as a result of the action of soil forming factors

$$S = f (P, Cl, O)$$

Further, Jenny (1941) formulated the following equation

$$S = f (Cl, O, R, P, T, …)$$

Where,
      Cl – environmental climate
      O – Organisms and vegetation (biosphere)
      R – Relief or topography
      P – Parent material
      T- Time
      … - additional unspecified factors

The five soil forming factors, acting simultaneously at any point on the surface of the earth, to produce soil.

Two groups

Passive : i) Parent material, ii) Relief, iii) Time

Active : iv) Climate, v) Vegetation & organism

Passive Soil forming factors

The passive soil forming factors are those which represent the source of soil forming mass and conditions affecting it. These provide a base on which the active soil forming factors work or act for the development of soil.

Parent Material

It is that mass (consolidated material) from which the soil has formed.

Two groups of parent material

➢ **Sedentary**

Formed in original place. It is the residual parent material. The parent material differ as widely as the rocks

➢ **Transported**

The parent material transported from their place of origin. They are named according to the main force responsible for the transport and redeposition.

a) by gravity - Colluvial
b) by water - Alluvial , Marine , Locustrine
c) by ice - Glacial
d) by wind - Eolian

Colluvium

It is the poorly sorted materials near the base of strong slopes transported by the action of gravity.

Alluvium

The material transported and deposited by water is, found along major stream courses at the bottom of slopes of mountains and along small streams flowing out of drainage basins.

Lacustrine

Consists of materials that have settled out of the quiet water of lakes.

Moraine

Consists of all the materials picked up, mixed, disintegrated, transported and deposited through the action of glacial ice or of water resulting primarily from melting of glaciers.

Loess or Aeolian

These are the wind blown materials. When the texture is silty - loss; when it is sand.

Eolian

The soils developed on such transported parent materials bear the name of the parent material; viz. Alluvial soils from alluvium, colluvial soils from colluvium etc. In the initial stages, however, the soil properties are mainly determined by the kind of parent material.

Endodynamomorphic soils

With advanced development and excessive leaching, the influence of parent material on soil characteristics gradually diminishes. There are soils wherein the composition of parent material subdues the effects of climate and vegetation. These soils are temporary and persist only until the chemical decomposition becomes active under the influence of climate and vegetation.

Ectodynamomorphic soils

Development of normal profile under the influence of climate and vegetation.

Soil properties as influenced by parent material: Different parent materials affect profile development and produce different soils, especially in the initial stages.

➢ Acid igneous rocks (like granite, rhyolite) produce light-textured soils (Alfisols).

➢ Basic igneous rocks (basalt), alluvium or colluvium derived from limestone or basalt, produce fine-textured cracking-clay soils (Vertisols).

➢ Basic alluvium or aeolian materials produce fine to coarse-textured soils (Entisols or Inceptisols).

➢ The nature of the elements released during the decaying of rocks has a specific role in soil formation. (e.g.) Si and Al forms the skeleton for the production of secondary clay minerals.

➢ Iron and manganese are important for imparting red colour to soils and for oxidation and reduction phenomena.

➢ Sodium and potassium are important dispersing agents for day and humus colloids.

> ➤ Calcium and magnesium have a flocculating effect and result in favorable and stable soil structure for plant growth.

2. Relief or Topography

The relief and topography sometimes are used as synonymous terms. They denote the configuration of the land surface. The topography refers to the differences in elevation of the land surface on a broad scale.

The prominent types of topography designations, as given in FAO Guidelines (1990) are:

Land surface	with slopes of
1 Flat to Almost flat	0 – 2 %
2 Gently undulating	2 - 5 %
3 Undulating	5 – 10 %
4 Rolling	10 – 15 %
5 Hilly	15 –3 0 %
6 Steeply dissect	> 30 % with moderate range of elevation (<300 m)
7 Mountainous	> 30% with great range of elevation (>300 m)

Soil formation on flat to almost flat position

On level topographic positions, almost the entire water received through rain percolates through the soil. Under such conditions, the soils formed may be considered as representative of the regional climate. They have normal solum with distinct horizons. But vast and monotonous level land with little gradient often has impaired drainage conditions.

Soil formation on undulating topography

The soils on steep slopes are generally shallow, stony and have weakly- developed profiles with less distinct horizonation. It is due to accelerated erosion, which removes surface material before it has the time to develop. Reduced percolation of water through soil is because of surface runoff, and lack of water for the growth of plants, which are responsible for checking of erosion and promote soil formation.

Soil formation in depression

The depression areas in semi-arid and sub humid regions reflect more moist conditions than actually observed on level topographic positions due to the additional water received as runoff. Such conditions (as in the Tarai region of the Uttar Pradesh) favour more vegetative growth and slower rate of decay of organic remains. This results in the formation of comparatively dark- coloured soils rich in organic matter (Mollisols).

Soil formation and Exposure/ Aspect

Topography affects soil formation by affecting temperature and vegetative growth through slope exposures (aspect}. The southern exposures (facing the sun) are warmer and subject to marked fluctuations in temperature and moisture. The northern exposures, on the other hand are cooler and more humid. The eastern and western exposures occupy intermediate position in this respect.

3. Time

Soil formation is a very slow process requiring thousands of years to develop a mature pedon. The period taken by a given soil from the stage of weathered rock (i.e. regolith) up to the stage of maturity is considered as time. The matured soils mean the soils with fully developed horizons (A, B, C). It takes hundreds of years to develop an inch of soil. The time that nature devotes to the formation of soils is termed as Pedologic Time.

It has been observed that rocks and minerals disintegrate and/or decompose at different rates; the coarse particles of limestone are more resistant to disintegration than those of sandstone. However, in general, limestone decomposes more readily than sandstone (by chemical weathering).

Weathering stages in soil formation

Stages	Characteristic
1 Initial	Un weathered parent material
2 Juvenile	Weathering started but much of the original material still un weathered
3 Virile	Easily weatherable minerals fairly decomposed; clay content increased, slowly weatherable minerals still appreciable
4 Senile	Decomposition reaches at a final stage; only most resistant minerals survive
5 Final	Soil development completed under prevailing environments

➢ The soil properties also change with time, for instance nitrogen and organic matter contents increase with time provided the soil temperature is not high.

➢ $CaCO_3$ content may decrease or even lost with time provided the climatic conditions are not arid

➢ In humid regions, the H^+ concentration increases with time because of chemical weathering.

B. Active Soil Forming Factors

The active soil forming factors are those which supply energy that acts on the mass for the purpose of soil formation. These factors are climate and vegetation (biosphere).

1. Climate

Climate is the most significant factor controlling the type and rate of soil formation. The dominant climates recognized are:

➢ **Arid climate:** The precipitation here is far less than the water-need. Hence the soils remain dry for most of the time in a year.

➢ **Humid climate:** The precipitation here is much more than the water need. The excess water results in leaching of salt and bases followed by translocation of clay colloids.

➢ **Oceanic climate:** Moderate seasonal variation of rainfall and temperature.

➢ **Mediterranean climate:** The moderate precipitation. Winters and summers are dry and hot.

➢ **Continental climate:** Warm summers and extremely cool or cold winters.

➢ **Temperate climate:** Cold humid conditions with warm summers.

➢ **Tropical and subtropical climate:** Warm to hot humid with isothermal conditions in the tropical zone.

Climate affects the soil formation directly and indirectly.

Directly, climate affects the soil formation by supplying water and heat to react with parent material.

Indirectly, it determines the fauna and flora activities which furnish a source of energy in the form of organic matter. This energy acts on the rocks and minerals in the form of acids, and salts are released. The indirect effects of climate on soil formation are most clearly seen in the relationship of soils to vegetation.

Precipitation and temperature are the two major climatic elements which contribute most to soil formation.

Precipitation

Precipitation is the most important among the climatic factors. As it percolates and moves from one part of the parent material to another. It carries with it substances in solution as well as in suspension. The substances so carried are re deposited in another part or completely removed from the material through percolation when the soil moisture at the surface evaporates causing an upward movement of water. The soluble substances move with it and are translocated to the upper layer. Thus rainfall brings about a redistribution of substances both soluble as well as in suspension in soil body.

Temperature

- ➢ Temperature is another climatic agent influencing the process of soil formation.
- ➢ High temperature hinders the process of leaching and causes an upward movement of soluble salts.
- ➢ High temperature favors rapid decomposition of organic matter and increase microbial activities in soil while low temperatures induce leaching by reducing evaporation and there by favour the accumulation of organic matter by slowing down the process of decomposition. Temperature thus controls the rate of chemical and biological reactions taking place in the parent material.

Jenney (1941} computed that in the tropical regions the rate of weathering proceeds three times faster than in temperate regions and nine times faster than in arctic .

2. Organism & Vegetation

Organism

- ➢ The active components of soil ecosystem are plants, animals, microorganisms and man.
- ➢ The role of microorganisms in soil formation is related to the humification and mineralization of vegetation
- ➢ The action of animals especially burrowing animals to dig and mix-up the soil mass and thus disturb the parent material
- ➢ Man influences the soil formation through his manipulation of natural vegetation, agricultural practices etc.

- ➢ Compaction by traffic of man and animals decrease the rate of water infiltration into the soil and thereby increase the rate of runoff and erosion.

- ➢ The roots of the plants penetrate into the parent material and act both mechanically and chemically.
- ➢ They facilitate percolation and drainage and bring about greater dissolution of minerals through the action of CO_2 and acidic substances secreted by them.
- ➢ The decomposition and humification of the materials further adds to the solubilization of minerals
- ➢ Forests – reduces temperature, increases humidity, reduce evaporation and increases precipitation.
- ➢ Grasses reduce runoff and result greater penetration of water in to the parent material.

Soil Forming Processes

The pedogenic processes, although slow in terms of human life, yet work faster than the geological processes in changing lifeless parent material into true soil full of life.

- The pedogenic processes are extremely complex and dynamic involving many chemical and biological reactions, and usually operate simultaneously in a given area.
- One process may counteract another, or two different processes may work simultaneously to achieve the same result.
- Different processes or combination of processes operate under varying natural environment.

The collective interaction of various soil forming factors under different environmental conditions set a course to certain recognized soil forming processes.

The basic process involved in soil formation (Simonson, 1959) includes the following.

- ➢ Gains or Additions of water, mostly as rainfall, organic and mineral matter to the soil.
- ➢ Losses of the above materials from the soil.
- ➢ Transformation of mineral and organic substances within the soil.
- ➢ Translocation or the movement of soil materials from one point to another within the soil. It is usually divided into
  - movement of solution (leaching) and
  - movement in suspension (eluviation) of clay, organic matter and hydrous oxides

A. Fundamental Soil forming Processes

Humification

Humification is the process of transformation of raw organic matter into humus. It is extremely a complex process involving various organisms.

First, simple compounds such as sugars and starches are attacked followed by proteins and cellulose and finally very resistant compounds, such as tannins, are decomposed and the dark coloured substance, known as humus, is formed.

Eluviation

It is the mobilization and translocation of certain constituent's viz. Clay, Fe_2O_3, Al_2O_3, SiO_2, humus, $CaCO_3$, other salts etc. from one point of soil body to another. Eluviation means washing out. It is the process of removal of constituents in suspension or solution by the percolating water from the upper to lower layers. The eluviation encompasses mobilization and

translocation of mobile constituents resulting in textural differences. The horizon formed by the process of eluviation is termed as eluvial horizon (A_2 or E horizon).

Translocation depends upon relative mobility of elements and depth of percolation.

Illuviation

The process of deposition of soil materials (removed from the eluvial horizon) in the lower layer (or horizon of gains having the property of stabilizing translocated clay materials) is termed as Illuviation. The horizons formed by this process are

termed as illuvial horizons (B-horizons, especially Bt) The process leads to textural contrast between E and Bt horizons, and higher fine: total clay ratio in the Bt horizon.

Horizonation

It is the process of differentiation of soil in different horizons along the depth of the soil body. The differentiation is due to the fundamental processes, humification, eluviation and illuviation.

B. Specific Soil Forming Processes

The basic pedologic processes provide a framework for later operation of more specific processes

Calcification

It is the process of precipitation and accumulation of calcium carbonate ($CaCO_3$) in some part of the profile. The accumulation of $CaCO_3$ may result in the development of a calcic horizon. Calcium is readily soluble in acid soil water and/or when CO_2 concentration is high in root zone as:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 + Ca \rightarrow Ca\,(HCO_3)_2 \text{ (soluble)}$$

$$\text{Temp.}$$

$$Ca\,(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2 \text{ (precipitates)}$$

$$CO_2$$
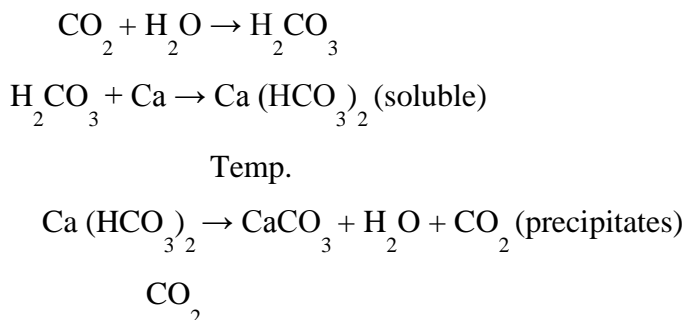
The process of precipitation after mobilization under these conditions is called calcification and the resulting illuviated horizon of carbonates is designated as Bk horizon (Bca).

Decalcification

It is the reverse of calcification that is the process of removal of CaCO3 or calcium ions from the soil by leaching

Temp.

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca (HCO_3)_2 \text{ (soluble)}$$

(insoluble)   **CO_2**
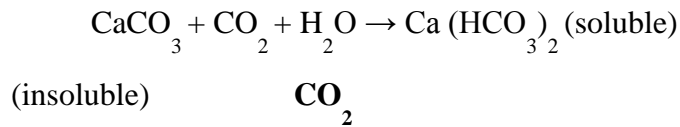
Podzolization

It is a process of soil formation resulting in the formation of Podzols and Podzolic soils. In many respects, podzolization is the negative of calcification. The calcification process tends to concentrate calcium in the lower part of the B horizon, whereas podzolization leaches the entire solum of calcium carbonates.

Apart from calcium, the other bases are also removed and the whole soil becomes distinctly acidic. In fact, the process is essentially one of acid leaching.

The process operates under favorable combination of the following environments.

 i) **Climate:** A cold and humid climate is most favorable for podzolization.

ii) **Parent material:** Siliceous (Sandy) material, having poor reserves of weatherable minerals, favor the operation of podzolization as it helps in easy percolation of water.

 iii) **Vegetation:** Acid producing vegetation such as coniferous pines is essential

 iv) **Leaching and Translocation of Sesquioxide:** In the process of decomposition of organic matter various organic acids are produced. The organic acids thus formed act with Sesquioxide and the remaining clay minerals, forming organic- Sesquioxide and organic clay complexes, which are soluble and move with the percolating water to the lower horizons (Bh, Bs).

Aluminium ions in a water solution hydrolyze and make the soil solution very acidic.

$$2Al + 6H_2O \longrightarrow 2 Al (OH)_3 + 6H^+$$
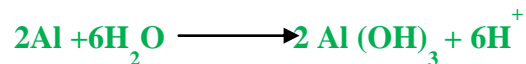
As iron and aluminium move about, the A horizon gives a bleached grey or ashy appearance. The Russians used the term Podzols (pod means under, the zola means ash like i.e. ash-like horizon appearing beneath the surface horizon) for such soils.

To conclude, the Podzolization is a soil forming process which prevails in a cold and humid climate where coniferous and acid forming vegetations dominate. The humus and Sesquioxide become mobile and leached out from the upper horizon s and deposited in the lower horizon.

 4. Laterization

The term laterite is derived from the word later meaning brick or tile and was originally applied to a group of high clay Indian soils found in Malabar hills of Kerala, Tamil Nadu, Karnataka and Maharashtra.

It refers specifically to a particular cemented horizon in certain soils which when dried, become very hard, like a brick. Such soils (in tropics) when massively impregnated with sesquioxides (iron and aluminium oxides) to extent of 70 to 80 per cent of the total mass, are called laterites or latosols (Oxisols). The soil forming process is called Laterization or Latozation.

Laterization is the process that removes silica, instead of sesquioxides from the upper layers and thereby leaving sesquioxides to concentrate in the solum. The process operates under the following conditions.

i)   Climate

Unlike podzolization, the process of laterization operates most favorable in warm and humid (tropical) climate with 2000 to 2500 mm rainfall and continuous high temperature (25°C) throughout the year.

ii)   Natural vegetation

The rain forests of tropical areas are favorable for the process.

iii)   Parent Material

Basic parent materials, having sufficient iron bearing ferromagnesian minerals (Pyroxene, amphiboles, biotite and chlorite), which on weathering release iron, are congenial for the development of laterites.

5. Gleization

The term *glei* is of Russian origin means blue, grey or green clay. The Gleization is a process of soil formation resulting in the development of a glei (or gley horizon) in the lower part of the soil profile above the parent material due to poor drainage condition (lack of oxygen) and where waterlogged conditions prevail. Such soils are called hydro orphic soils.

The process is not particularly dependent on climate (high rainfall as in humid regions) but often on drainage conditions.

The poor drainage conditions result from:

➢ Lower topographic position, such as depression land, where water stands continuously at or close to the surface.

> ➢ Impervious soil parent material, and.
>
> ➢ Lack of aeration.

Under such conditions, iron compounds are reduced to soluble ferrous forms. The reduction of iron is primarily biological and requires both organic matter and microorganisms capable of respiring anaerobically. The solubility of Ca, Mg, Fe, and Mn is increased and most of the iron exists as Fe^{++} organo - complexes in solution or as mixed precipitate of ferric and ferrous hydroxides.

This is responsible for the production of typical bluish to grayish horizon with mottling of yellow and or reddish brown colors.

6. Salinization

It is the process of accumulation of salts, such as sulphates and chlorides of calcium, magnesium, sodium and potassium, in soils in the form of a salty (salic) horizon. It is quite common in arid and semi arid regions. It may also take place through capillary rise of saline ground water and by inundation with seawater in marine and coastal soils. Salt accumulation may also result from irrigation or seepage in areas of impeded drainage.

7. Desalinization

It is the removal by leaching of excess soluble salts from horizons or soil profile (that contained enough soluble salts to impair the plant growth) by ponding water and improving the drainage conditions by installing artificial drainage network.

8. Solonization or Alkalization

The process involves the accumulation of sodium ions on the exchange complex of the clay, resulting in the formation of sodic soils (Solonetz).

All cations in solution are engaged in a reversible reaction with the exchange sites on the clay and organic matter particles.

The reaction can be represented as

$$Ca.Mg.2NaX \longrightarrow Ca^{++} + Mg^{++} + 2Na^{+} + x^{-6} + 3CO_3^{2-} \longrightarrow Na_2CO_3 + MgCO_3 + CaCO_3$$
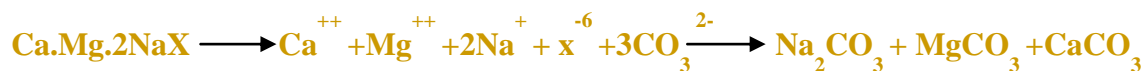
(Where X represents clay or organic matter exchange sites)

9. Solodization or dealkalization

The process refers to the removal of Na^+ from the exchange sites. This process involves dispersion of clay. Dispersion occurs when Na^+ ions become hydrated.

Much of the dispersion can be eliminated if Ca^{++} and or Mg^{++} ions are concentrated in the water, which is used to leach the soonest. These Ca and Mg ion can replace the Na on exchange complex, and the salts of sodium are leached out as :

$$2NaX + CaSO_4 \longrightarrow Na_2SO_4 + CaX$$
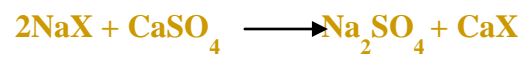
(leachable)

10. Pedoturbation

Another process that may be operative in soils is pedoturbation. It is the process of mixing of the soil.

Mixing to a certain extent takes place in all soils. The most common types of pedoturbation are:

➢ **Faunal pedoturbation:** It is the mixing of soil by animals such as ants, earthworms, moles, rodents, and man himself

➢ **Floral pedoturbation :** It is the mixing of soil by plants as in tree tipping that forms pits and mounds

➢ **Argillic pedoturbation:** It is the mixing of materials in the solum by the churning process caused by swell shrink clays as observed in deep Black Cotton Soils.

✱✱✱✱✱✱✱✱✱✱

Soil profile

The vertical section of the soil showing the various layers from the surface to the unaffected parent material is known as a soil profile.

The various layers are known as horizons. A soil profile contains three main horizons.

They are named as horizon A, horizon B and horizon C.

> ➢ The surface soil or that layer of soil at the top which is liable to leaching and from which some soil constituents have been removed is known as horizon A or the horizon of eluviation.

> ➢ The intermediate layer in which the materials leached from horizon A have been re-deposited is known as horizon B or the horizon of illuviation.

> ➢ The parent material from which the soil is formed is known as horizon C .

A Study of soil profile is important as it is historic record of all the soil forming processes and it forms the basis for the study in pedagogical investigations. Soil profile is the key for the soil classification and also forms the basis for the practical utility of soils.

A hypothetical mineral soil profile will include O, A, B, C and R master horizons and all the possible sub-horizons.

Master horizons and sub horizons

O horizon - It is called as organic horizon. It is formed in the upper part of the mineral soil, dominated by fresh or partly decomposed organic materials.

> ➢ This horizon contains more than 30% organic matter if mineral fraction has more than 50 % clay (or) more than 20 % organic matter if mineral fraction has less clay.

> ➢ The organic horizons are commonly seen in forest areas and generally absent in grassland, cultivated soils.

> ➢ **O1** - Organic horizon in which the original forms of the plant and animal residues can be recognized through naked eye.

> ➢ **O2** - Organic horizon in which the original plant or animal matter can not be recognized through naked eye.

> ➢ **A horizon** - Horizon of organic matter accumulation adjacent to surface and that has lost clay, iron and aluminium.

- ➤ **A1** - Top most mineral horizon formed adjacent to the surface. There will be accumulation of humified organic matter associated with mineral fraction and darker in Colour than that of lower horizons due to organic matter.

- ➤ **A2** - Horizon of maximum eluviation of clay, iron and aluminium oxides and organic matter. Loss of these constituents generally results in accumulation of quartz and other sand and silt size resistant minerals. Generally lighter in Colour than horizons above and below.

- ➤ **A3** - A transitional layer between A and B horizons with more dominated properties of A1 or A2 above than the underlying B horizon. This horizon is sometimes absent. Solum.

- ➤ **B horizon** - Horizon in which the dominant features are accumulation of clay, iron, aluminium or humus alone or in combination. Coating of sesquioxides will impart darker, stronger of red Colour than overlying or underlying horizons.

- ➤ **B1** - A transitional layer between A and B. More like A than B.

- ➤ **B2** - Zone of maximum accumulation of clay, iron and aluminium oxide that may have moved down from upper horizons or may have formed in situ. The organic matter content is generally higher and Colour darker than that of A2 horizon above.

- ➤ **B3** - Transitional horizon between B and C and with properties more similar to that of overlying B2 than underlying C.

- ➤ **C horizon** - It is the horizon below the solum (A + B), relatively less affected by soil forming processes. It is outside the zone of major biological activity. It may contain accumulation of carbonates or sulphates, calcium and magnesium .

- ➤ **R** - Underlying consolidated bed rock and it may or may not be like the parent rock from which the solum is formed.

Besides, lower case letters are used to indicate the special features of master horizons. This case letters follow the subdivisions of master horizons. eg. Ap - ploughed layer eg. B2t - illuvial clay When two or more genetically unrelated (contrasting) materials are present in a profile as in the case of alluvial or colluvial soils then the phenomenon is known as lithological discontinuity. This is indicated by the use of Roman letters as prefixes to the master horizons. eg. Ap, B2, II B22, IIIC.
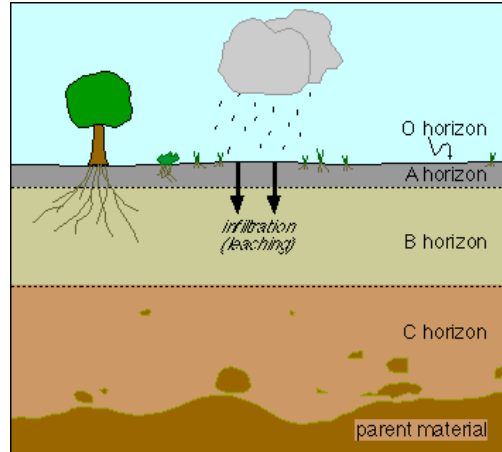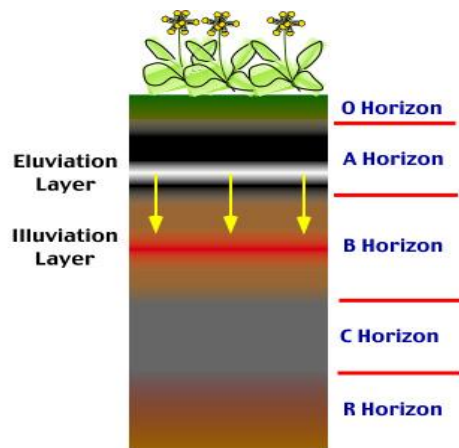
Special Features

Soil Individual or Polypedon: The Soil Survey Staff (1960) defined the soil individual or polypedon (Pedon, Ground) as a natural unit of soil that differs from its adjoining unit on the landscape in one or more properties.

The term pedon has been proposed for small basic soil entities that are part of the continuum mantling the land.

A **pedon** is the smallest volume that can be called "a soil". The set of pedons must fit within the range of one series and occur in a contiguous group to form a polypedon.

A **polypedon** is therefore, defined as a contiguous similar pedons bounded on all sides by "not-soil or by pedons of unlike characters. It is a real physical soils body which has a minimum area of more than 1 sq. km and an unspecified maximum area.

****

Soil physical properties

Physical properties (mechanical behaviour) of a soil greatly influence its use and behaviour towards plant growth. The plant support, root penetration, drainage, aeration, retention of moisture, and plant nutrients are linked with the physical condition of the soil. Physical properties also influence the chemical and biological behaviour of soil. The physical properties of a soil depend on the amount, size, shape, arrangement and mineral composition of its particles. These properties also depend on organic matter content and pore spaces.

Important physical properties of soils.

1. Soil texture, 2. Soil structure, 3. Surface area, 4. Soil density,

5. Soil porosity, 6.Soil colour, 7.Soil consistence

Soil texture- Textural classes- Particle size distribution

Definition

Soil texture refers to the relative proportion of particles or it is the relative percentage by weight of the three soil separates viz., sand, silt and clay or simply refers to the size of soil particles. The proportion of each size group in a given soil (the texture) cannot be easily altered and it is considered as a basic property of a soil. The soil separates are defined in terms of diameter in millimeters of the particles Soil particles less than 2 mm in diameter are excluded from soil textural determinations.

Stones and gravels may influence the use and management of land because of tillage difficulties but these larger particles make little or no contribution to soil properties such as WHC and capacity to store plant nutrients and their supply.

Gravels : 2 – 4 mm

Pebbles : 4 – 64 mm

Cobbles : 64 – 256 mm

Boulders : > 256 mm

Particles less than 2 mm is called fine earth, normally considered in chemical and mechanical analysis.

The components of fine earth: Sand, Silt and Clay (Soil separates. The size limits of these fractions have been established by various organizations. There are a number of systems of naming soil separates.

(a) The American system developed by USDA

(b) The English system or British system (BSI)

(c) The International system (ISSS)

(d) European system

i) USDA

Soil separates	Diameter (mm)
Clay	< 0.002 mm
Silt	0.002 – 0.05
Very Fine Sand	0.05 – 0.10
Fine Sand	0.10 – 0.25
Medium Sand	0.25 - 0.50
Coarse Sand	0.50 - 1.00
Very Coarse Sand	1.00 – 2.00

ii) BSI

Soil separates	Diameter (mm)
Clay	< 0.002 mm
Fine Silt	0.002 – 0.01
Medium Silt	0.01 – 0.04
Coarse Silt	0.04 – 0.06
Fine Sand	0.06 - 0.20
Medium Sand	0.20 - 1.00
Coarse Sand	1.00 – 2.00

iii) ISSS

Soil separates	Diameter (mm)
1. Clay	< 0.002 mm
2. Silt	0.002 – 0.02 mm
3. Fine sand	0.02 – 0.2 mm
4. Coarse sand	0.2 – 2.0 mm

iv) European System

S.No	Soil separates	Diameter (mm)
1	Fine clay	< 0.0002 mm
2	Medium clay	0.0002 – 0.0006
3	Coarse clay	0.0006 – 0.002
4	Fine silt	0.002 - 0.006

5	Medium silt	0.006 - 0.02
6	Coarse silt	0.02 - 0.06
7	Fine sand	0.06 - 0.20
8	Medium sand	0.20 - 0.60
9	Coarse sand	0. 60 - 2.00

Sand

> Usually consists of quartz but may also contain fragments of feldspar, mica and occasionally heavy minerals viz., zircon, Tourmaline and hornblende.

> Has uniform dimensions

> Can be represented as spherical

> Not necessarily smooth and has jagged surface

Silt

> Particle size intermediate between sand and clay

> Since the size is smaller, the surface area is more

> Coated with clay

> Has the physico- chemical properties as that of clay to a limited extent

> Sand and Silt forms the SKELETON

Clay

> Particle size less than 0.002 mm

> Plate like or needle like in shape

> Belong to alumino silicate group of minerals

> Sometimes considerable concentration of fine particles which does not belong to alumino silicates. (eg). iron oxide and $CaCO_3$

> These are secondary minerals derived from primary minerals in the rock

> Flesh of the soil

Knowledge on Texture is important. It is a guide to the value of the land .Land use capability and methods of soil management depends on Texture

Particle size distribution/ determination

The determination of relative distribution of the ultimate or individual soil particles below 2 mm diameter is called as Particle size analysis or Mechanical analysis

Two steps are involved

i) Separation of all the particles from each other i.e. Complete dispersion into ultimate particles

ii) Measuring the amount of each group

Separation

S.No	Aggregating agents	Dispersion method
1	Lime and Oxides of Fe & Al	Dissolving in HCl
2	Organic matter	Oxidises with H_2O_2
3	High concn. of electrolytes (soluble salts)	Precipitate and decant or filter with suction
4	Surface tension	Elimination of air by stirring with water or boiling

After removing the cementing agents , disperse by adding NaOH

Measurement

Once the soil particles are dispersed into ultimate particles, measurement can be done

i) Coarser fractions – sieving – sieves used in the mechanical analysis corresponds to the desired particle size separation

For 2 mm, 1 mm and 0.5 mm – sieves with circular holes

For smaller sizes, wire mesh screens are used (screening)

ii) Finer fractions – by settling in a medium

The settling or the velocity of the fall of particles is influenced by

Viscosity of the medium

Difference in density between the medium and falling particles

Size and shape of object

Stokes' Law

Particle size analysis is based on a simple principle i.e. "when soil particles are suspended in water they tend to sink. Because there is little variation in the density of most soil particles, their velocity (V) of settling is proportional to the square of the radius 'r' of each particles.

Thus $V = kr^2$, where k is a constant. This equation is referred to as Stokes' law.

Stokes (1851) was the first to suggest the relationship between the radius of the particles and its rate of fall in a liquid. He stated that "the velocity of a falling particle is proportional to the square of the radius and not to its surface. The relation between the diameter of a particle and its settling velocity is governed by Stokes' Law:

$$V = \frac{2\,gr^2\,(ds - dw)}{9\,n}$$

Where ,

V - velocity of settling particle (cm/sec.)

g - acceleration due to gravity cm/ sec^2 (981)

ds - density of soil particle (2.65)

dw - density of water (1)

n - coefficient of viscosity of water (0.0015 at 4oC)

r - radius of spherical particles (cm).

Assumptions and Limitations of Stokes' Law

Particles are rigid and spherical / smooth. This requirement is very difficult to fulfill, because the particles are not completely smooth over the surface and spherical. It is established that the particles are not spherical and irregularly shaped such as plate and other shapes.

The particles are large in comparison with the molecules of the liquid so that in comparison with the particle the medium can be considered as homogenous. Ie the particles must be big enough to avoid Brownian movement. The particles less than 0.0002 mm exhibit this movement so that the rate of falling is varied.

The fall of the particles is not hindered or affected by the proximity (very near) of the wall of the vessel or of the adjacent particles. Many fast falling particles may drag finer particles down along with them.

The density of the particles and water and as well as the viscosity of the medium remain constant. But this is usually not so because of their different chemical and mineralogical composition.

The suspension must be still. Any movement in the suspension will alter the velocity of fall and such movement is brought by the sedimentation of larger particles (> 0.08 mm). They settle so fast and create turbulence in the medium.

The temperature should be kept constant so that convection currents are not set up.

Methods of Textural determination

Numerous methods for lab and field use have been developed

i) Elutriation method – Water & Air ; ii)Pipette method

iii) Decantation/ beaker method ; iv) Test tube shaking method

v) Feel method – Applicable to the field – quick method – by feeling the soil between thumb and fingers

Feel Method

Evaluated by attempting to squeeze the moistened soil into a thin ribbon as it is pressed with rolling motion between thumb and pre finger or alternately to roll the soil into a thin wire.

η Four aspects to be seen – i) Feel by fingers, ii)Ball formation , iii) Stickiness and iv) Ribbon formation

Soil Textural Classes

To convey an idea of the textural make up of soils and to give an indication of their physical properties, soil textural class names are used. These are grouped into three main fractions viz., Sand, Silt and Clay.

According to the proportion of these three fractions a soil is given a name to indicate its textural composition. Such a name gives an idea not only of the textural composition of a soil but also of its various properties in general.

On this basis soils are classified into various textural classes like sands clays, silts, loams etc

Sands

The sand group includes all soils in which the sand separates make up at least 70% and the clay separate 15% or less of the material by weight. The properties of such soils are therefore characteristically those of sand in contrast to the stickier nature of clays. Two specific textural classes are recognized in this group sandy and loamy sand although in practice two subclasses are also used Loamy fine sand and loamy very fine sand.

Silt

The silt group includes soils with at least 80% silt and 12% or less clay. Naturally the properties of this group are dominated by those of silt. Only one textural class - Silt is included in this group.

Clays

To be designated a clay a soi1 must contain at least 35% of the clay separate and in most cases not less than 40%. In such soils the characteristics of the clay separates are distinctly dominant, and the class names are clay, sandy clay and silty clay. Sandy clays may contain more sand than clay. Likewise, the silt content of silty clays usually exceeds clay fraction.

Loams

The loam group, which contains many subdivisions, is a more complicated soil textural class. An ideal loam may be defined as a mixture of sand, silt and day particles that exhibits the properties of those separates in about equal proportions. Loam soils do not exhibit dominant physical properties of sand, silt or clay. Loam does not contain equal percentage of sand, silt and clay. However, exhibit approximately equal properties of sand, silt and clay.

Determination of Textural Class

In the American system as developed by the United State Department of Agriculture twelve textural classes are proposed.

The textural triangle

It is used to determine the soil textural name after the percentages of sand, silt, and clay are determined from a laboratory analysis. Since the soil's textural classification includes only mineral particles and those of less than 2mm diameter, the sand plus silt plus clay percentages equal 100 percent. (note that organic matter is not included.) Knowing the amount of any two fractions automatically fixes the percentage of the third one.

To use the diagram, locate the percentage of clay first and project inward parallel to sand line. Do likewise for the per cent silt and project inward parallel to clay line and for sand, project inward parallel to silt. The point at which the projections cross or intersect will identify the class name Some times, the intersecting point exactly fall on the line between the textural classes. Then it is customary to use the name of the finer fraction when it happens. (eg). Soil containing 40% clay, 30% sand.

Importance of Soil Texture

Presence of each type of soil particles makes its contribution to the nature and properties of soil as a whole

- Texture has good effect on management and productivity of soil. Sandy soils are of open character usually loose and friable.
- Such type of the texture is easy to handle in tillage operations.
- Sand facilitates drainage and aeration. It allows rapid evaporation and percolation.
- Sandy soils have very little water holding capacity. Such soils can not stand drought and unsuitable for dry farming.
- Sandy soils are poor store house of plant nutrients

- Contain low organic matter
- Leaching of applied nutrients is very high.
- In sandy soil, few crops can be grown such as potato, groundnut and cucumbers.
- Clay particles play a very important role in soil fertility.
- Clayey soils are difficult to till and require much skill in handling. When moist clayey soils are exceedingly sticky and when dry, become very hard and difficult to break.
- They have fine pores, and are poor in drainage and aeration.
- They have a high water holding capacity and poor percolation, which usually results in water logging.
- They are generally very fertile soils, in respect of plant nutrient content. Rice, jute, sugarcane can be grown very successfully in these soils.
- Loam and Silt loam soils are highly desirable for cultivation
- Generally, the best agriculture soils are those contain $10 - 20$ per cent clay, $5 - 10$ per cent organic matter and the rest equally shared by silt and sand and 30% silt - called as clay rather than clay loam.
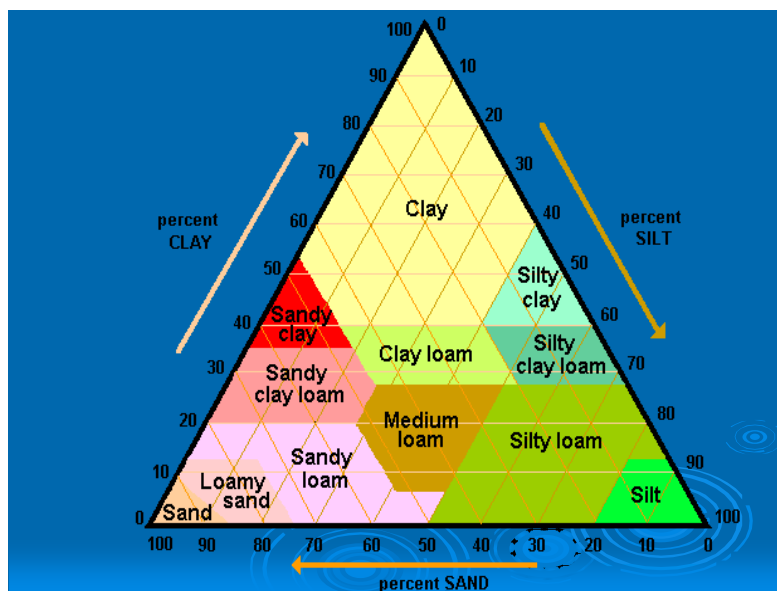
Soil structure – Classification

Soil conditions and characteristics such as water movement, heat transfer, aeration, and porosity are much influenced by structure. In fact, the important physical changes imposed by the farmer in ploughing, cultivating, draining, liming, and manuring his land are structural rather than textural.

Definition

The arrangement and organization of primary and secondary particles in a soil mass is known as soil structure. Soil structure controls the amount of water and air present in soil. Plant roots and germinating seeds require sufficient air and oxygen for respiration. Bacterial activities also depend upon the supply of water and air in the soil.

Formation of soil structure

Soil particles may be present either as single individual grains or as aggregate i.e. group of particles bound together into granules or compound particles. These granules or compound particles are known as secondary particles. A majority of particles in a sandy or silty soil are present as single individual grains while in clayey soil they are present in granulated condition. The individual particles are usually solid, while the aggregates are not solid but they possess a porous or spongy character. Most soils are mixture of single grain and compound particle. Soils, which predominate with single grains are said to be structureless, while those possess majority of secondary particles are said to be aggregate, granulated or crumb structure.

Mechanism of Aggregate Formation

The bonding of the soil particles into structural unit is the genesis of soil structure. The bonding between individual particles in the structural units is generally considered to be stronger than the structural units themselves.

In aggregate formation, a number of primary particles such as sand, silt and clay are brought together by the cementing or binding effect of soil colloids. The cementing materials taking part in aggregate formation are colloidal clay, iron and aluminium hydroxides and decomposing organic matter. Whatever may be the cementing material, it is ultimately the dehydration of colloidal matter accompanied with pressure that completes the process of aggregation.

Colloidal clay

By virtue of high surface area and surface charge, clay particles play a key role in the formation of soil aggregates. Sand and silt particles can not form aggregates as they do not possess the power of adhesion and cohesion. These particles usually carry a coating of clay particles; they are enmeshed in the aggregates formed by the adhering clay particles. Colloidal particles form aggregates only when they are flocculated. There is vast difference between flocculation and aggregation. Flocculation is brought about by coalescence of colloidal particles and is the first step in aggregation.

Aggregation is something more than flocculation involving a combination of different factors such as hydration, pressure, dehydration etc. and required cementation of flocculated particles. The cementation may be caused by cations, oxides of Fe and Al, humus substances and products of microbial excretion and synthesis. Clay particles form aggregates only if they are wetted by a liquid like water whose molecules possess an appreciable dipole moment.

$$Clay^{-} - {}^{+}Water^{-} - {}^{+}Cation^{+} - {}^{-}Clay^{-} - {}^{+}Water^{-} - {}^{+}Cation^{+} - {}^{-}Clay^{-}$$

The aggregation also depends upon the nature of clay particles, size and amount of clay particles, dehydration of clay particles, cations like calcium and anions like phosphate.

Fe and Al oxides

The colloidal Fe oxides act as cementing agent in aggregation. Al oxides bind the sand and silt particles. These act in two ways. A part of the hydroxides acts as a flocculating agent and the rest as a cementing agent.

Organic matter: It also plays an important role in forming soil aggregates.

➢ During decomposition, cellulosic substances produce a sticky material very much resembling mucus or mucilage. The sticky properly may be due to the presence of humic or humic acid or related compounds produced.

➢ Certain polysaccharides formed during decomposition.

➢ Some fungi and bacteria have cementing effect probably due to the presence of slimes and gums on the surface of the living organisms produced as a result of the microbial activity

Classification

The primary particles –sand, silt and clay - usually occur grouped together in the form of aggregates.

Natural aggregates are called peds where as clod is an artificially formed soil mass. Structure is studied in the field under natural conditions and it is described under three categories

1 Type - Shape or form and arrangement pattern of peds

2 Class - Size of Peds

3 Grade - Degree of distinctness of peds

Types of Structure: There are four principal forms of soil structure

Plate-like (Platy)

In this type, the aggregates are arranged in relatively thin horizontal plates or leaflets. The horizontal axis or dimensions are larger than the vertical axis. When the units/ layers are thick they are called platy. When they are thin then it is laminar. Platy structure is most noticeable in the surface layers of virgin soils but may be present in the subsoil. This type is inherited from the parent material, especially by the action of water or ice.
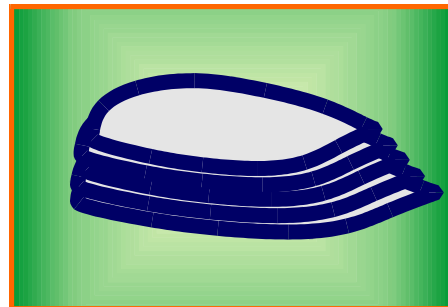
Prism-like

The vertical axis is more developed than horizontal, giving a pillar like shape.

Vary in length from 1- 10 cm. Commonly occur in sub soil horizons of Arid and Semi arid regions. When the tops are rounded, the structure is termed as columnar when the tops are flat / plane, level and clear cut - prismatic.

Block like

All three dimensions are about the same size. The aggregates have been reduced to blocks .Irregularly six faced with their three dimensions more or less equal. When the faces are flat and distinct and the edges are sharp angular, the structure is named as angular blocky.

When the faces and edges are mainly rounded it is called sub angular blocky. These types usually are confined to the sub soil and characteristics have much to do with soil drainage, aeration and root penetration.
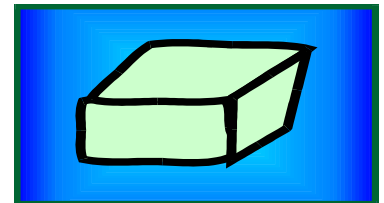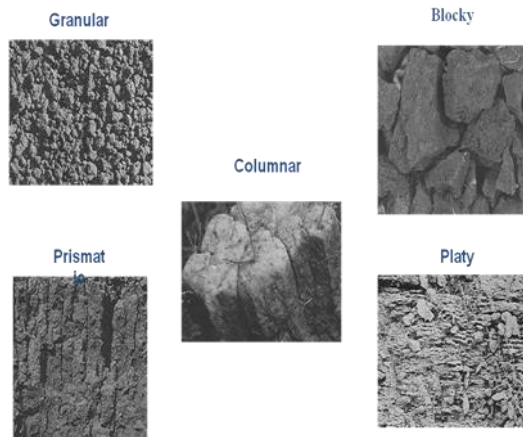

Spheroidal (Sphere like)

All rounded aggregates (peds) may be placed in this category. Not exceeding an inch in diameter. These rounded complexes usually loosely arranged and readily separated. When wetted, the intervening spaces generally are not closed so readily by swelling as may be the case with a blocky structural condition. Therefore in sphere-like structure, infiltration, percolation and aeration are not affected by wetting of soil. The aggregates of this group are usually termed as granular which are relatively less porous. When the granules are very porous, it is termed as crumb. This is specific to surface soil particularly high in organic matter/ grass land soils.

Classes of Structure: Each primary structural type of soil is differentiated into 5 size classes depending upon the size of the individual peds.
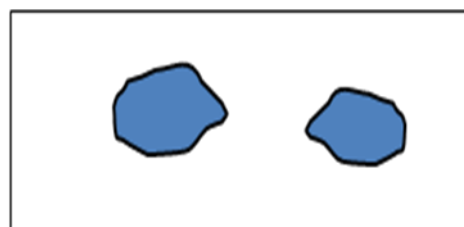
Soil structure –with structure   # Soil structure –without structure

The terms commonly used for the size classes are
1. Very fine or very thin

2. Fine or thin

3. Medium

4. Coarse or thick

5. Very Coarse or very thick

The terms thin and thick are used for platy types, while the terms fine and coarse are used for other structural types.

Grades of Structure

Grades indicate the degree of distinctness of the individual peds. It is determined by the stability of the aggregates. Grade of structure is influenced by the moisture content of the soil. Grade also depends on organic matter, texture etc. Four terms commonly used to describe the grade of soil structure are:

1. **Structureless:** There is no noticeable aggregation, such as conditions exhibited by loose sand.

2. **Weak Structure:** Poorly formed, indistinct formation of peds, which are not durable and much un aggregated material.

3. **Moderate structure:** Moderately well developed peds, which are fairly durable and distinct.

4. **Strong structure:** Very well formed peds, which are quite durable and distinct.

Structure naming

For naming a soil structure the sequence followed is grade, class and type; for example strong coarse angular blocky, moderate thin platy, weak fine prismatic.

Factors Affecting Soil Structure

The development of structure in arable soil depends on the following factors:

1. **Climate**

Climate has considerable influence on the degree of aggregation as well as on the type of structure. In arid regions there is very little aggregation of primary particles. In semi arid regions, the degree of aggregation is greater.

2. **Organic matter**

Organic matter improves the structure of a sandy soil as well as of a clay soil. In case of a sandy soil, the sticky and slimy material produced by the decomposing organic matter and the associated microorganism cement the sand particles together to form aggregates. In case of clayey soil, it modifies the properties of clay by reducing its cohesiveness. This helps making clay more crumby.

3. **Tillage**

Cultivation implements break down the large clods into smaller fragments and aggregates. For obtaining good granular and crumby structure, optimum moisture content in the soil is necessary. If the moisture content is too high it will form large clods on drying. If it is too low some of the existing aggregates will be broken down.

4. **Plants, Roots and Residues**

Excretion of gelatinous organic compounds and exudates from roots serve as a link
Root hairs make soil particles to cling together. – Grass and cereal roots Vs other roots
Pressure exerted by the roots also held the particles together
Dehydration of soil - strains the soil due to shrinkage ☻ result in cracks ☻ lead to aggregation
Plant tops and residues – shade the soil – prevent it from extreme and sudden temperature and moisture changes and also from rain drop impedance.
Plant residues – serve as a food to microbes – which are the prime aggregate builders.

5. Animals

Among the soil fauna small animals like earthworms, moles and insects etc., that burrow in the soil are the chief agents that take part in the aggregation of finer particles.

6. Microbes

Algae, fungi, actinomycetes and fungi keep the soil particles together. Fungi and actinomycetes exert mechanical binding by mycelia, Cementation by the products of decomposition and materials synthesized by bacteria.

7. Fertilizers

Fertilizer like Sodium Nitrate destroys granulation by reducing the stability of aggregates. Few fertilizers for example, CAN help in development of good structures.

8. Wetting and drying

When a dry soil is wetted, the soil colloids swell on absorbing water. On drying, shrinkage produces strains in the soil mass gives rise to cracks, which break it up into clods and granules of various sizes.

9. Exchangeable cations

Ca, Mg ------------ H, Na

Flocculating Deflocculating

Good structure Poor structure

10. Inorganic cements: $CaCO_3$ and Sesquioxides

11. Clay, 12. Water

Effect of Soil Structure on other Physical Properties

Porosity

Porosity of a soil is easily changed. In plate like structure, pore spaces are less where as in crumby structure pore spaces are more.

Temperature

Crumby structure provides good aeration and percolation of water in the soil. Thus these characteristics help in keeping optimum temperature in comparison to plate like structure.

Density: Bulk density varies with the total pore space present in the soil. Structure chiefly influences pore spaces Platy structure with less total pore spaces has high bulk density where as crumby structure with more total pore spaces has low bulk density

Consistence of soil also depends on structure. Plate-like structure exhibits strong plasticity.

Colour

Bluish and greenish colors of soil are generally due to poor drainage of soil. Platy structure normally hinders free drainage.

Importance of Structure: Soil structure influences rather indirectly by the formation of an array of pores of various shapes and sizes. These pores are controlling factors governing water, air and temperature in soil.

The role of soil structure in relation to plant growth

➢ Soil structure influences the amount and nature of porosity.

➢ Structure controls the amount of water and air present in the soil. Not only the amount of water and air dependent on soil structure, but their movement and circulation are also controlled by soil structure.

➢ It affects tillage practices.

➢ Structure controls runoff and erosion.

➢ Platy structure normally hinders free drainage whereas sphere like structure (granular and crumby) helps in drainage.

➢ Crumby and granular structure provides optimum infiltration, water holding capacity, aeration and drainage. It also provides good habitat for microorganisms and supply of nutrients.

Class of Soil Structure as differentiated by size of soil peds

Class	Platy	Prismatic	Columnar	Blocky	S.A.Blocky	Granular	Crumb
V.Fine or V.Thin	<1	<10	<10	<5	<5	<1	<1
Fine or Thin	1-2	10-20	10-20	5-10	5-10	1-2	1-2
Medium	2-5	20-50	20-50	10-20	10-20	2-5	2-5
Coarseor Thick	5-10	50-100	50-100	20-50	20-50	5-10	-

V.C	>10	>100	>100	>50	>50	>10	-
or V.Thic							

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Soil aggregates-significance-soil consistency-soil crusting

Soil aggregates

Soil aggregates are 'clumps' of soil particles that are held together by moist clay, organic matter (such as roots), by organic compounds (from bacteria and fungi) and by fungal hyphae (*pronounced "highfee"*). Aggregates vary in size from about 2 thousandths of a millimetre across up to about 2 millimetres across, and are made up of particles of varying sizes. Some of these particles fit closely together and some do not and this creates spaces of many different sizes in the soil. These spaces, or pores, within and between soil aggregates are essential for storing air and water, microbes, nutrients and organic matter. Soils with many aggregates are called "well-aggregated". Such soils are more stable and less susceptible to erosion.

There are two ways that bacteria could be involved in soil aggregation. One way is by producing organic compounds called polysaccharides. Bacterial polysaccharides are more stable than plant polysaccharides, resisting decomposition long enough to be involved in holding soil particles together in aggregates. The other way bacteria are involved in soil aggregation is by developing a small electrostatic charge that attracts the electrostatic charge on clay surfaces, bringing together small aggregates of soil.
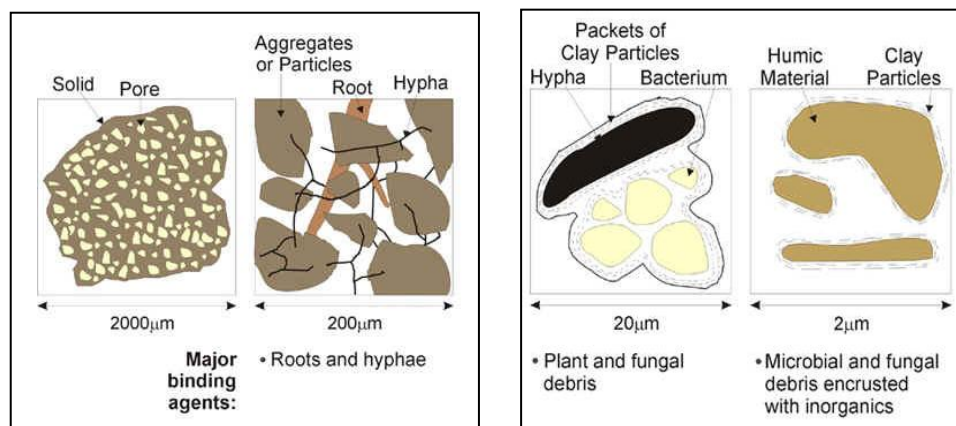
Fungi grow in long, threadlike structures, called hyphae. The amount of aggregation in the soil has been found to relate to the length of fungal hyphae in the soil. Fungi help to form aggregates in the soil by enmeshing soil particles with their hyphae and forming cross-links between soil particles. Mycorrhizal fungi and fungi that colonise fresh organic matter

are believed to be the most important for assisting with stabilisation of soil particles into aggregates.

Significance of soil aggregation

Crop growth is often constrained by poor root development, by slow water infiltration and water movement through the soil, and by poor soil aeration. These constraints are often associated with poor soil porosity. Soil aggregation is important to developing and maintaining good soil porosity and hence to good root growth and to movement of soil water and gases. With more soil in water stable aggregates, it is expected that:

- The rate of water infiltration and percolation will increase
- Soil crusting will be less – which improved root penetration and access to soil moisture and nutrients and emergence of seedlings
- Resistance to the splash effect of raindrops will increase and soil erodibility will decrease; and
- Runoff will decrease, making more water available to the crop.

The importance of soil physical properties to crop growth, including soil aggregation properties, is often under-estimated by producers, and practical exercises can be useful in conveying information on the importance of these properties.

Soil Consistence

Soil consistence is defined as "the resistance of a soil at various moisture contents to mechanical stresses or manipulations".

It combines both the '**cohesive**' and '**adhesive**' forces, which determine the ease with which a soil can be reshaped or ruptures.

Adhesion	Cohesion
Molecular attraction that holds the surfaces of two substances (eg. Water and soil particles) in contact	Holding together: force holding a solid or liquid together, owing to attraction between like molecules. Decreases with rise in temperature

Soil consistence is described at three moisture levels namely 'wet', 'moist' and 'dry'.

1. Wet soils: Consistency is denoted by terms stickiness and plasticity

Stickiness is grouped into four categories namely i) non sticky, ii) slightly sticky, iii) sticky and iv) very sticky

Plasticity of a soil is its capacity to be moulded (to change its shape depending on stress) and to retain the shape even when the stress is removed. Soils containing more than about 15% clay exhibit plasticity – pliability and the capacity of being molded. There are four degrees in plasticity namely i) non plastic, ii) slightly plastic, iii) plastic and iv) very plastic.

2. Moist soil: Moist soil with least coherence adheres very strongly and resists crushing between the thumb and forefinger. The different categories are

i. Loose-non coherent

ii. Very friable - coherent, but very easily crushed

iii. Friable - easily crushed

iv. Firm - crushable with moderate pressure

v. Very firm - crushable only under strong pressure

vi. Extremely firm -   completely resistant to crushing. (type and amount of clay and humus influence this consistency)

3. Dry soil: In the absence of moisture, the degree of resistance is related to the attraction of particles for each other. The different categories are

i) Loose - non coherent

ii) Soft - breaks with slight pressure and becomes powder

iii) Slightly hard - break under moderate pressure

iv) Hard - breaks with difficulty with pressure

v) Very hard - very resistant to pressure

vi) Extremely hard - extreme resistance and cannot be broken

Soil crusting

Formation mechanism:

Soil crusts usually are formed as a result of compaction at the immediate surface due to an externally applied force. This force is supplied primarily by the impact of raindrops as the soil is wetted and the radiant energy of the sun as the soil dries. When the rain drops fall on dry soil.

Bulk density and particle density of soils & porosity

Particle Density

The weight per unit volume of the solid portion of soil is called particle density. Generally particle density of normal soils is 2.65 grams per cubic centimeter. The particle density is higher if large amount of heavy minerals such as magnetite, limonite and hematite are present in the soil. With increase in organic matter of the soil the particle density decreases. Particle density is also termed as true density.

Table Particle density of different soil textural classes

Textural class	Particle density (g/ cm^3)
Coarse sand	2.655
Fine sand	2.659
Silt	2.798
Clay	2.837

Bulk Density

The oven dry weight of a unit volume of soil inclusive of pore spaces is called bulk density. The bulk density of a soil is always smaller than its particle density. The bulk density of sandy soil is about 1.6 g / cm^3, whereas that of organic matter is about 0.5. Bulk density normally decreases, as mineral soils become finer in texture. The bulk density varies indirectly with the total pore space present in the soil and gives a good estimate of the porosity of the soil. Bulk density is of greater importance than particle density in understanding the physical behavior of the soil. Generally soils with low bulk densities have favorable physical conditions.

Bulk density of different textural classes

Textural class	Bulk density (g/cc)	Pore space (%)
Sandy soil	1.6	40
Loam	1.4	47
Silt loam	1.3	50
Clay	1.1	58

Factors affecting bulk density

1. **Pore space**

   Since bulk density relates to the combined volume of the solids and pore spaces, soils with high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space. Consequently, any factor that influences soil pore space will affect bulk density.

2. **Texture**

   Fine textured surface soils such as silt loams, clays and clay loams generally have lower bulk densities than sandy soils. This is because the fine textured soils tend to organize in porous grains especially because of adequate organic matter content. This results in high pore space and low bulk density. However, in sandy soils, organic matter content is generally low, the solid particles lie close together and the bulk density is commonly higher than in fine textured soils.

3. **Organic matter content**

   More the organic matter content in soil results in high pore space there by shows lower bulk density of soil and vice-versa.

Porosity

Soil porosity refers to that part of a soil volume that is not occupied by soil particles or organic matter.

The pore space of a soil is the space occupied by air and water. The amount or ratio of pore space in a soil is determined by the arrangement of soil particles like sand, silt and clay. In sandy soils, the particles are arranged closely and the pore space is low. In clay soils, the particles are arranged in popous aggregates and the pore space is high. Presence of organic matter increases the pore space.

Factors influencing pore space

Soil texture

Sandy surface soil   : 35 to 50 %

Medium to fine textured soils   : 50 to 60 %

Compact sub soils   : 25 to 30%

Crops / vegetation

Some crops like blue grass increases the porosity to 57.2% from the original 50% Cropping reduces the porosity as cultivation reduces the organic matter content and hence decrease in granulation. Virgin soils have more pore space.

Continuous cropping reduces pore space than intermittent cropping. More the number of crops per year, lesser will be the pore space particularly macro pores. Conservation tillage and no tillage reduces porosity than conventional tillage

Size of pores

1. Macro pores (non-capillary pores)   : diameter >0.05 mm
2. Micro pores (capillary pores)   : diameter < 0.05 mm

In macro pores, air and water moves freely due to gravitation and mass flow. In micro pores, the movement of air and water is very slow and restricted to capillary movement and diffusion.

Sandy soil have more macro pores and clay soils have more micro pores. So in sandy soils, water and air movement is rapid due to macro pores though the pore space is higher and in clay soils the air and water is slower due to micro pores though the total pore space is higher.

Loamy soils will have 50% porosity and have equal portion of macro and micro pores.
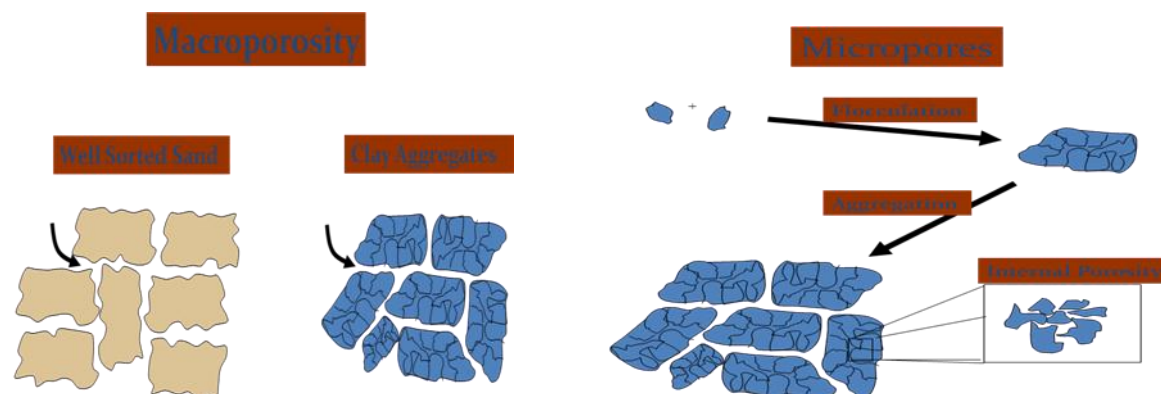
Significance and manipulation of soil porosity

The bulk density and pore space are inter related. Development of low bulk density values also means the development of large amount of pore spaces. In nature, low bulk density values are usually found in soilswith high organic matter contents. High biological activities are necessary for formation and large accumulation of organic matter. Together with the effect of soil organisms, the high humus content will encourage aggregation, increasing in this way soil porosity, and thereby decreasing bulk density values. The cultivation effect of the

soil macro and micro fauna produces an intricate system of macropores, which is a major factor for lowering the bulk density of soil. Continous cropping is noted to decrease the amount of organic matter in soils, and is expected to decrease soil aggregation. Tillage by ploughing is designed to increase the pore space in soils, but is infact decrasing organic matter. To alleviate these problems conservation tillage and no tillage have been introduced. Though many claimed that this increased the organic matter, the later have not always increased the total pore space.

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Soil compaction

Soil compaction is defined as the method of mechanically increasing the density of soil. In construction, this is a significant part of the building process. If performed improperly, settlement of the soil could occur and result in unnecessary maintenance costs or structure failure. Almost all types of building sites and construction projects utilize mechanical compaction techniques.

Soil Density

Loose Soil
(poor load support)

Compacted Soil
(improved load support)
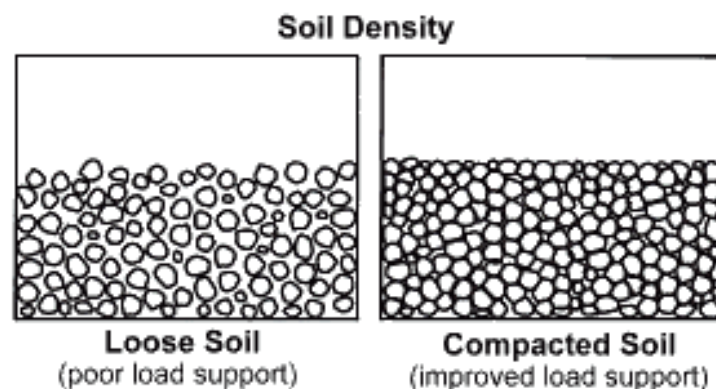
Soil Colour

Soil colour indicates many soil features. A change in soil colour from the adjacent soils indicates a difference in the soil`s mineral origin (parent material) or in the soil development. Soil colour varies among different kinds as well as within the soil profile of the same kind of soil. It is an important soil properties through which its description and classification can be made.

Kinds of soil colour

Soil colour is inherited from its parent material and that is referred to as lithochromic, e.g. red soils developed from red sandstone. Besides soil colour also develops during soil formation through different soil forming processes and that is referred to as acquired or pedochromic colour, e.g. red soils developed from granite or schist.

Factors affecting soil colour

There are various factors or soil constituents that influence the soil colour which are as follows:

➤ **Organic matter:** soils containing high amount of organic matter show the colour variation from black to dark brown.

➤ **Iron compounds:** soil containing higher amount of iron compounds generally impart red, brown and yellow tinge colour.

➤ **Silica, lime and other salts:** Sometimes soils contain either large amounts of silica and lime or both.

Due to presence of such materials in the soil the colour of the soil appears like white or light coloured.

➤ **Mixture of organic matter and iron oxides:** Very often soils contain a certain amount of organic matter and iron oxides. As a result of their existence in soil, the most common soil colour is found and known as brown.

➤ **Alternate wetting and drying condition:** During monsoon period due to heavy rain the reduction of soil occurs and during dry period the oxidation of soil also takes place.due to development of such alternating oxidation and reduction condition,the colour of soil in different horizons of the soil profile is variegated or mottled. This mottled colour is due to residual products of this process especially iron and manganese compounds.

➤ **Oxidation-reduction conditions:** when soils are waterlogged for a longer period, the permanent reduced condition will develop. The presence of ferrous compounds resulting from the reducing condition in waterlogged soils impart bluish and greenish colour.

Therefore, it may be concluded that soil colour indirectly indicative of many other important soil properties.besides soil colour directly modify the soil

temperature e.g.dark coloured soils absorb more heat than light coloured soils.

Determination of soil colour

The soil colours are best determined by the comparison with the Munsell colour.

This colour chart is commonly used for this purpose.the colour of the soil is a result of the light reflected from the soil.soil colour rotation is divided into three parts:

Hue - it denotes the dominant spectral colour (red,yellow ,blue and green).

Value - it denotes the lightness or darkness of a colour (the amount of reflected light).

Chroma - it represents the purity of the colour (strength of the colour).

The Munsell colour notations are systematic numerical and letter designations of each of these three variables (Hue,Value and Chroma).For example ,the numerical notation 2.5 YR6/6 suggests a hue of 2.5 YR,value of 5 and chroma of 6. The equivalent or parallel soil colour name for this Munsell notation is `red`.

Soil water

Water, an excellent solvent for most of the plant nutrients,is a primary requisite for plant growth,

Importance of Soil Water

➢ Soil water serves as a solvent and carrier of food nutrients for plant growth

➢ Yield of crop is more often determined by the amount of water available rather than the deficiency of other food nutrients

➢ Soil water acts as a nutrient itself

➢ Soil water regulates soil temperature

➢   Soil forming processes and weathering depend on water

➢   Microorganisms require water for their metabolic activities

➢   Soil water helps in chemical and biological activities of soil

➢   It is a principal constituent of the growing plant

➢   Water is essential for photosynthesis

Water serves **four functions** in plants:

➢ it is the major constituents of plant protoplasm(85-95%)

➢ it is essential for photosynthesis and conversion of strarches to sugars

➢ it is the solvent in which nutrients move into and through plant parts to capture sunlight.

➢ In fact, the soil water is a great regulator of physical, chemical and biological activities in the soil.

Plants absorb some water through leaf stomata (openings), but most of the water used by plants is absorbed by the roots from the soil. For optimum water used, it is vital to know how water moves into and through the soil, how the soil stores water, how the plant absorbs it, how nutrients are lost from the soil by percolation, and how to measure soil water content and losses.

Soil also serves as a regulated reservoir for water because it receives precipitation and irrigation water.

A representative cultivated loam soil contains approximately 50% solid particles (sand, silt, clay and organic matter), 25% air and the rest 25%mater.only half of this water is available to plants because of the mechanics of water storage in the soil.

Structure of water

Water can participate in a series of reactions occurring in soils and plants, only because of its structural behavior. Water is simple compound, its individual molecules containing one oxygen atom and two much smaller hydrogen atoms.

The elements are bonded together covalently, each hydrogen or proton sharing its single electron with the oxygen. Instead of the atoms being arranged linearly (H-O-H) the hydrogen atoms are attached to the oxygen as a v shaped.

Factors Affecting Soil Water

1. Texture: Finer the texture, more is the pore space and also surface area, greater is the retention of water.

2. Structure: Well-aggregated porous structure favors better porosity, which in turn enhance water retention.

3. Organic matter: Higher the organic matter more is the water retention in the soil.

4. Density of soil: Higher the density of soil, lower is the moisture content.

5. Temperature: Cooler the temperature, higher is the moisture retention.

6. Salt content: More the salt content in the soil less is the water available to the plant.

7. Depth of soil: More the depth of soil more is the water available to the plant.

8. Type of clay: The 2:1 type of day increases the water retention in the soil.

Classification of soil water

Soil water has been classified from a physical and biological point of view as Physical classification of soil water, and biological classification of soil water.

Physical classification of soil water

i) Gravitational water ii) Capillary water and iii) Hygroscopic water

1. Gravitational water: Gravitational water occupies the larger soil pores (macro pores) and moves down readily under the force of gravity. Water in excess of the field capacity is termed gravitational water. Gravitational water is of no use to plants because it occupies the larger pores. It reduces aeration in the soil. Thus, its

removal from soil is a requisite for optimum plant growth. Soil moisture tension at gravitational state is zero or less than 1/3 atmosphere.

Factors affecting gravitational water

i. Texture: Plays a great role in controlling the rate of movement of gravitational water. The flow of water is proportional to the size of particles. The bigger the particle, the more rapid is the flow or movement. Because of the larger size of pore, water percolates more easily and rapidly in sandy soils than in clay soils.

ii. Structure: It also affects gravitational water. In platy structure movement of gravitational water is slow and water stagnates in the soil. Granular and crumby structure helps to improve gravitational water movement. In clay soils having single grain structure, the gravitational water, percolates more slowly. If clay soils form aggregates (granular structure), the movement of gravitational water improves.
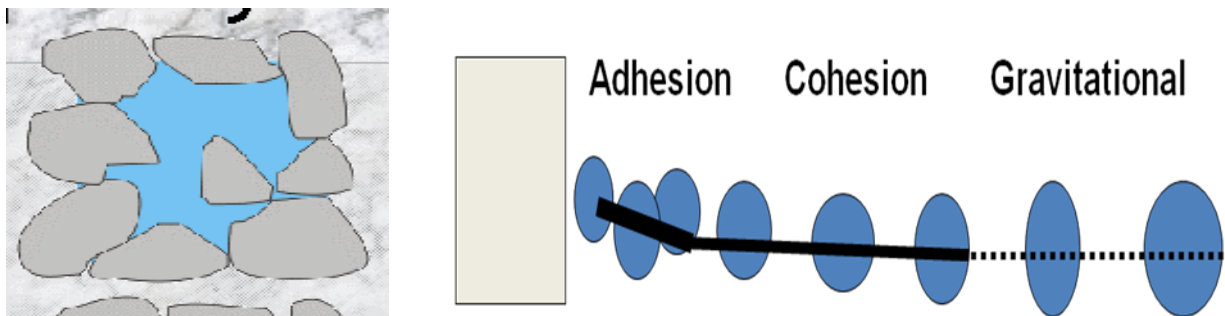
2. Capillary water: Capillary water is held in the capillary pores (micro pores). Capillary water is retained on the soil particles by surface forces. It is held so strongly that gravity cannot remove it from the soil particles. The molecules of capillary water are free and mobile and are present in a liquid state. Due to this reason, it evaporates easily at ordinary temperature though it is held firmly by the soil particle; plant roots are able to absorb it. Capillary water is, therefore, known as available water. The capillary water is held between 1/3 and 31 atmosphere pressure.

Factors affecting capillary water

The amount of capillary water that a soil is able to hold varies considerably. The following factors are responsible for variation in the amount of capillary water.

i. Surface tension: An increase in surface tension increases the amount of capillary water.

ii. Soil texture: The finer the texture of a soil, greater is the amount of capillary water holds. This is mainly due to the greater surface area and a greater number of micro pores.

iii. Soil structure: Platy structure contains more water than granular structure.

iv. Organic matter: The presence of organic matter helps to increase the capillary capacity of a soil. Organic matter itself has a great capillary capacity. Undecomposed organic matter is generally porous having a large surface area, which helps to hold more capillary water. The humus that is formed on decomposition has a great capacity for absorbing and holding water. Hence the presence of organic matter in soil increases the amount of capillary water in soil.

3. Hygroscopic water: The water that held tightly on the surface of soil colloidal particle is known as hygroscopic water. It is essentially non-liquid and moves primarily in the vapour form.

Hygroscopic water held so tenaciously {31 to 10000 atmosphere) by soil particles that plants cannot absorb it. Some microorganism may utilize hygroscopic water. As hygroscopic water is held tenaciously by surface forces its removal from the soil requires a certain amount of energy. Unlike capillary water which evaporates easily at atmospheric temperature, hygroscopic water cannot be separated from the soil unless it is heated

Factors affecting hygroscopic water:

Hygroscopic water is held on the surface of colloidal particles by the dipole orientation of water molecules. The amount of hygroscopic water varies inversely

with the size of soil particles. The smaller the particle, the greater is the amount of hygroscopic water it adsorbs.

Fine textured soils like clay contain more hygroscopic water than coarse - textured soils. The amount of clay and also its nature influences the amount of hygroscopic water. Clay minerals of the montmoril1onite type with their large surface area adsorb more water than those of the kaolinite type, while illite minerals are intermediate.
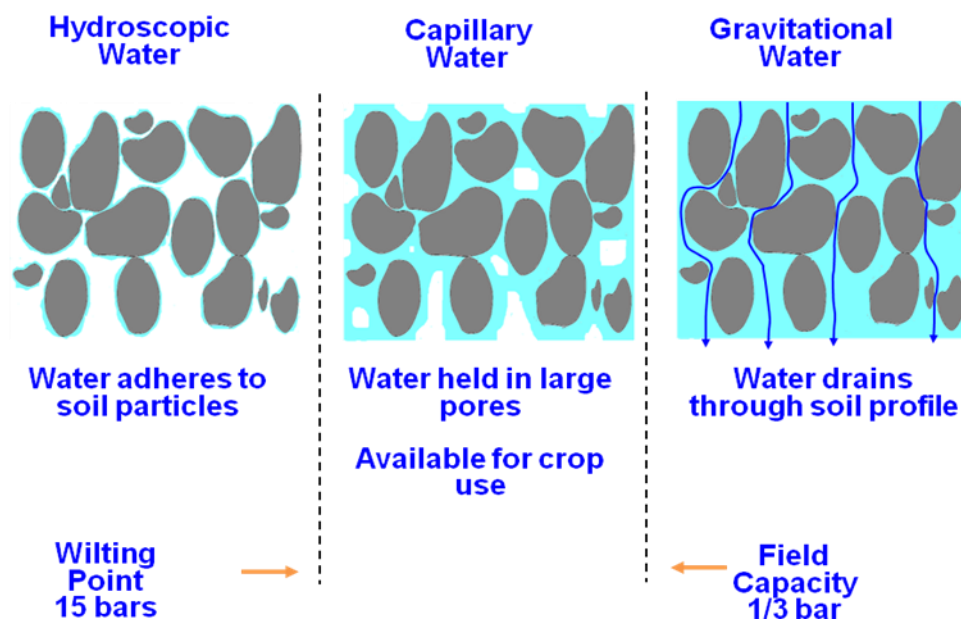
B. Biological Classification of Soil Water: There is a definite relationship between moisture retention and its utilization by plants. This classification based on the availability of water to the plant. Soil moisture can be divided into three parts.

i. Available water: The water which lies between wilting coefficient and field capacity. It is obtained by subtracting wilting coefficient from moisture equivalent.

ii. Unavailable water: This includes the whole of the hygroscopic water plus a part of the capillary water below the wilting point.

iii. Super available or superfluous water: The water beyond the field capacity stage is said to be super available. It includes gravitational water plus a part of the capillary water removed from larger interstices. This water is unavailable for the use of plants. The presence of super-available water in a soil for any extended period is harmful to plant growth because of the lack of air.

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Retention of Water by Soil

The soils hold water (moisture) due to their colloidal properties and aggregation qualities. The water is held on the surface of the colloids and other particles and in the pores. The forces responsible for retention of water in the soil after the drainage has stopped are due to surface tension and surface attraction and are called surface moisture tension. This refers to the energy concept in moisture retention relationships. The force with which water is held is also termed as suction.

The water retained in the soil by following ways

1. Cohesion and adhesion forces: These two basic forces are responsible for water retention in the soil. One is the attraction of molecules for each other i.e., cohesion. The other is the attraction of water molecules for the solid surface of soil i.e. adhesion. By adhesion, solids (soil) hold water molecules rigidly at their soil - water interfaces. These water molecules in turn hold by cohesion. Together, these forces make it possible for the soil solids to retain water.

Adhesion

Ball and stick model of water.
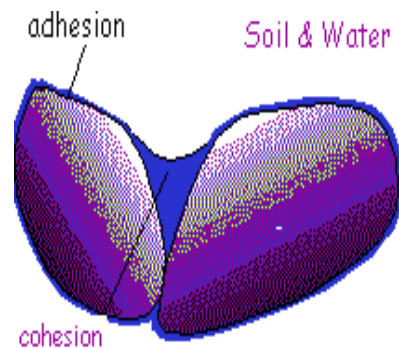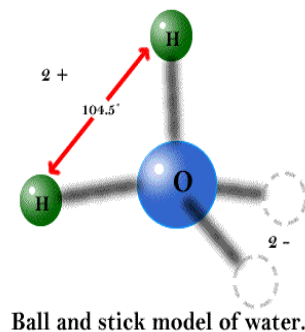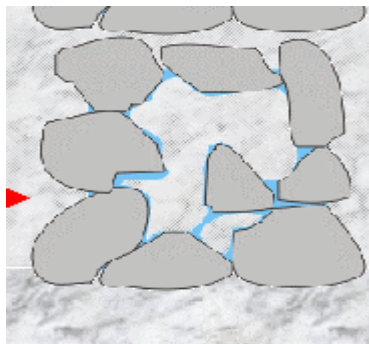
Cohesion
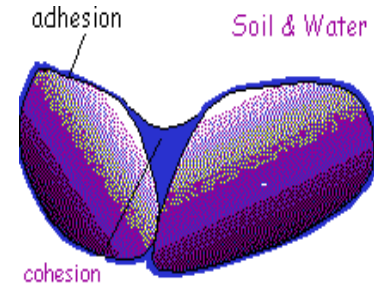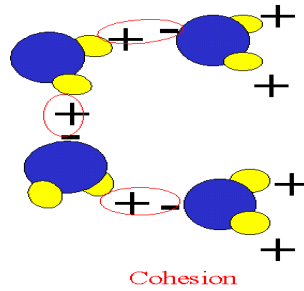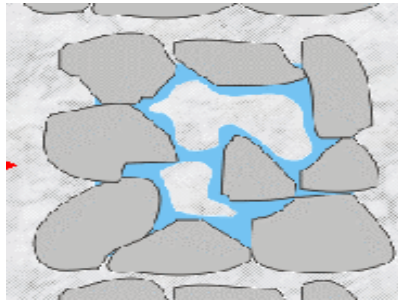
2. Surface tension: This phenomenon is commonly evidenced at water- air interfaces. Water behaves as if its surface is covered with a stretched elastic membrane. At the surface, the attraction of the air for the water molecules is much less than that of water molecules for each other. Consequently, there is a net downward force on the surface molecules, resulting in sort of a compressed film (membrane) at the surface. This phenomenon is called surface tension.

3. Polarity or dipole character: The retention of water molecules on the surface of clay micelle is based on the dipole character of the molecule of water. The water molecules are held by electrostatic force that exists on the surface of colloidal particles. By virtue of their dipole character and under the influence of electrostatic forces, the molecules of water get oriented (arranged) on the surface of the clay particles in a particular manner.

Each water molecule carries both negative and positive charges. The clay particle is negatively charged. The positive end of water molecule gets attached to the negatively charged surface of clay and leaving its negative end outward. The water molecules attached to the clay surface in this way present a layer of negative charges to which another layer of oriented water molecules is attached. The number of successive molecular layers goes on increasing as long as the water molecules oriented. As the molecular layer gets thicker, orientation becomes weaker, and at a certain distance from the particle surface the water molecules cease to orientate and capillary water (liquid water) begins to appear. Due to the

forces of adsorption (attraction) exerted by the surface of soil particles, water gets attached on the soil surface. The force of gravity also acts simultaneously, which tries to pull it downwards. The surface force is far greater than the force of gravity so water may remain attached to the soil particle. The water remains attached to the soil particle or move downward into the lower layers, depending on the magnitudeof the resultant force.

Potentials

Soil water potential:

The retention and movement of water in soils, its uptake and translocation in plants and its loss to the atmosphere are all energy related phenomenon. The more strongly water is held in the soil the greater is the heat (energy) required. In other words, if water is to be removed from a moist soil, work has to be done against adsorptive forces. Conversely, when water is adsorbed by the soil, a negative amount of work is done. The movement is from a zone where the free energy of water is high (standing water table) to one where the free energy is low (a dry soil). This is called soil water energy concept.

Free energy of soil solids for water is affected by:

i) Matric (solid) force i.e., the attraction of the soil solids for water (adsorption) which markedly reduces the free energy (movement) of the adsorbed water molecules.

ii) Osmotic force *i.e.*, the attraction of ions and other solutes for water to reduce the free energy of soil solution.

Matric and Osmotic potentials are negative and reduce the free energy level of the soil water. These negative potentials are referred as suction or tension.

iii) Force of gravity: This acts on soil water, the attraction is towards the earth's center, which tends to pull the water down ward. This force is always positive. The

difference between the energy states of soil water and pure free water is known as soil water potential. **Total water potential** (Pt) is the sum of the contributions of **gravitational potential** (Pg), **matric potential** (Pm) and the **Osmotic potential** or **solute potential** (Po).

$$Pt = Pg + Pm + Po$$

Potential represents the difference in free energy levels of pure water and of soil water. The soil water is affected by the force of gravity, presence of soil solid (matric) and of solutes.

Soil moisture constants

Earlier classification divided soil water into gravitational, capillary and hygroscopic water. The hygroscopic and capillary waters are in equilibrium with the soil under given condition. The hygroscopic coefficient and the maximum capillary capacity are the two equilibrium points when the soil contains the maximum amount of hygroscopic and capillary waters, respectively. The amount of water that a soil contains at each of these equilibrium points is known as soil moisture constant.

The soil moisture constant, therefore, represents definite soil moisture relationship and retention of soil moisture in the field.

The three classes of water (gravitational, capillary and hygroscopic) are however very broad and do not represent accurately the soil - water relationships that exists under field conditions.

Though the maximum capillary capacity represents the maximum amount of capillary water that a soil holds, the whole of capillary water is not available for the use of the plants. A part of it, at its lower limit approaching the hygroscopic coefficient is not utilized by the plants. Similarly a part of the capillary water at its upper limit is also not available for the use of plants. Hence two more soil constants, viz., field capacity and wilting coefficient have been introduced to

express the soil-plant-water relationships as it is found to exist under field conditions.

1. Field capacity: Assume that water is applied to the surface of a soil. With the downward movement of water all macro and micro pores are filled up. The soil is said to be saturated with respect to water and is at maximum water holding capacity or maximum retentive capacity. It is the amount of water held in the soil when all pores are filled.Sometimes, after application of water in the soil all the gravitational water is drained away, and then the wet soil is almost uniformly moist. The amount of water held by the soil at this stage is known as the field capacity or normal moisture capacity of that soil. **It is the capacity of the soil to retain water against the downward pull of the force of gravity. At this stage only micropores or capillary pores are filled with water and plants absorb water for their use. At field capacity water is held with a force of 1/3 atmosphere. Water at field capacity is readily available to plants and microorganism.**

2. Wilting coefficient: As the moisture content falls, a point is reached when the water is so firmly held by the soil particles that plant roots are unable to draw it. The plant begins to wilt. At this stage even if the plant is kept in a saturated atmosphere it does not regain its turgidity and wilts unless water is applied to the soil. The stage at which this occurs is termed the Wilting point and the percentage amount of water held by the soil at this stage is known as the Wilting Coefficient. It represents the point at which the soil is unable to supply water to the plant. Water at wilting coefficient is held with a force of 15 atmosphere.

3. Hygroscopic coefficient: The hygroscopic coefficient is the maximum amount of hygroscopic water absorbed by 100 g of dry soil under standard conditions of humidity (50% relative humidity) and temperature (15°C). This tension is equal to
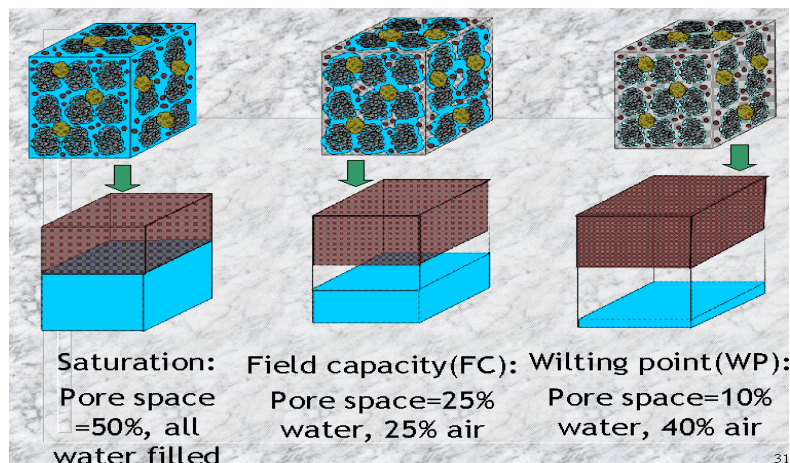
a force of 31 atmospheres. Water at this tension is not available to plant but may be available to certain bacteria.

4. Available water capacity: The amount of water required to apply to a soil at the wilting point to reach the field capacity is called the "available" water. The water supplying power of soils is related to the amount of available water a soil can hold. The available water is the difference in the amount of water at field capacity (- 0.3 bar) and the amount of water at the permanent wilting point (- 15 bars).

5. Maximum water holding capacity: It is also known as maximum retentive capacity. It is the amount of moisture in a soil when its pore spaces both micro and macro capillary are completely filled with water. It is a rough measure of total pore space of soil. Soil moisture tension is very low between $1/100^{th}$ to $1/1000^{th}$ of an atmosphere or pF 1 to 0.

6. Sticky point moisture: It represents the moisture content of soil at which it no longer sticks to a foreign object. The sticky point represents the maximum moisture content at which a soil remains friable. Sticky point moisture values vary nearly approximate to the moisture equivalent of soils. Summary of the soil moisture constants, type of water and force with which it held is given in following table.
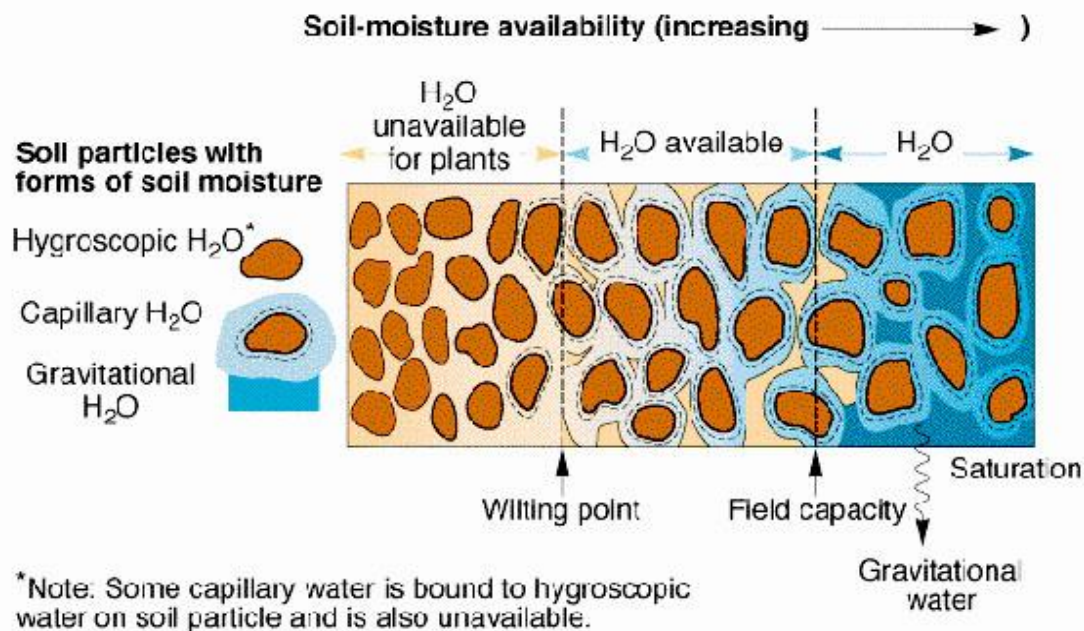
Soil water capacity

Saturation: Pore space =50%, all water filled

Field capacity(FC): Pore space=25% water, 25% air

Wilting point(WP): Pore space=10% water, 40% air

Moisture equivalent : It is defined as the percentage of water held by one centimeter thick moist layer of soil subjected to a centrifugal force of 1000 times of gravity for half an hour.

Soil moisture constants and range of tension and pF

S.No.	Moisture class	Tension (atm)	pF
1	Chemically combined	Very high	---
2	Water vapour	Held at saturation point in the soil air	---
3	Hygroscopic	31 to 10,000	4.50 to 7.00
4	Hygroscopic coefficient	31	4.50
5	Wilting point	15	4.20
6	Capillary	1/3 to 31	2.54 to 4.50
	Moisture equivalent	1/3 to 1	2.70 to 3.00
	Field capacity	1/3	2.54
	Sticky point	1/3 (more or less)	2.54
	Gravitational	Zero or less than 1/3	<2.54
	Maximum water holding capacity	Almost zero	---

Soil-moisture availability (increasing ──────►)

Soil particles with forms of soil moisture

Hygroscopic H_2O^*

Capillary H_2O

Gravitational H_2O

H_2O unavailable for plants ◄── ◄─ H_2O available ─►◄─ H_2O ─►

Wilting point   Field capacity

Saturation

Gravitational water

*Note. Some capillary water is bound to hygroscopic water on soil particle and is also unavailable.

Relationship between soil moisture and tension

Hygroscopic coef.	Wilting coef.	Field capacity

31 atm.	15 atm.	1/3 atm.
Hygroscopic Water	**Capillary Water**	**Gravitational Water**

Unavailable H_2O	**Available** H_2O	**Superflous** H_2O

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Movement of soil water- Infiltration, percolation, permeability – Drainage - Methods of determination of soil moisture –

Soil Water Movement

i) Saturated Flow

ii) Unsaturated Flow

iii) Water Vapour Movement

Saturated flow: This occurs when the soil pores are completely filled with water. This water moves at water potentials larger than – 33 kPa. Saturated flow is water flow caused by gravity's pull. It begins with *infiltration*, which is water movement into soil when rain or irrigation water is on the soil surface. When the soil profile is wetted, the movement of more water flowing through the wetted soil is termed percolation.

Hydraulic conductivity can be expressed mathematically as

$$V = kf$$

Where,

V = Total volume of water moved per unit time

f = Water moving force

k = Hydraulic conductivity of soil

Factors affecting movement of water

1. Texture, 2.Structure, 3.Amount of organic matter, 4.Depth of soil to hard pan, 5.Amount of water in the soil, 6.temperature and 7. Pressure

Vertical water flow

The vertical water flow rate through soil is given by *Darcy's law*. The law states that the rate of flow of liquid or flux through a porous medium is proportional to the hydraulic gradient in the direction of floe of the liquid.

(dw) At

$$QW = - k \, (dw) \, At / Ds$$

Where,

QW = Quantity of water in cm^{-1}

k   = rate constant (cm/s)

dw   = Water height (head), cm

A   = Soil area (cm$^{2)}$)

t   = Time

ds   = Soil depth (cm)

(ii) Unsaturated Flow

It is flow of water held with water potentials lower than- 1/3 bar. Water will move toward the region of lower potential (towards the greater "pulling" force). In a uniform soil this means that water moves from wetter to drier areas. The water movement may be in any direction .The rate of flow is greater as the water potential gradient (the difference in potential between wet and dry) increases and as the size of water filled pores also increases. The two forces responsible for this movement are the attraction of soil solids for water (adhesion) and capillarity. Under field conditions this movement occurs when the soil macropores (non-capillary) pores with filled with air and the micropores (capillary) pores with water and partly with air.

Factors Affecting the Unsaturated Flow

Unsaturated flow is also affected in a similar way to that of saturated flow. Amount of moisture in the soil affects the unsaturated flow. The higher the percentage of water in the moist soil, the greater is the suction gradient and the more rapid is the delivery.

(iii) Water Vapour Movement

The movement of water vapour from soils takes place in two ways: (a) Internal movement—the change from the liquid to the vapour state takes place within the soil, that is, in the soil pores and (b) External movement—the phenomenon occurs at the land surface and the resulting vapour is lost to the atmosphere by diffusion and convection.

The movement of water vapour through the diffusion mechanism taken place from one area to other soil area depending on the vapour pressure gradient (moving force).This gradient is simply the difference in vapour pressure of two points a unit distance apart. The greater this difference, the more rapid the diffusion and the greater is the transfer of water vapour during a unit period.
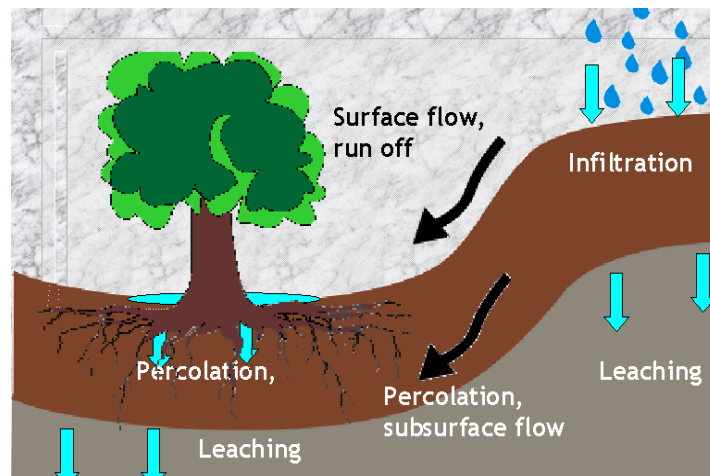
Soil conditions affecting water vapour movement:

There are mainly two soil conditions that affect the water vapour movement namely moisture regimes and thermal regimes. In addition to these, the various other factors which influence the moisture and thermal regimes of the soil like organic matter, vegetative cover, soil colour etc. also affect the movement of water vapour. The movement takes place from moist soil having high vapour pressure to a dry soil (low vapour pressure). Similarly the movement takes place from warmer soil regions to cooler soil region.In dry soils some water movement takes place in

the vapour form and such vapour movement has some practical implications in supplying water to drought resistant plants.

Entry of Water into Soil

Infiltration: Infiltration refers to the downward entry or movement of water into the soil surface

- ❖ It is a surface characteristic and hence primarily influenced by the condition of the surface soil.
- ❖ Soil surface with vegetative cover has more infiltration rate than bare soil
- ❖ Warm soils absorb more water than colder ones
- ❖ Coarse surface texture, granular structure and high organic matter content in surface soil, all help to increase infiltration
- ❖ Infiltration rate is comparatively lower in wet soils than dry soils

Factors affecting infiltration

i. Clay minerals
ii. Soil Texture
iii. Soil structure
iv. Moisture content
v. Vegetative cover
vi. Topography

Percolation: The movement of water through a column of soil is called percolation. It is important for two reasons.

i) This is the only source of recharge of ground water which can be used through wells for irrigation

ii) Percolating waters carry plant nutrients down and often out of reach of plant roots (leaching)

- ❖ In dry region it is negligible and under high rainfall it is high

❖ Sandy soils have greater percolation than clayey soil

❖ Vegetation and high water table reduce the percolation loss

Permeability: It indicates the relative ease of movement of water with in the soil. The characteristics that determine how fast air and water move through the soil is known as permeability. The term hydraulic conductivity is also used which refers to the readiness with which a soil transmits fluids through it

Drainage

The frequency and duration of periods when the soil is free from saturation with water. It controls the soil cum water relationship and the supply of nutrients to the plants.

Drainage class

Very poorly drained

Poorly drained

Imperfect

Moderately well

Well

Somewhat excessive

Excessive

Hysterisis

The moisture content at different tensions during wetting of soil varies from the moisture content at same tensions during drying. This effect is called as hysterisis. This is due to the presence of capillary and non capillary pores. The moisture content is always low during sorption and high during desorption. Hystersis phenomenon exists in soil minerals as a consequence of shrinking and swelling. Shrinking and swelling affect pore size on a microbasis as well as on the basis of overall bulk density. So, hystersis phenomenon occurs due to factors like shape and size of soil pores and their interconnection with each other pore configuration,

nature of soil colloids bulk density of soil and entrapped air. The most important factor affecting hystersis is the entrapment of air in the soil under rewetting condition. This clogs some pores and prevent effective contact between others.

Methods of determination of soil moisture

Two general types of measurements relating to soil water are ordinarily used

    i) By some methods the moisture content is measured directly or indirectly

    ii) Techniques are used to determine the soil moisture potential (tension or suction)

Measuring soil moisture content in laboratory

1. Gravimetric method: This consists of obtaining a moist sample, drying it in an oven at 105°C until it losses no more weight and then determining the percentage of moisture. The gravimetric method is time consuming and involves laborious processes of sampling, weighing and drying in laboratory.

2. Electrical conductivity method: This method is based upon the changes in electrical conductivity with changes in soil moisture. Gypsum blocks inside of with two electrodes at a definite distance are apart used in this method. These blocks require previous calibration for uniformity. The blocks are buried in the soil at desired depths and the conductivity across the electrodes measured with a modified Wheatstone bridge. These electrical measurements are affected by salt concentration in the soil solution and are not very helpful in soils with high salt contents.

Measuring soil moisture potential insitu (field)

Suction method or equilibrium tension method: Field tensiometers measure the tension with which water is held in the soils. They are used in determining the need for irrigation. The tensiometer is a porous cup attached to a glass tube, which is

connected to a mercury monometer. The tube and cup are filled with water and cup inserted in the soil. The water flows through the porous cup into the soil until equilibrium is established. These tension readings in monometer, expressed in terms of cm or atmosphere, measures the tension or suction of the soil.

If the soil is dry, water moves through the porous cup, setting up a negative tension (or greater is the suction). The tensiometers are more useful in sandy soils than in fine textured soils. Once the air gets entrapped in the tensiometer, the reliability of readings is questionable.

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Thermal properties of soils – Soil temperature – Soil air – Gaseous exchange –

Influence of soil temperature and air on plant growth –

Thermal properties of soils

The thermal properties of soils are a component of soil physics that has found importants uses in engineering, climatology and agriculture. These properties influence how energy is partitioned in the soil profile. While related to soil temperature, it is more accurately associated with the transfer of heat throughout the soil, by radiation, conduction and convection.

Main soil thermal properties:

Volumetric heat capacity, SI units: $Jm^{-3}K^{-1}$

Thermal conductivity, SI units: $W.m^{-1}K^{-1}$

Thermal diffusivity, SI units: m2.s

Soil temperature – Soil air – Gaseous exchange

Soil Temperature

Soil temperature is an important plant growth factor like air, water and nutrients. Soil temperature affects plant growth directly and also indirectly by influencing moisture, aeration, structure, microbial and enzyme activities, rate of organic matter decomposition, nutrient availability and other soil chemical reactions. Specific crops are adapted to specific soil temperatures. Apple grows well when the soil temperature is about 18°C, maize 25°C, potato 16 to 21°C, and so on.

Sources of soil heat

The sources of heat for soil are solar radiation (external), heat released during microbial decomposition of organic matter and respiration by soil organisms including plants and the internal source of heat is the interior of the

Earth - which is negligible. The rate of solar radiation reaching the earth's atmosphere is called as solar constant and has a value of 2 cal cm^{-2} min^{-1}. Major part of this energy is absorbed in the atmosphere, absorbed by plants and also scattered. Only a small part of it reaches soil. Thermal energy is transmitted in the form of thermal infrared radiation from the sun across the space and through the atmosphere.

Factors affecting soil temperature

The average annual soil temperature is about 1°C higher than mean annual air temperature. Soil temperature is influenced by climatic conditions. The factors that affect the transfer of heat through the atmosphere from sun affect the soil temperature also.

Environmental factors

Solar radiation: The amount of heat received from sun on Earth's surface is 2 cal cm^{-2} min^{-1}. But the amount of heat transmitted into soil is much lower. The heat transmission into soil depends on the angle on incident radiation, latitude, season, time of the day, steepness and direction of slope and altitude. The insulation by air, water vapour, clouds, dust, smog, snow, plant cover, mulch *etc*., reduces the amount of heat transferred into soil.

Soil factors

a) Thermal (Heat) capacity of soil: The amount of energy required to raise the temperature by 1°C is called *heat capacity*. When it is expressed per unit mass (Calories per gram), then it is called as *specific heat*. The specific heat of water is 1.00 cal g^{-1} where the specific heat of a dry soil is 0.2 cal g^{-1}. Increasing water content in soil increases the specific heat of the soil and hence a dry soil heats up quickly than a moist soil.

b) Heat of vaporization: The evaporation of water from soil requires a large amount of energy, 540 kilocalories kg^{-1} soil. Soil water utilizes the energy from solar radiation to evaporate and thereby rendering it unavailable for heating up of soil. Also the thermal energy from soil is utilized for the evaporation of water, thereby reducing the soil temperature. This is the reason that surface soil temperatures will be sometimes 1 to 6°C lower than the sub-surface soil temperature. That is why the specific heat of a wet soil is higher than dry soil.

c) Thermal conductivity and diffusivity: This refers to the movement of heat in soils. In soil, heat is transmitted through conduction. Heat passes from soil to water about 150 times faster than soil to air. So the movement of heat will be more in wet soil than in dry soil where the pores will be occupied with air. Thermal conductivity of soil forming materials is 0.005 thermal conductivity units, and that of air is 0.00005 units, water 0.001 units. A dry and loosely packed soil will conduct heat slower than a compact soil and wet soil.

d) Biological activity: Respiration by soil animals, microbes and plant roots evolve heat. More the biological activity more will be the soil temperature.

e) Radiation from soil: Radiation from high temperature bodies (Sun) is in short waves (0.3 to 2.2 μ) and that from low temperature bodies (soil) is in long waves (6.8 to 100 μ) Longer wavelengths have little ability to penetrate water vapour, air and glass and hence soil remains warm during night hours, cloudy days and in glass houses.

f) Soil colour: Colour is produced due to reflection of radiation of specific wavelengths. Dark coloured soils radiate less heat than bright coloured soils. The ratio between the incoming (incident energy) and outgoing (reflected energy) radiation is called *albedo*. The larger the albido, the cooler is the soil. Rough surfaced soil absorbs more solar radiation than smooth surface soils.

$$\text{Albido} = \frac{\text{Reflected energy}}{\text{Incident energy}}$$

g) Soil structure, texture and moisture: Compact soils have higher thermal conductivity than loose soils. Natural structures have high conductivity than disturbed soil structures. Mineral soils have higher conductivity than organic soils. Moist soil will have uniform temperature over depth because of its good conductivity than dry soils.

h) Soluble salts: Indirectly affects soil temperature by influencing the biological activities, evaporation *etc*.

Soil Air

Soil air is a continuation of the atmospheric air. Unlike the other components, it is constant state of motion from the soil pores into the atmosphere and from the atmosphere into the pore space. This constant movement or circulation of air in the soil mass resulting in the renewal of its component gases is known as soil aeration. .

Composition of Soil Air: The soil air contains a number of gases of which nitrogen, oxygen, carbon dioxide and water vapour are the most important. Soil air constantly moves from the soil pores into the atmosphere and from the atmosphere into the pore space. Soil air and atmospheric air differ in the compositions. Soil air contains a much greater proportion of carbon dioxide and a lesser amount of oxygen than atmospheric air. At the same time, soil air contains a far great amount of water vapour than atmospheric air. The amount of nitrogen in soil air is almost the same as in the atmosphere.

Composition of soil and atmospheric air

Percentage by volume

Nitrogen	Oxygen	Carbon

Soil air	79.2	20.60	0.30
Atmospheric air	79.9	20.97	0.03

Factors Affecting the Composition of Soil Air:

1. Nature and condition of soil: The quantity of oxygen in soil air is less than that in atmospheric air.

The amount of oxygen also depends upon the soil depth.

The oxygen content of the air in lower layer is usually less than that of the surface soil. This is possibly due to more readily diffusion of the oxygen from the atmosphere into the surface soil than in the subsoil.

Light texture soil or sandy soil contains much higher percentage than heavy soil.

The concentration of CO_2 is usually greater in subsoil probably due to more sluggish aeration in lower layer than in the surface soil.

2. Type of crop: Plant roots require oxygen, which they take from the soil air and deplete the concentration of oxygen in the soil air. Soils on which crops are grown contain more CO_2 than fallow lands. The amount of CO_2 is usually much greater near the roots of plants than further away. It may be due to respiration by roots.

3. Microbial activity: The microorganisms in soil require oxygen for respiration and they take it from the soil air and thus deplete its concentration in the soil air. Decomposition of organic matter produces CO_2 because of increased microbial activity. Hence, soils rich in organic matter contain higher percentage of CO_2.

4. Seasonal variation: The quantity of oxygen is usually higher in dry season than during the monsoon. Because soils are normally drier during the summer months, opportunity for gaseous exchange is greater during this period. This results in relatively high O_2 and low CO_2 levels. Temperature also influences the CO_2 content in the soil air. High temperature during summer season encourages microorganism activity which results in higher production of CO_2.

Exchange of Gases between Soil and Atmosphere

The exchange of gases between the soil and the atmosphere is facilitated by two mechanisms

1. Mass flow: With every rain or irrigation, a part of the soil air moves out into the atmosphere as it is displaced by the incoming water. As and when moisture is lost by evaporation and transpiration, the atmospheric air enters the soil pores. The variations in soil temperature cause changes in the temperature of soil air. As the soil air gets heated during the day, it expands and the expanded air moves out into the atmosphere. On the other hand, when the soil begins to cool, the soil air contracts and the atmospheric air is drawn in.

2. Diffusion: Most of the gaseous interchange in soils occurs by diffusion. Atmospheric and soil air contains a number of gases such as nitrogen, oxygen, carbon dioxide etc., each of which exerts its own partial pressure in proportion to its concentration.

The movement of each gas is regulated by the partial pressure under which it exists. If the partial pressure on one of the gases (i.e. carbon dioxide) is greater in the soil air than in the atmospheric air, it (CO_2) moves out into the atmosphere. Hence, the concentration of CO_2 is more in soil air.

On the other hand, partial pressure of oxygen is low in the soil air, as oxygen present in soil air is consumed as a result of biological activities. The oxygen present in the atmospheric air (partial pressure of O_2 is greater) therefore, diffuses into the soil air till equilibrium is established. Thus, diffusion allows extensive movement and continual change of gases between the soil air and the atmospheric air. Oxygen and carbon dioxide are the two important gases that take in diffusion

Importance of Soil Aeration:

1. Plant and root growth: Soil aeration is an important factor in the normal growth of plants. The supply of oxygen to roots in adequate quantities and the

removal of CO_2 from the soil atmosphere are very essential for healthy plant growth.

When the supply of oxygen is inadequate, the plant growth either retards or ceases completely as the accumulated CO_2 hampers the growth of plant roots. The abnormal effect of insufficient aeration on root development is most noticeable on the root crops. Abnormally shaped roots of these plants are common on the compact and poorly aerated soils. The penetration and development of root are poor. Such undeveloped root system cannot absorb sufficient moisture and nutrients from the soil

2. Microorganism population and activity: The microorganisms living in the soil also require oxygen for respiration and metabolism. Some of the important microbial activities such as the decomposition of organic matter, nitrification, Sulphur oxidation etc depend upon oxygen present in the soil air. The deficiency of air (oxygen) in soil slows down the rate of microbial activity.

For example, the decomposition of organic matter is retarded and nitrification arrested. The microorganism population is also drastically affected by poor aeration.

3. Formation of toxic material: Poor aeration results in the development of toxin and other injurious substances such as ferrous oxide, H_2S gas, CO_2 gas etc in the soil.

4. Water and nutrient absorption: A deficiency of oxygen has been found to check the nutrient and water absorption by plants. The energy of respiration is utilized in absorption of water and nutrients. Under poor aeration condition (this condition may arise when soil is water logged), plants exhibit water and nutrient deficiency

5. Development of plant diseases: Insufficient aeration of the soil also lead to the development of diseases. For example, wilt of gram and dieback of citrus and peach.

Influence of soil temperature and air on plant growth

4. Effect of soil temperature on plant growth

a) Soil temperature requirements of plants: The soil temperature requirements of plants vary with the species. The temperature at which a plant thrives and produces best growth is called *optimum range* (*temperature*). The entire range of temperature under which a plant can grow including the optimum range is called *growth range*. The maximum and minimum temperatures beyond which the plant will die are called *survival limits*.

Range	Maize (°C)	Wheat (°C)
Optimum range	25 - 35	15 - 27
Growth range	10 - 39	5 - 35
Survival limits	0 - 43	0 - 43

b) Availability of soil water and plant nutrients: The free energy of water increases with temperature. Up to wilting point limit, warming of soil increases water availability beyond which it decreases. Low temperatures reduce the nutrient availability, microbial activities and root growth and branching. The ability to absorb nutrients and water by plants reduces at low temperatures.

Soil temperature management

Use of organic and synthetic mulches: Mulches keep soil cooler in hot summer and warm in cool winter.

Soil water management: High moisture content in humid temperate region lowers soil temperature.

Tillage management: Tilling soil to break the natural structure reduces the heat conductance and heat loss. A highly compact soil looses heat faster than loose friable soil.

Methods of measuring soil temperature: Mercury soil thermometers of different lengths, shapes and sizes with protective cover are buried at different depths to measure the temperature. Thermo couple and thermister based devices are also available. Infra-red thermo meters measure the surface soil temperature. Automatic continuous soil thermographs record the soil temperatures on a time scale. The International Meteorological Organization recommends standard depths to measure soil temperatures at 10, 20, 50 and 100 cm.

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Soil colloids – Properties, nature, types and significance

SOIL COLLOIDS

The colloidal state refers to a two-phase system in which one material in a very finely divided state is dispersed through second phase. The examples are: Solid in liquid (Dispersion of clay in water) and Liquid in gas (Fog or clouds in atmosphere). The clay fraction of the soil contains particles less than 0.002 mm in size. Particles less than 0.001 mm size possess colloidal properties and are known as soil colloids.

General Properties of Soil Colloids

1. Size

The inorganic and organic colloids are extremely small size - smaller than 2 micrometers in diameter. These particles cannot be seen using an ordinary light microscope but can be seen only with an electron microscope.

2. Surface area

Because of their small size, all soil colloids have a larger external surface area per unit mass. The external surface area of 1 g of colloidal clay is 1000 times that of 1 g of coarse sand. Certain silicate clays have extensive internal surfaces occurring between plate like crystal units that make up each particle and often greatly exceed the external surface area. The total surface area of soil colloids ranges from 10 m^2/g for clays with only external surfaces to more than 800 m^2/g for clays with extensive internal surfaces. The colloid surface area in the upper 15 cm of a hectare of a clay soil could be as high as 700,000 $km^2\,g^{-1}$.

3. Surface charges

Both external and internal surfaces of soil colloids carry negative and/or positive charges. Most of the organic and inorganic soil colloids carry a negative charge. When an electric current is passed through a suspension of soil colloidal particles they migrate to anode, the positive electrode indicating that they carry a negative

charge. The magnitude of the charge is known as *zeta potential*. The presence and intensity of the particle charge influence the attraction and repulsion of the particles towards each other, there by influencing both physical and chemical properties. The sources of negative charge on clays comes from

i)   ionizable hydrogen ions

ii)   isomorphous substitution.

i) Ionizable hydrogen ions: These are hydrogen from hydroxyl (OH) ions on clay surfaces. The -Al-OH or -Si-OH portion of the clay ionizes the H and leaves an un-neutralized negative charge on the oxygen (-AlO$^-$ or - SiO$^-$). The extent of ionized hydrogen depends on solution pH and hence these negative charges are *pH dependent charges*. More ionization occurs in alkaline (basic) solutions.

ii) Isomorphous substitution: This is due to the substitution of a cation of higher valence with another cation of lower valence but similar size in the clay crystal structure. In clay crystals some ions fit exactly into mineral lattice sites because of their convenient size and charge. Dominantly, clays have Si^{4+} in tetrahedral sites and Al^{3+} in octahedral sites. Other ions present in large amounts during clay crystallization can replace some of the Al^{3+} and Si^{4+} cations. Common substitutions are the Si^{4+} replaced by Al^{3+}, and replacement of Al^{3+} by Fe^{3+}, Fe^{2+}, Mg^{2+} or Zn^{2+}. As the total negative charge from the anions (oxygen) remains unchanged, the lower positive charge of the substituted cations result in excess negative charges on clay crystals.

4. Adsorption of cations: As soil colloids possess negative charge they attract and attach the ions of positive charge on the colloidal surfaces. They attract cations like H^+, Al^{3+}, Ca^{2+} and Mg^{2+}. This gives rise to an ionic double layer.

The Isomorphous substitution in the colloidal particle makes the external and internal layers of clay minerals negatively charged and these surfaces act as huge anions, which form the inner layer of the double layer. The outer layer is

made up of a swarm of loosely held (adsorbed) cations attracted to the negatively charged surfaces.

5. Adsorption of water: A large number of water molecules are associated with soil colloidal particles. Some water molecules are attracted to the adsorbed cations and the cation is said to be in hydrated state. Others water molecules are held in the internal surfaces of the colloidal clay particles. These water molecules play a critical role in determining both the physical and chemical properties of soil.

6. Cohesion: (Attractive force between similar molecules or materials). Cohesion indicates the tendency of clay particles to stick together. This tendency is due to the attraction of clay particles for water molecules held between them. When colloidal substances are wetted, water first adheres to individual clay particles and then brings about cohesion between two or more adjacent colloidal particles.

7. Adhesion: (Attractive force between different molecules or materials). Adhesion refers to the attraction of colloidal materials to the surface of any other body or substance with which it comes in contact.

8. Swelling and shrinkage: Some soil clay colloids belonging to smectite group like Montmorillonite swell when wet and shrink when dry. After a prolonged dry spell, soils high in smectite clay (e.g. Black soil -Vertisols) often show crises-cross wide and deep cracks. These cracks first allow rain to penetrate rapidly. Later, because of swelling, the cracks will close and become impervious. But soils dominated by kaolinite, chlorite, or fine grained micas do not swell or shrink. Vermiculite is intermediate in its swelling and shrinking characteristics.

9. Dispersion and flocculation: As long as the colloidal particles remain negatively charged, they repel each other and the suspension remains stable. If on any account they loose their charge, or if the magnitude of the charge is reduced, the particles coalesce, form flock or loose aggregates, and settle down. This phenomenon of coalescence and formation of flocks is known as flocculation. The

reverse process of the breaking up of flocks into individual particles is known as de-flocculation or dispersion.

10. Brownian movement: When a suspension of colloidal particles is examined under a microscope the particles seem to oscillate. The oscillation is due to the collision of colloidal particles or molecules with those of the liquid in which they are suspended. Soil colloidal particles with those of water in which they are suspended are always in a constant state of motion. The smaller the particle, the more rapid is its movement.

11. Non permeability: Colloids, as opposed to crystalloids, are unable to pass through a semi-permeable membrane. Even though the colloidal particles are extremely small, they are bigger than molecules of crystalloid dissolved in water. The membrane allows the passage of water and of the dissolved substance through its pores, but retains the colloidal particles.

TYPES OF SOIL COLLOIDS

There are four major types of colloids present in soil

  1. Layer silicate clays

  2. Iron and aluminum oxide clays (sesquioxide clays)

  3. Allophane and associated amorphous clays

  4. Humus

Layer silicate clays, iron and aluminum oxide clays, allophane and associated amorphous clays are inorganic colloids while humus is an organic colloid.

1. Layer silicate clays

These important silicate clays are also known as phyllosilicates (Phyllon - leaf) because of their leaf-like or plate like structure. These are made up of two kinds of horizontal sheets. One dominated by silicon and other by aluminum and/or magnesium.

Silica tetrahedron: The basic building block for the silica-dominated sheet is a unit composed of one silicon atom surrounded by four oxygen atoms. It is called the silica tetrahedron because of its four-sided configuration. An interlocking array or a series of these silica tetrahedra tied together horizontally by shared oxygen anions gives a tetrahedral sheet.

Alumina octahedron: Aluminium and/or magnesium ions are the key cations surrounded by six oxygen atoms or hydroxyl group giving an eight sided building block termed octahedron. Numerous octahedra linked together horizontally comprise the octahedral sheet.

An aluminum-dominated sheet is known as a di-octahedral sheet, whereas one dominated by magnesium is called a tri-octahedral sheet. The distinction is due to the fact that two aluminum ions in a di-octahedral sheet satisfy the same negative charge from surrounding oxygen and hydroxyls as three magnesium ions in a tri-octahedral sheet.

The tetrahedral and octahedral sheets are the fundamental structural units of silicate clays. These sheets are bound together within the crystals by shared oxygen atoms into different layers. The specific nature and combination of sheets in these layers vary from one type of clay to another and control the physical and chemical properties of each clay.

2. Iron and aluminum oxide clays (sesquioxide clays): Under conditions of extensive leaching by rainfall and long time intensive weathering of minerals in humid warm climates, most of the silica and alumina in primary minerals are dissolved and slowly leached away. The remnant materials, which have lower solubility are called sesquioxides. Sesquioxides (metal oxides) are mixtures of aluminum hydroxide, $Al(OH)_3$, and iron oxide, Fe_2O_3, or iron hydroxide, $Fe(OH)_3$. The Latin word *sesqui* means one and one-half times, meaning one and one-half times more oxygen than Al and Fe. These clays can grade from amorphous to

crystalline. Examples of iron and aluminum oxides common in soils are gibbsite ($Al_2O_3.3H_2O$) and geothite ($Fe_2O_3.H_2O$). Less is known about these clays than about the layer silicates. These clays do not swell, not sticky and have high phosphorus adsorption capacity.

3. Allophane and other amorphous minerals: These silicate clays are mixtures of silica and alumina. They are amorphous in nature. Even mixture of other weathered oxides (iron oxide) may be a part of the mixture. Typically, these clays occur where large amount of weathered products existed. These clays are common in soils forming from volcanic ash (e.g., Allophane). These clays have high anion exchange capacity or even high cation exchange capacity. Almost all of their charge is from accessible hydroxyl ions (OH^-), which can attract a positive ion or lose the H^+ attached. These clays have a variable charge that depends on H^+ in solution (the soil acidity).

4. Humus (Organic Colloid)

Humus is amorphous, dark brown to black, nearly insoluble in water, but mostly soluble in dilute alkali (NaOH or KOH) solutions. It is a temporary intermediate product left after considerable decomposition of plant and animal remains. They are temporary intermediate because the organic substances remain continue to decompose slowly. The humus is often referred to as an organic colloid and consists of various chains and loops of linked carbon atoms. The humus colloids are not crystalline. They are composed basically of carbon, hydrogen, and oxygen rather than of silicon, aluminum, iron, oxygen, and hydroxyl groups.

The organic colloidal particles vary in size, but they may be at least as small as the silicate clay particles. The negative charges of humus are associated with partially dissociated enolic (-OH), carboxyl (-COOH), and phenolic groups; these groups in turn are associated with central units of varying size and complexity.

Difference between organic and inorganic colloids

Humus	Clay
Made up of C,H,O	Made up of Si,Ai,O
Complex amorphous organic colloid	Inorganic and crystalline
More dynamic,formed and destroyed more rapidly	Clays are stable relatively
Complex structure not well known	Clays have definite and well known structure

Significance of soil colloids

Th organic and inorganic contaminats are often transported via colloidal particles.

Majority of surface area and electrostatic charge in a soil resides in the less than I μm size fraction, with particles with radii between 20 and 1000 mm constituting the major part of soil surface area. Since major part of the surface area is in the colloidal fraction of the soil, almost all surface controlled processes including adsorption reactions, nucleation and precipitation involve colloids. In addition to these chemical processes, colloids are mobile in soils, and thus affect not only the chemical transport of otherwise immobile chemicals, but also exert a strong influence on soil hydraulic properties.

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Layer silicate clays – Genesis and classification

Genesis of Clay Minerals

The silicate clays are developed from the weathering of a wide variety of minerals by the two distinct process

1. Alteration- A slight physical and chemical alteration of certain primary minerals.

Changes in particle size. Alteration of muscovite mica to fine grained mica is the good example. As weathering occurs muscovite mineral is broken down in size to the colloidal range, part of the potassium is lost and some silicon is added from weathering solutions. Net result is the less rigid crystal structure and an electronegative charge. The fine mica colloid has a 2:1 structure, only have been altered in this process

2.Recrystallization- Decomposition of primary minerals with subsequent recrystallization of certain of their products in to the silicate clays

Complete breakdown of clay structures and re-crystallization of clay minerals from product of this breakdown. It is the result of much more intense weathering than that required for alteration. Formation of Kaolinite (1;1) from solutions containing soluble aluminum and silicon that came from the breakdown of the primary minerals having 2;1 type structure

Relative stages of weathering

Weathering

The contact of rocks and water produces clays, either at or near the surface of the earth" (from Velde, 1995).

Rock +Water → Clay

The CO2 gas can dissolve in water and form carbonic acid, which will become hydrogen ions H+ and bicarbonate ions, and make water slightly acidic.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H+ + HCO_3^-$$

The acidic water will react with the rock surfaces and tend to dissolve the K ion and silica from the feldspar. Finally, the feldspar is transformed into kaolinite.
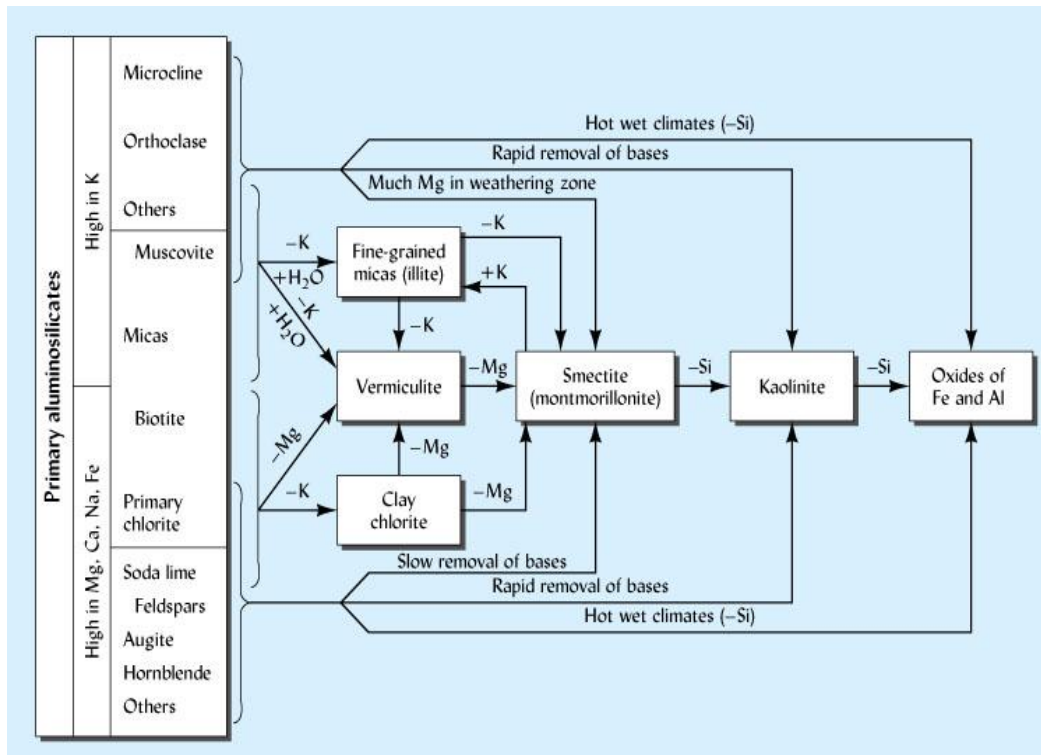
Feldspar + hydrogen ions + water → clay (kaolinite) + cations, dissolved silica

$$2KAlSi_3O_8 + 2H+ + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2K+ + 4SiO_2$$

Fine grained micas and magnesium rich chlorites represent earlier weathering stages of the silicates and kaolinite and ultimately iron and aluminum oxides the most advanced stages

Genesis of individual clays

Figure:General conditions for the formation of the various layer silicate clays and oxides of iron and aluminum. Fine-grained micas, chlorite, and vermiculite are formed through rather mild weathering of primary aluminosilicate minerals, whereas kaolinite and oxides of iron and aluminum are products of much more intense weathering. Conditions of intermediate weathering intensity encourage the formation of smectite. In each case silicate clay genesis is accompanied by the removal in solution of such elements as K, Na, Ca, and Mg.

1. Layer silicate clays

These important silicate clays are also known as phyllosilicates (Phyllon - leaf) because of their leaf-like or plate like structure. These are made up of two kinds of horizontal sheets. One dominated by silicon and other by aluminum and/or magnesium.

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block termed octahedron. Numerous octahedra linked together horizontally comprise the octahedral sheet.

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Tetrahedral & Octahedral Sheets

For simplicity, let's represent silica tetrahedral sheet by:

Si

and alumina octahedral sheet by:

Al
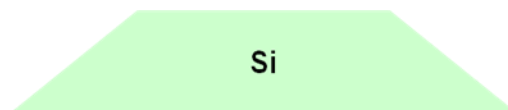
The building blocks and structural components of silicate clays
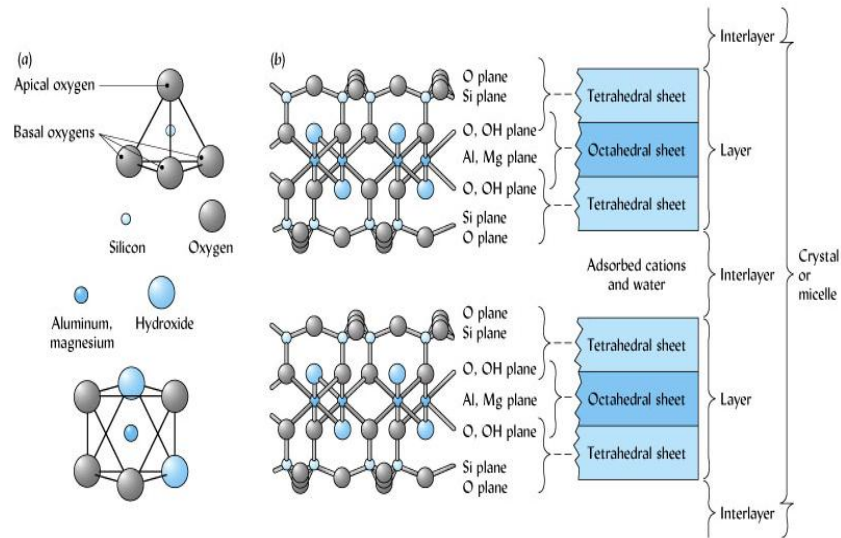
Classification of layer silicate clays

On the basis of the number and arrangement of tetrahedral (silica) and octahedral (alumina-magnesia) sheets contained in the crystal units or layers, silicate clays are classified into three different groups

1)   1 :1 Type clay minerals

2)   2:1 Type clay minerals

3)   2: 1: 1 (or) 2:2 Type clay minerals

The basic building blocks of tetetrahedral and octahedral sheets are the silica tetrahedron and the aluminum octahedran

The $Si4^+$ cation occurs in fourfold and tetrahedral coordination with oxygen while the $Al3^+$ is generally found in six fold or octahedral coordination

Layer silicate minerals are sometimes defined on the basis of the number of certain positions occupied by cations. When two-thirds of the octahedral positions are

occupied, the mineral is called dioctahedral; when all 3 positions are occupied it is called trioctahedral.
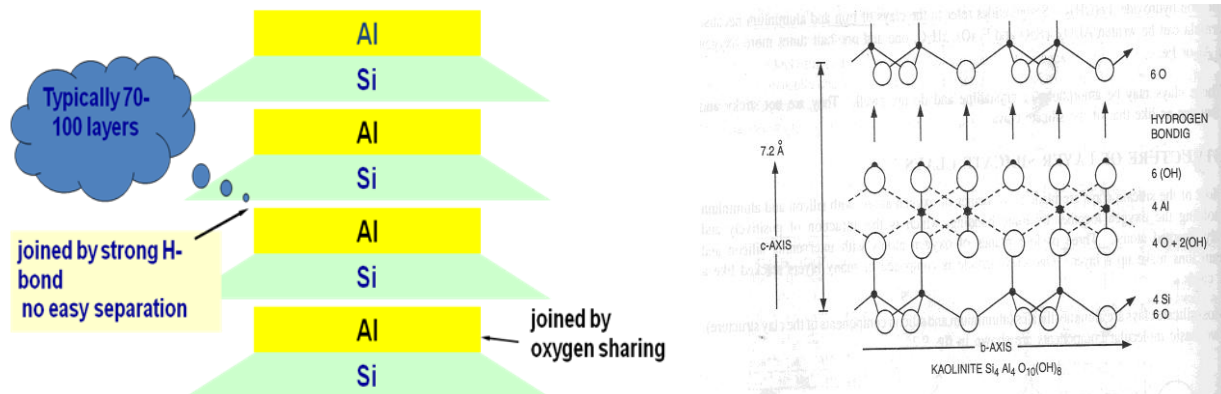
1:1 type minerals

The layers of the 1:1-type minerals are made up of one tetrahedral (silica) sheet combined with one octahedral (alumina) sheet. In soils, **kaolinite group** is the most prominent 1:1 clay mineral, which includes kaolinite, hallosite, nacrite and dickite. The tetrahedral and octahedral sheets in a layer of a kaolinite crystal are held together tightly by oxygen atoms, which are mutually shared by the silicon and aluminum cations in their respective sheets. These layers, in turn, are held together by hydrogen bonding. Consequently, the structure is fixed and no expansion ordinarily occurs between layers when the clay is wetted.

Cations and water do not enter between the structural layers of a 1:1 type mineral particle. The effective surface of kaolinite is restricted to its outer faces or to its external surface area. Also, there is little isomorphous substitution in this 1:1 type mineral. Because of low surface area and little isomorphous substitution the capacity to adsorb cations is also low.
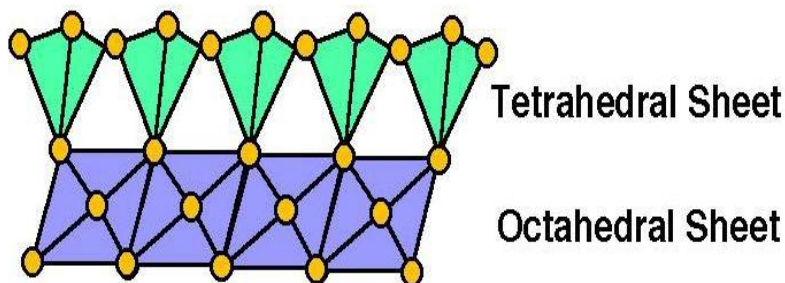

Kaolinite crystals usually are hexagonal in shape. In comparison with other clay particles, they are large in size, ranging from 0.10 to 5 ☐m across with the majority falling within the 0.2 to 2 ☐m range. Because of the strong binding forces between their structural layers, kaolinite particles are not readily broken down into

extremely thin plates. Kaolinite exhibits very little plasticity (capability of being molded), cohesion, shrinkage, and swelling.

2:1-Type Minerals

The crystal units (layers) of these minerals are characterized by an octahedral sheet sandwiched between two tetrahedral sheets. Three general groups have this basic crystal structure.
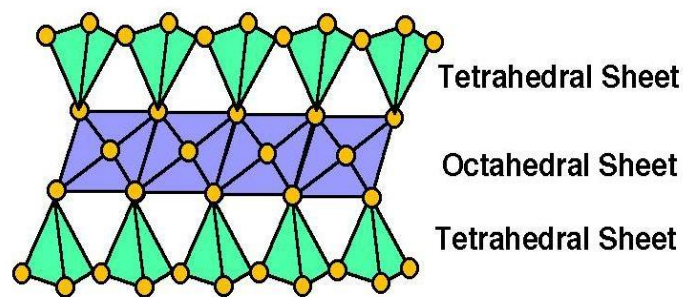

➢ Expanding type: Smectite group and vermiculite

➢ Non-expanding type: mica group (illite)

Expanding Minerals: The smectite group of minerals is noted for their interlayer expansion and swelling when wetted. The water enters the interlayer space and forces the layers apart. Montmorillonite is the most prominent member of this group in soils. Beidellite, nontronite, and saponite are also found in soils.

The flake-like crystals of smectite (e.g., **Montmorillonite**) are composed of an expanding lattice 2:1 type clay mineral. Each layer is made up of an octahedral sheet sandwiched between two tetrahedral (silica) sheets. There is little attraction between oxygen atoms in the bottom tetrahedral sheet of one unit and those in the top tetrahedral sheet of another. This permits a ready and variable space between layers, which is occupied by water and exchangeable cations. This internal surface exceeds the external surface of clay crystal. In montmorillonite, magnesium replaces replaced aluminum in some sites of octahedral sheet. Likewise, some silicon atoms in the tetrahedral sheet may be replaced by aluminum. These substitutions give rise to a negative charge.
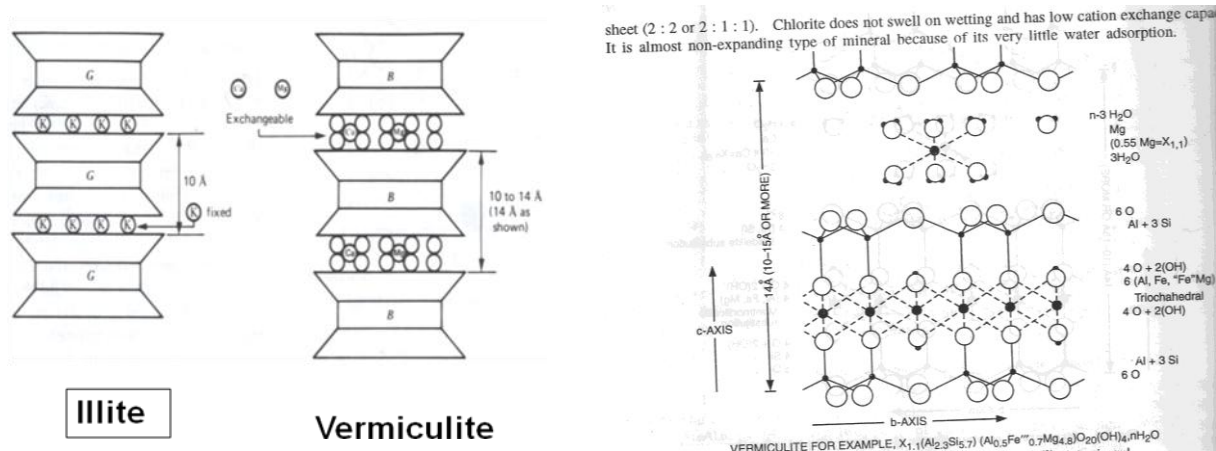
These minerals show high cation exchange capacity, swelling and shrinkage properties. Wide cracks commonly form in smectite dominated soils (e.g., Vertisols) when dried. The dry aggregates or clods are very hard, making such soils difficult to till.
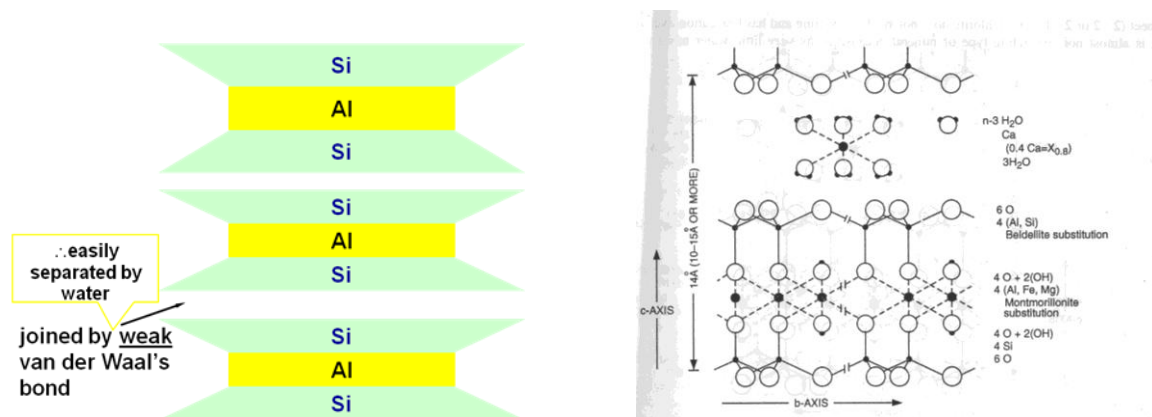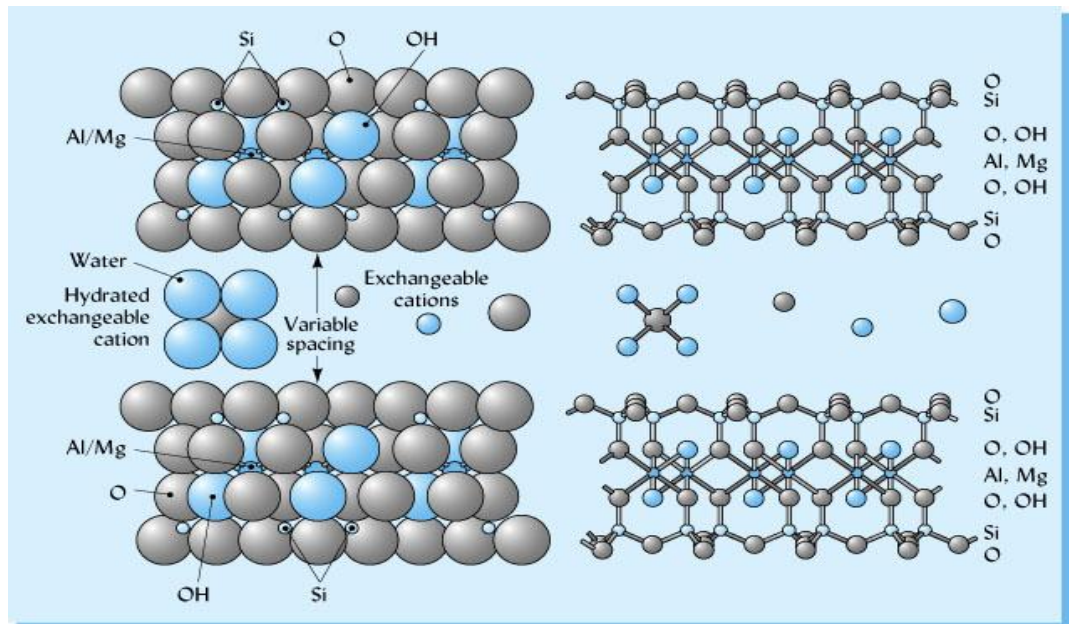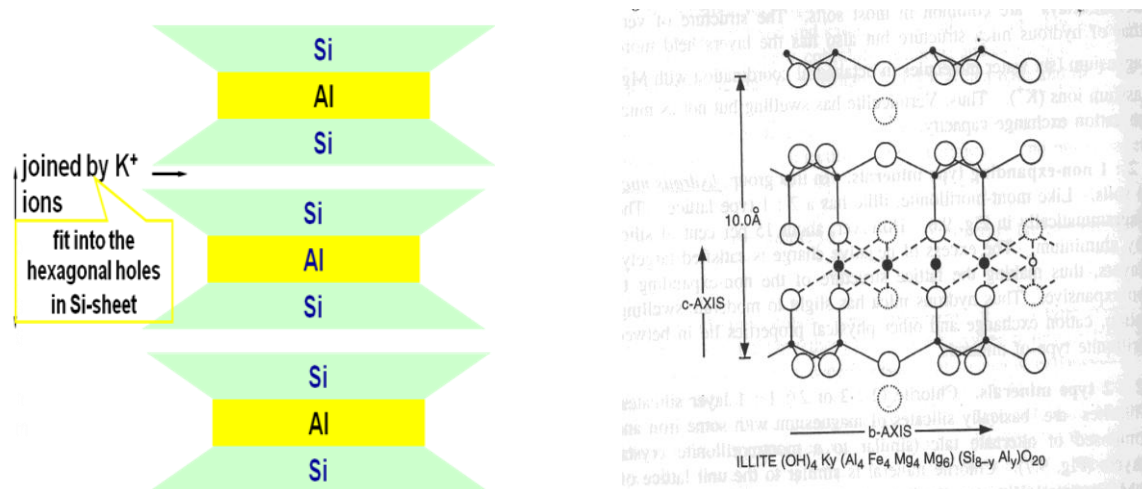
Vermiculites are also 2:1 type minerals in that an octahedral sheet occurs between two tetrahedral sheets. In most soils vermiculites, the octahedral sheet is aluminum dominated (di-octahedral), although magnesium dominated (tri-octahedral) vermiculites are also present. In the tetrahedral sheet of most vermiculite, aluminum is substituted by silicon in most of the sites. This accounts for most of the very high net negative charge associated with these minerals. Water molecules, along with magnesium and other ions, are strongly adsorbed in the interlayer space of vermiculites. They act primarily as bridges holding the units together rather than as wedges driving them apart. The degree of swelling is, therefore considerable less for vermiculites than for smectite. For this reason, vermiculites are considered limited expansion clay minerals, expanding more than kaolinite but much less than the smectite. The **cation exchange capacity** (CEC) of vermiculite is higher than all other silicate clays, including montmorillonite and other smectite because of very high negative charge in the tetrahedral sheet. Vermiculite crystals are larger than those of the smectite but much smaller than those of kaolinite.

Structure of vermiculite

sheet (2 : 2 or 2 : 1 : 1). Chlorite does not swell on wetting and has low cation exchange capa...
It is almost non-expanding type of mineral because of its very little water adsorption.

Illite

Vermiculite

n-3 H₂O
Mg
(0.55 Mg=X₁,₁)
3H₂O

6 O
Al + 3 Si

4 O + 2(OH)
6 (Al, Fe, "Fe"Mg)
Triochahedral
4 O + 2(OH)

Al + 3 Si
6 O

VERMICULITE FOR EXAMPLE, $X_{1.1}(Al_{2.3}Si_{5.7})$ $(Al_{0.5}Fe'''_{0.7}Mg_{4.8})O_{20}(OH)_4.nH_2O$

Structure of illite

joined by K⁺ ions fit into the hexagonal holes in Si-sheet

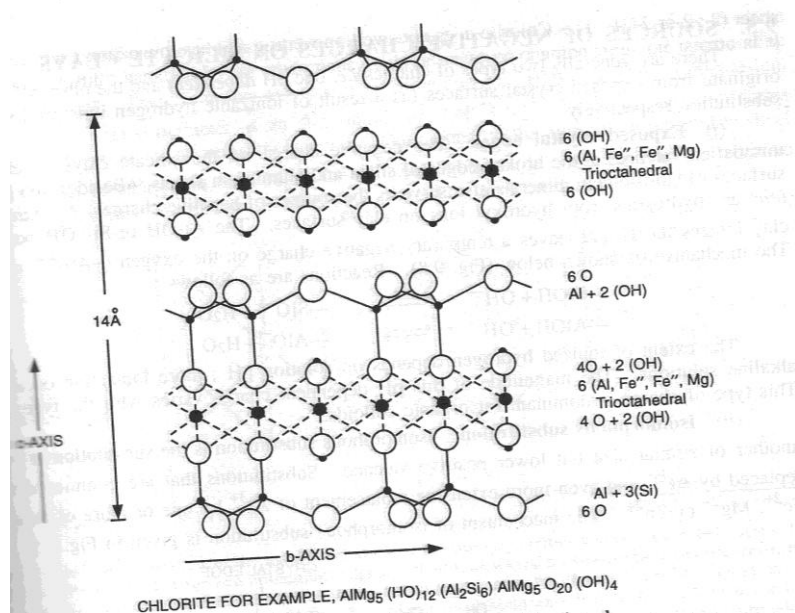ILLITE $(OH)_4 K_y (Al_4 Fe_4 Mg_4 Mg_6) (Si_{8-y} Al_y)O_{20}$

2:1 Non-expanding minerals: Micas are the type minerals in this group. (e.g.) Muscovite and biotite. Weathered minerals similar in structure to these micas are found in the clay fraction of soils. They are called fine-grained micas. Like smectite, fine-grained micas have a 2:1 type crystal. However, the particles are much larger than those of the smectite. Also, the major source of charge is in the tetrahedral sheet where aluminum atoms occupy about 20% of the silicon sites.

This result in a net negative charge in the tetrahedral sheet and the charge is higher than that found in vermiculites. To satisfy this charge, potassium ions are strongly attracted in the interlayer space and are just the right size to fit into spaces in the adjoining tetrahedral sheets. The potassium thereby acts as a binding agent, preventing expansion of the crystal. Hence, fine-grained micas are quite non-expanding.
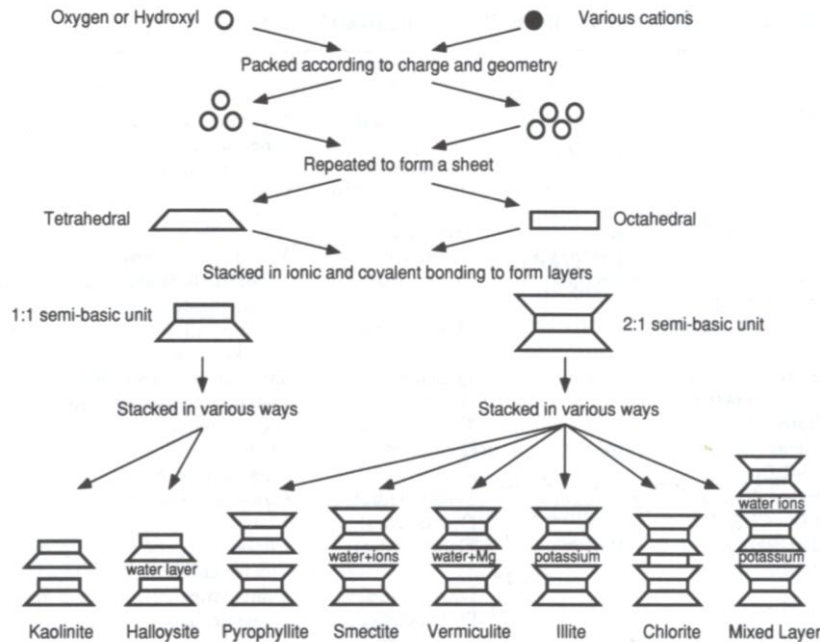
The properties such as hydration, cation adsorption, swelling, shrinkage and plasticity are less intense in fine grained micas than in smectite but are more than kaolinite due to the presence of interstratified layers of smectite or vermiculite. Fine grained mica crystals are intermediate in size between the smectite and kaolinite. Their specific surface area varies from 70 to 100 $m^2 g^{-1}$, about one eighth that for the smectite.

2:1:1 Type Minerals: This silicate group is represented by **chlorites**. Chlorites are basically iron magnesium silicates with some aluminum present. In a typical chlorite clay crystal, 2:1 layers, such as in vermiculites, alternate with a magnesium dominated tri-octahedral sheet, giving a 2:1:1 ratio. Magnesium also dominates the tri-octahedral sheet in the 2:1 layer of chlorites. Thus, the crystal unit contains two silica tetrahedral sheets and two magnesium-dominated tri-octahedral sheets giving rise to the term 2:1:1 or 2:2 type structure.

The negative charge of chlorites is about the same as that of fine grained mica and less than smectite or vermiculites. Like fine micas, chlorites may be interstratified with vermiculites or smectites in a single crystal. Particle size and surface area for chlorites are also about the same as for fine grained micas. There is no water adsorption between the chlorite crystal units, which accounts for the non expanding nature of this mineral.

6 (OH)
6 (Al, Fe″, Fe″, Mg)
Trioctahedral
6 (OH)

6 O
Al + 2 (OH)

4O + 2 (OH)
6 (Al, Fe″, Fe″, Mg)
Trioctahedral
4 O + 2 (OH)

Al + 3(Si)
6 O

14Å

b-AXIS

CHLORITE FOR EXAMPLE, $AlMg_5 (HO)_{12} (Al_2Si_6) AlMg_5 O_{20} (OH)_4$

Mixed and interstratified layers: Specific groups of clay minerals do not occur independently of one another. In a given soil, it is common to find several clay minerals in an intimate mixture. Furthermore, some mineral colloids have properties and composition intermediate between those of any two of the well defined minerals described. Such minerals are termed mixed layer or interstratified because the individual layers within a given crystal may be of more than one type. Terms such as "chlorite-vermiculite" and "mica - smectite" are used to describe mixed layer minerals. In some soils, they are more common than single structured minerals such as montmorillonite.

2. Iron and aluminum oxide clays (sesquioxide clays): Under conditions of extensive leaching by rainfall and long time intensive weathering of minerals in humid warm climates, most of the silica and alumina in primary minerals are dissolved and slowly leached away. The remnant materials, which have lower solubility are called sesquioxides. Sesquioxides (metal oxides) are mixtures of aluminum hydroxide, Al $(OH)_3$, and iron oxide, Fe_2O_3, or iron hydroxide, $Fe(OH)_3$. The Latin word *sesqui* means one and one-half times, meaning one and one-half times more oxygen than Al and Fe. These clays can grade from amorphous to crystalline. Examples of iron and aluminum oxides common in soils are gibbsite $(Al_2O_3.3H_2O)$ and geothite $(Fe_2O_3.H_2O)$. Less is known about these clays than about the layer silicates. These clays do not swell, not sticky and have high phosphorus adsorption capacity.

Sesquioxide Clays (Metal Oxides and Hydrous Oxides)

Also found in finer component. These tend to form in soils as Si is depleted by leaching.Gibbsite is the most common Al oxide mineral and is often found in

highly weatherd sois such as oxisoils in tropical areas and ultisols found predominatly in the southeastern U.S.The most commn iron oxides are Goetihte (FeO(OH) and Hematiite (Fe_2O_3) Thess are also found in highly weathered soils and gives many red soils their color. The metal oxides gibbsite and goethite tend to persist in the environment because Si is readily leached than Al, or Fe and significant amount of soluble organic matter is present. Manganese oxides are also quite common in soils. Apart from being an essential plant nutrient, they are an nutrural oxidant to certain metals such as As^{3+} and Cr^{3+}. Birnessite(MnO_2) is the most comon Mn oxide found in soils. Most of the charges developed on the metal oxides are pH-dependent.

Allophane and other amorphous minerals: These silicate clays are mixtures of silica and alumina. They are amorphous in nature. These are structurally disordered aluminosilicates. Typically, these clays occur where large amount of weathered products existed. They are normally derived from volcanic ash materials and constitute a major component of volacnic soils. Allophane is is often associated with clay minerals of the kaolinite group. Imogolite has the empirical formula $SiAl_4O_{10}.5H_2O$. These clays have high anion exchange capacity or even high cation exchange capacity. Almost all of their charge is from accessible hydroxyl ions (OH^-), which can attract a positive ion or lose the H^+ attached.

These clays have a variable charge that depends on H^+ in solution (the soilacidity).
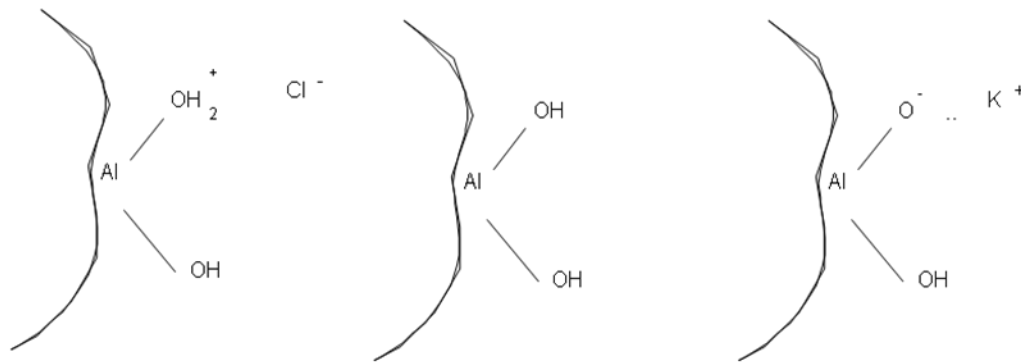
Low pH (protonated,   Zero Point of Charge   High pH (depronotated,
anion exchange site)   cation exchange site)

Carbonate and Sulfate Minerals

The carbonate and sulfate minerals are highly soluble compared to the alumino-silicates and are more prevalent in arid and semi arid regions.The major carbonate minerals are calcite ($CaCO_3$) and Dolomite ($CaMg(CO_3)_2$ The major sulfate mineral is gypsum.

Comparative properties of silicate clay minerals

Property	Montmorillonite	Illite	Kaolinite
Structure	2:1 lattice	2:1 lattice	1:1 lattice
	Substitution in octahedral sheet by Mg or Fe	Substitution inTetra hedral sheet by Al	No Substitution
Shape	Irregular flakes	Irregular flakes	Hexagonal crystals
Total surface area (m2g-1)	700-800	100-120	5-20

Cohesion Plasticity and swelling capacity	High	Medium	Low
External surface Internal surface	Very high	Medium	Not at all
Cation Exchange capacity	80-100	15-40	3-15
Anion exchange capacity	Low	Medium	High

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Adsorption of ions–Ion exchange–CEC& AEC – Factors influencing ion exchange- Significance.

Adsorption of ions

Ion adsorption and subsequent exchange are important processes that take place between soil colloidal particles (clays, organic matter, sesquioxides, and amorphous minerals) and various ions. Soil colloids serve very much as a modern bank. They are the sites within the soil where ions of essential plant nutrients are held and protected from excessive loss by leaching. Subsequently, the nutrients can be "withdrawn" from the colloidal "bank" sites and taken up by plant roots. In turn, these elements can be "deposited" or returned to the colloids through the addition of commercial fertilizers, lime, manures, and plant residues.

The charges associated with soil particles attract ions (simple and complex) of opposite charge. In temperate region soils, negative charges generally predominate on the soil particles (colloids), hence adsorbed cations are present in larger quantities than anions. In more highly weathered soils (e.g. in tropics) where 1:1 type clays and Fe/Al oxides are the most dominant type of colloids, anion adsorption and exchange is relatively more prominent.

Ion exchange reactions – Cation exchange, anion exchange and base saturation - significance

The Ion Exchange phenomenon was first identified by Harry Stephen Thompson in England during 1850. When soil was leached (washed) with ammonium sulphate, calcium sulphate was detected in the leachate. The ammonium ion in the solution replaced calcium in the soil.

$$(NH_4)_2SO_4 + Soil\ Ca \rightarrow Soil\ (NH_4)_2 + CaSO_4$$

The process by which ions are exchanged between solid and liquid phases and /or between solid phases if in close contact with each other is called ion exchange.

The common exchangeable cations are Ca^{2+} mg^{2+} H^+ ,K^+, NH_4^+ and Na. The common anions are So_4^{2-}, Cl^- Po_4^{-3} and $N0_3^-$.

The ion exchange in soil is due to the presence of residual positive and negative charges on the soil colloids. These residual charges result due to the process of isomorphous substitution and ionisation of hydrogen and hydroxide functional groups. The negative charges attract positively charged ions and the positive charges attract negatively charged ions from soil solutions coming in contact with colloids. The ions thus attracted are reversible and are on equivalent proportions.

Exchange of cation is called cation exchange and exchange of anion is called anion exchange. The cation exchange phenomenon was first discovered by Thomasway (1850) Ion exchange is the second most important reaction is nature. The first one is photosynthesis by green plants.

The capacity of the soil to hold cation is called cation exchange capacity. The unit is C mol (P^+) / kg. The capacity to hold anion is called Anion exchange capacity (AEC). The unit of expression is C mol (e^-) / kg

Mechanism of cation exchange.

Clay colloids have negative charges. Cations are attracted to the clay particles. These cations are held on the held on the clay surfaces electro statistically. They are held by small particles of clay and organic matter. These small particles are called Micelle (Micro cell). The cations that can be replaced on

exchange site by other cations are called exchangeable cations. They are weekly held and they are in direct contact with the soil solution. They can be exchanged fairly easily. Ions that are held very lightly with the colloid may be traped between layers of clay micelle. They do not pass to the soil solution very easily. They are called non exchangeable cations. When any cation is added to the soil such as Ca^{++}, K^{+} or NH_4 through fertilizers and soil amendments they are exchanged with those ions held on the colloid. When calcium is added to an acid soil the following reaction takes place.
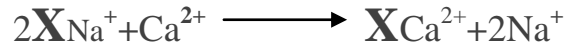
$$\boxed{micelle} \quad H^{+} \quad + Ca \quad \text{-------} \quad \boxed{micelle} \quad Ca + 2H^{+}$$

$$H^{+}$$

Similarly when H^{+} is added to the soil solution through the decomposition of organic matter or through acidic materials Ca^{2+} is replaced from the exchange complex by H^{+}.

$$\boxed{Micelle} \quad Ca^{2+} \quad + \quad 2H \quad \text{----------} \quad \boxed{micelle} \quad ^{H} + Ca^{2+}$$

$$H$$

Example: Ca^{2+} exchange displaces exchangeable Na^{+}

Negatively-charged clay

$$2\mathbf{X}\mathrm{Na}^+ + \mathrm{Ca}^{2+} \longrightarrow \mathbf{X}\mathrm{Ca}^{2+} + 2\mathrm{Na}^+$$
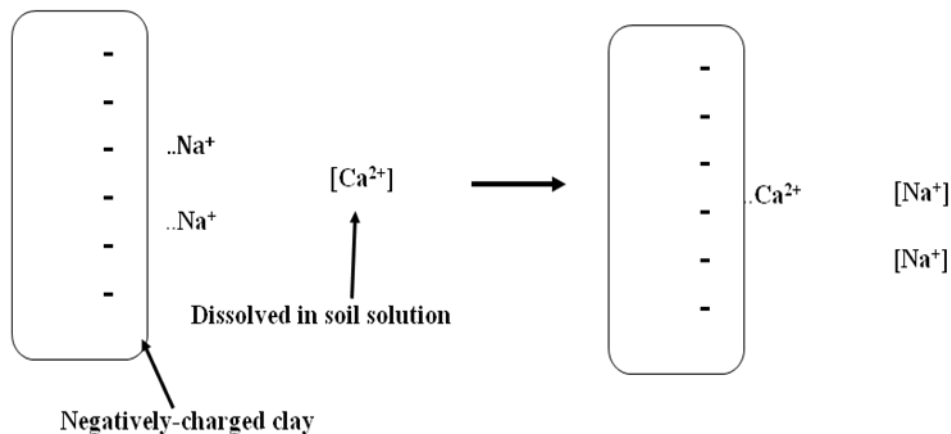
$$\mathbf{X} = \text{exchangeable}$$

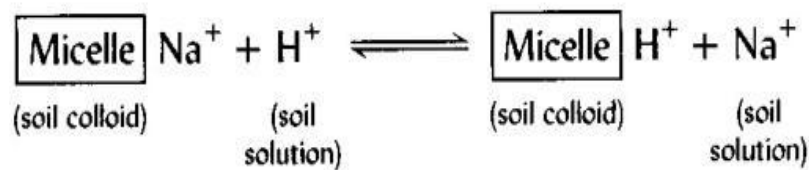## Cation exchage capacity (CEC)

The sum total of the exchangeable cations that a soil can adsorb is called as cation exchange capacity.

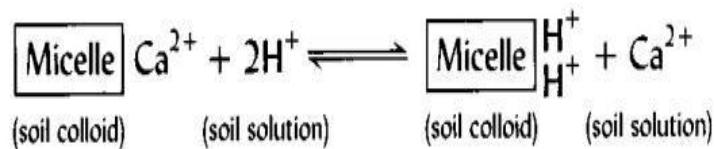It is also defined as "the amount of cationic species bound at p^H 7.0".

Some authors consider p^H 4.0 as the appropriate point.
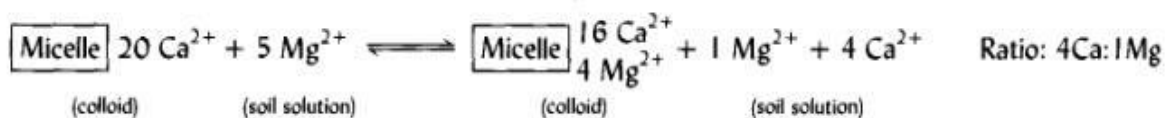
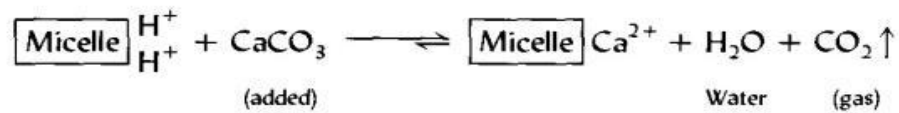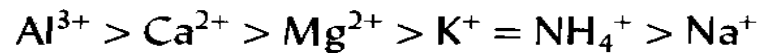## Principles governing cation exchange reaction

Reversibility

$$\boxed{\text{Micelle}}\ \mathrm{Na}^+ + \mathrm{H}^+ \rightleftharpoons \boxed{\text{Micelle}}\ \mathrm{H}^+ + \mathrm{Na}^+$$

(soil colloid)   (soil solution)   (soil colloid)   (soil solution)

Charge equivalence

$$\boxed{\text{Micelle}}\ \mathrm{Ca}^{2+} + 2\mathrm{H}^+ \rightleftharpoons \boxed{\text{Micelle}\ \begin{smallmatrix}\mathrm{H}^+\\\mathrm{H}^+\end{smallmatrix}} + \mathrm{Ca}^{2+}$$

(soil colloid)   (soil solution)   (soil colloid)   (soil solution)

Ratio law

$$\boxed{\text{Micelle}}\ 20\ \mathrm{Ca}^{2+} + 5\ \mathrm{Mg}^{2+} \rightleftharpoons \boxed{\text{Micelle}\ \begin{smallmatrix}16\ \mathrm{Ca}^{2+}\\4\ \mathrm{Mg}^{2+}\end{smallmatrix}} + 1\ \mathrm{Mg}^{2+} + 4\ \mathrm{Ca}^{2+} \qquad \text{Ratio: } 4\mathrm{Ca}{:}1\mathrm{Mg}$$

(colloid)   (soil solution)   (colloid)   (soil solution)

Anion effects on mass action

$$\boxed{Micelle} \begin{matrix} H^+ \\ H^+ \end{matrix} + CaCO_3 \ \rightleftharpoons \ \boxed{Micelle}\, Ca^{2+} + H_2O + CO_2\uparrow$$

$$\quad\quad\quad\quad (added) \quad\quad\quad\quad\quad\quad\quad\quad\quad Water \quad (gas)$$

Cation selectivity

$$Al^{3+} > Ca^{2+} > Mg^{2+} > K^+ = NH_4^+ > Na^+$$

Complementary ion effect
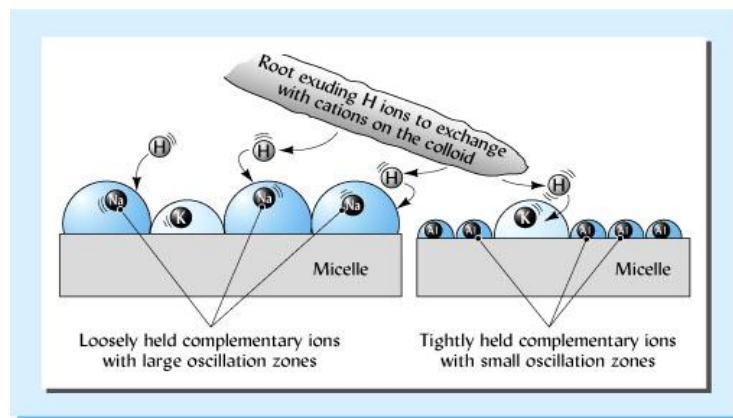
CEC of different textural classes.

Sand	0-5 C mol (P$^+$) / Kg.
Sandy loam	5-10 "
Loam	10-15 "
Clay loam	15-30
Clay	30.0

CEC of important clay minerals

Kaolinite	7-10 C mol (P$^+$) / Kg
Montmorillonite	80-100 "
Vermiculite	100-150 "
Illite	25-30 "
Chlorite	25-30 "

Fe & Al oxides	5.0	''
Humus	200-400	''

Factors influencing CEC

1. **Soil Texture**: CEC increases with fineness of the soil particles. This means increasing clay content will increase the CEC. As the particle size decreases the surface area increases per unit volume. This naturally increases the net charge and the CEC.

2. **Organic matter**: In general CEC increases with increase in organic matter content. The p^H dependent charges in the organic matter cause variation in CEC. When p^H of the soil solution increases the CEC will also increase.

3. **Nature of clay:** CEC of clay minerals vary soil dominated with montmorillonite and vermiculite have higher CEC than those dominated with kaolinite, chlorite or illite.

4. **Soil reaction**: In general CEC increases with increase in soil p^H. As the p^H increases the p^H dependent charge increases. In Humus most CEC is p^H dependent.

Replacing power of ions:

Replacing power of ions increases with atomic weight.   Divalent   cations   have more replacing power than monovalent ions. Hydrogen is an exemption. H ions are adsorbed more strongly than other monovalent or divalent ions. The replacing power of cations varies with the **type of ion**, **size, degree of hydration**, **valence**, **concentration** and the **kind of clay mineral** involved. As it is controlled by number of factors no single order of replacement can be given. All other factors being equal the replacing power of monovalent cations increases in the following order: Li < Na < K < Rb < Cs < H and for divalent cations: Mg < Ca < Sr < Ba. In case of mixture of monovalent and divalent cations as they exist in normal soils the

replacing power increases in the following order: Na < K < NH_4 < Mg < Ca < H. This means Na is more easily replaced than K and K more easily than NH_4.

In general the power of replacement is

H   > Ca >   Mg   > NH4 >   K >   Na

Base saturation

The percentage of CEC that is satisfied by the base forming cations is called base saturation percentage.

% Base saturation = Exchangeable base forming cations (C mol / kg) x $_{100}$

CEC (C mol / kg)

Aluminium and hydrogen are considered as acid forming ions. Calcium, Magnesium, Potassium and Sodium are considered as base forming ions. Base forming substances are called as besoids and acid forming substances are called as acidoids.   The percentage of sodium in the total CEC is called Exchangeable sodium percentage **(ESP) [(Na/CEC) x 100].** These parameters are considered while deriving fertilizer prescription and amendments for problem soils A knowledge of base saturation percentage is useful in many ways.

1. It helps in determining the quantity of lime required to raise the p^H of acid soils.
2. It indicates the proportion of plant nutrients in CEC. It is an index of soil fertility.
3. Degree of saturation of a particular cation in CEC indicates the ease with which the cation can be released for plant nutrition. For example if calcium

saturation is more Ca can be very easily replaced from the exchange complex.

4. For a fertile soil it is considered that the base saturation percentage should be more than 80.

Anion exchange

Replacement of one anion by another anion on the positively charged colloids is called anion exchange, positive charges are due to OH of iron and aluminium, 1:1 clays and allophone (a morphous clays).

Anion exchange is p^H dependent. Lower the p^H greater is the anion exchange. Soils with Kaolinite dominant clay have higher anion exchange capacity than montmorillonite or illite.

The relative order of anion exchange is

$$OH > H_2PO_4 > SO_4 > NO_3 > Cl.$$

Importance of anion exchange:

1. The phenomenon of anion exchange is important for the release of fixed P in the soil.

In acid soils the phosphorus is fixed as insoluble Al-Phosphate. Liming the acid soils release fixed P. Here the OH ion replaces $H_2 PO_4$ from $Al(OH)_2 H_2PO_4$.

$$Al(OH)_2 H_2 PO_4 + OH \longrightarrow Al(OH)_3 + H_2 PO_4.$$
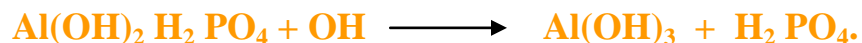
2. Similarly the availability of other nutrients like NO_3, SO_4 and Cl are influenced by anion exchange.

$$\boxed{Soil\ colloid}\ NO3 + Cl \longrightarrow \boxed{Soil\ colloid}\ Cl + NO_3$$
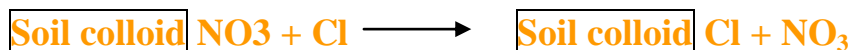
Significance of ion exchange

Next to photosynthesis ion exchange is the most important reaction in the world. Plants take up their food material from the soil through ion exchange only. Plant roots which are in contact with the soil solution exchange the nutrients from soil solution for H^+ ions present on the surfaces of root hairs.

Effect on soil fertility

A soil is considered to be fertile when the base saturation percentage is more than 80.   Each percent of humus contributes about 2 C mol /kg of CEC. Montmorillonite contributes about I C mole and Kaolinite contributes about 0.08 C mol/kg for every one percent.

Availability of applied nutrients

When fertilizers are applied to supply plant nutrients elements like K, Ca, Mg and NH_4 dissolve in soil solution.   These nutrients in soil solution are exchanged for other cation like H^+ present in the exchange complex. If there is no cation exchange the applied nutrients would be lost in drainage water. Similar is the case with anion radicals like PO_4, NO_3, SO_4 etc. Soils with high CEC can adsorb higher amounts of nutrients. Hence, in clay soils we can apply larger quantities of fertilizers in a single dose. Sandy soils have very low CEC and in such soils fertilizers should be applied in splits.

Effect of adsorbed cations.

When the soil exchange complex has calcium the soil will have desire able physical properties. The activity of soil micro organisms, ammonification and nitrification processes also are determined by the cations of exchange complex.

Toxic ions:

When the exchange complex had adsorbed metals like Cadmium, Nickel and lead they are toxic to the crop plants.

Effect on soil p^H

Clays with H are acidic and with Na are alkaline. The acidic and alkaline nature of soil has its own effect on soil properties

Soil organic matter – composition, decomposition, mineralization and immobilization

SOIL ORGANIC MATTER

Substances containing carbon are organic matter. Soil organic matter consists of decomposing plant and animal residues. It also includes substances of organic origin either leaving or dead.

Soil organic matter plays an important role in deciding / maintaining soil physical conditions. It also influences soil chemical properties especially cation exchange capacity. Organic matters supply the energy sources for soil micro organisms. Soil development is another aspect which is influenced by the soil organic matter.

Plant tissue is the major source. Animals are considered as the secondary sources. They attack original plant tissues, contribute waste products and leave their own bodies after death.

Factors affecting soil organic matter

1. Climate

2. Natural vegetation

3. Texture

4. Drainage

5. Cropping and Tillage

6. Crop rotations, residues and plant nutrients.

1. Climate: Temperature and rainfall exert a dominant influence on the amounts of N and organic matter found in soils.

a) Temperature: The organic matter and N content of comparable soils tend to increase if one moves from warmer to cooler areas. The decomposition of organic matter is accelerated in warm climates as compared to cooler climates. For each 10°C decline in mean annual temperature, the total organic matter and N increases by two to three times.

b) Rainfall: There is an increase in organic matter with an increase in rainfall. Under comparable conditions, the N and organic matter increase as the effective moisture becomes greater.

2. Natural Vegetation: The total organic matter is higher in soils developed under grasslands than those under forests.

3. Texture: Fine textured soils are generally higher in organic matter than coarse textured soils.

4. Drainage: Poorly drained soils because of their high moisture content and relatively poor aeration are much higher in organic matter and N than well drained soils.

5. Cropping and Tillage: The cropped lands have much low N and organic matter than comparable virgin soils. Modern conservation tillage practices helps to maintain high OM levels as compared to conventional tillage.

6. Rotations, residues and plant nutrients: Crop rotations of cereals with legumes results in higher soil organic matter. Higher organic matter levels, preferably where a crop rotation is followed.

Composition of organic residues:

Plant residues contain 75% moisture and 25% dry matter. This 25% is made up of Carbon (10-12%), Oxygen (9-10%) , Hydrogen (1.5-2.5%) , N(1-2%) and mineral matter (1-3%).

Composition of plant tissues:

Carbohydrates

Celluloses   20-50%

Hemicellulose   10-30%

Starch, Sugar   1-5%

Proteins   1-15%

Fats, waxes, tannins   1-10%

Lignins   10-30%

Inorganic residues (mineral matter)

1. Water insolubles

Proteins, Peptides

Nitrogenous   Peptones and S containing

materials

2. Water solubles

(No_3, NH4 compounds)

Soil organic residues

Non Nitrogenous   Carbohydrates (celluloses

Hemicellulose, ,Starch, Sugar etc)

Ether solubles (Fats, oils, waxes,

resins etc) Lignins

The organic matter is also classified on the basis of their rate of decomposition

1. Rapidly decomposed   : Sugars, starches, proteins etc.

2. Less rapidly decomposed   : Hemicelluloses, celluloses etc.

3. Very slowly decomposed   : Fats, waxes, resins, lignins etc

Decomposition of soil organic matter:

Different organic residues contain different organic compounds. There is great variation in the rate of decomposition of organic residues. Sugars, starches and simple proteins are very rapidly decomposed.   On the other hand Fats, waxes and lignins are very slowly decomposed. Hemicellulose, celluloses and protein are intermediate. Even though the composition may vary the end products are more or less the same.   The general reactions taking place during decomposition are

1. Enzymatic oxidation of the bulk with the release of Co_2 , water, energy and heat
2. Essential elements are released (N, P, S etc) and immobilized by a series of reactions.
3. Formation of compounds which are resistant to microbial action.

Molecules very resistant to microbial action is formed either through modification of compounds or by microbial synthesis

Under aerobic conditions the products formed are

Co_2, NH_4, NO_3 , H_2PO_4, SO_4, H_2O and essential plant nutrients like Ca, Mg, Fe, Cu, Zn etc.

Under anaerobic conditions

CH_4, organic acids like lactic, propionic, butyric, NH_4, various amine residues ($R-NH_2$) H_2S, ethylene ($CH_2=CH_2$) and humic substances.

A. Decomposition of soluble substances: When glucose is decomposed under aerobic conditions the reaction is as under:

$$Sugar + Oxygen \rightarrow CO_2 + H_2O$$

Under partially oxidized conditions,

Sugar + Oxygen $\rightarrow$ Aliphatic acids (Acetic, formic *etc*.) or Hydroxy acids (Citric, lactic etc.) or Alcohols (ethyl alcohol etc.)

Some of the reactions involved may be represented as under:

$$C_6H_{12}O_6 + 2O_2 \rightarrow 2CH_3.COOH + 2CO_2 + 2H_2O$$

$$2C_6H_{12}O_6 + 3O_2 \rightarrow C_6H_8O_7 + 4H_2O$$

$$C_6H_{12}O_6 + 2O_2 \rightarrow 2C_2H_5OH + 2CO_2$$

Ammonification – organic N - Polypeptides – Peptides – amonoacids – NH_3 or NH_4

i) Ammonification: The transformation of organic nitrogenous compounds (amino acids, amides, ammonium compounds, nitrates etc.) into ammonia is called ammonification. This process occurs as a result of hydrolytic and oxidative enzymatic reaction under aerobic conditions by heterotrophic microbes.

ii)Nitrification: The process of conversion of ammonia to nitrites (NO_2) and then to nitrate (NO_3^-) is known as nitrification. It is an aerobic process by autotrophic bacteria.

$$NH_3 \xrightarrow{\text{Nitrosomonas}} NO_2 \xrightarrow{\text{Nitrobacter}} NO_3^-$$
$$\text{Ammonia} \qquad \text{Nitrite} \qquad \text{Nitrate}$$
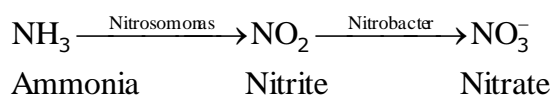
The net reactions are as follows:

$$\mathbf{NH_4 + O_2 \rightarrow NO_2 + 2H^+ + H_2O + energy}$$

$$\mathbf{NO_2 + O_2 \rightarrow NO_3^- + energy}$$

iii) Denitrification: The process, which involves conversion of soil nitrate into gaseous nitrogen or nitrous oxide, is called Denitrification. Water logging and high pH will increase N loss by Denitrification.

$$\text{Nitrate} \xrightarrow{\text{Pseudomonas / Bacillus}} N_2 \text{gas}$$
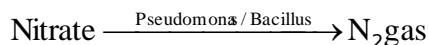
2. Under anaerobic conditions:

$C6H_{12}O_6$ (Glucose) - Lactic acid, butyric acid Ethyl alcohol are formed

Protein and other N compounds are converted into elemental N.

B. Decomposition of Insoluble Substances

i) Breakdown of Protein: During the course of decomposition of plant materials, the proteins are first hydrolyzed to a number of intermediate products.

Aminization: The process of conversion of proteins to aminoacids.

Ammonification: The process of conversion of aminoacids and amides to ammonia.

**ii) Breakdown of cellulose**: The decomposition of the most abundant carbohydrates.

Hydrolysis   hydrolysis   oxidation

Cellulose $\Rightarrow$ Cellobiose $\Rightarrow$ Glucose $\Rightarrow$ Organic acids $\Rightarrow$ $CO_2 + H_2O$

(cellulase)   (cellobiase)

This reaction proceeds more slowly in acid soils than in neutral and alkaline soils. It is quite rapid in well aerated soils and comparatively slow in poorly aerated soils.

iii) Breakdown of Hemicellulose: Decompose faster than cellulose and are first hydrolyzed to their components sugars and uronic acids. Sugars are attacked by microbes and are converted to organic acids, alcohols, carbon dioxide and water. The uronic acids are broken down to pentose and CO_2. The newly synthesized hemicelluloses thus form a part of the humus.

iv) Breakdown of Starch: It is chemically a glucose polymer and is first hydrolyzed to maltose by the action of amylases. Maltose is next converted to glucose by maltase. The process is represented as under:

$$(C_6H_{10}O_5)n + nH_2O \Rightarrow n(C_6H_{12}O_6)$$
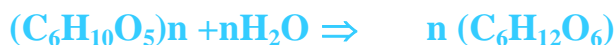
C. Decomposition of ether soluble substances:

Fats $\rightarrow$ glycerol + fatty acids

Glycerol $\rightarrow CO_2 +$ water

D. Decomposition of lignin: Lignin decomposes slowly, much slower than cellulose. Complete oxidation gives rise to CO_2 and H_2O.

Sulphur containing organic compounds:

Converted to SO_4^{-2} + H^+ + energy by sulphur oxidizing bacteria.

P containing organic compounds:

Various micro organisms mineralize phospholipids and other organic P compounds in the presence of phosphates enzymets H_2PO_4 and HPO_4^{-2} depending on soil P^H.

Mineralisation: The biological conversion of organic forms of C, N, P and S to inorganic or mineral forms is called mineralization.

Immobilization: The conversion of inorganic forms of C, N, P and S by the soil organism into organic forms is called Immobilization.

Factors affecting decomposition

1. Temperature: Cold periods retard plant growth and organic matter decomposition. Warm summers may permit plant growth and humus accumulation.

2. Soil moisture: Extremes of both arid and anaerobic conditions reduce plant growth and microbial decomposition. Near or slightly wetter than field capacity moisture conditions are most favorable for both processes.

3. Nutrients: Lack of nutrients particularly N slows decomposition.

4. Soil pH: Most of the microbes grow best at pH 6 to 8, but are severely inhibited below pH 4.5 and above pH 8.5.

5. Soil Texture: Soils higher in clays tend to retain larger amounts of humus.

6. Other Factors: Toxic levels of elements (Al, Mn, B, Se, Cl), excessive soluble salts, shade and organic phytotoxins in plant materials.

Role of organic matter

1. Organic matte creates a granular condition of soil which maintains favorable condition of aeration and permeability.
2. Water holding capacity of soil is increased and surface runoff, erosion etc., are reduced as there is good infiltration due to the addition of organic matter.
3. Surface mulching with coarse organic matter lowers wind erosion and lowers soil temperatures in the summer and keeps the soil warmer in winter.
4. Organic matter serves as a source of energy for the microbes and as a reservoir of nutrients that are essential for plant growth and also hormones, antibiotics.
5. Fresh Organic matter supplies food for earthworms, ants and rodents and makes soil P readily available in acid soils.
6. Organic acids released from decomposing organic matter help to reduce alkalinity in soils; organic acids along with released CO_2 dissolve minerals and make them more available.
7. Humus (a highly decomposed organic matter) provides a storehouse for the exchangeable and available cations.
8. It acts as a buffering agent which checks rapid chemical changes in pH and soil reaction.

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Humus – Fractionation of organic matter –

Humus

Humus is a complex and rather resistant mixture of brown or dark brown amorphous and colloidal organic substance that results from microbial decomposition and synthesis and has chemical and physical properties of great significance to soils and plants.

Humus Formation

The humus compounds have resulted from two general types of biochemical reactions: Decomposition and Synthesis.

1. Decomposition: a) Chemicals in the plant residues are broken down by soil microbes including lignin. b) Other simpler organic compounds that result from the breakdown take part immediately in the second of the humus-forming processes, biochemical synthesis. c) These simpler chemicals are metabolized into new compounds in the body tissue of soil microbes. d) The new compounds are subject to further modification and synthesis as the microbial tissue is subsequently attacked by other soil microbes.

2. Synthesis: Involve such breakdown products of lignin as the phenols and quinones. a) These monomers undergo polymerization by which polyphenols and polyquinones are formed. b) These high molecular weight compounds interact with N-containing amino compounds and forms a significant component of resistant humus. c) Colloidal clays encourage formation of these polymers. d) Generally two groups of compounds that collectively make up humus, the humic group and the nonhumic group.

Soil organic matter fractions

❖ Humic matter
❖ Non humic matter

❖ When soil is extracted with alkali the humic substances go into solution. The insoluble portion forms the non humic matter.

Humic group

❖ This group makes up about 60-80% of the soil organic matter.

❖ They are most complex. They are most resistant to microbial attack.

❖ Humic substances have aromatic ring type structures.

❖ These include polyphenols and poly quinones.

❖ These are formed by decomposition, synthesis and polymerization.

The humic substances are classified based on resistance to degradation and solubility in acids and alkalis into

❖ Humic acid

❖ Fulvic acid

❖ Humin

Non humic group

❖ This group makes upto 20-30% of the organic matter in soil.

❖ These are less complex and less resistant to microbial attack as compared to humic substances.

❖ They are polysaccharides, polymers having sugar like structures and polyuronides.

❖ These include proteins, carbohydrates, lignins, fats, waxes, resins, tannins and some compounds of low molecular weight.

Theories on humus formation

Lignin theory: Proposed by Waksman (1936).

❖ According to this theory humic substances are formed due to the incomplete degradation of lignin

Kononovas theory

❖ According to this theory humic substances are formed by cellulose decomposing mycobacteria earlier to lignin decomposition

Polyphenol theory: (Flaig and Sochtig (1964)

❖ As per this theory the humic substances are formed by the condensation of phenolic materials.

❖ The polyphenols of lignin are oxidized to quinones.

❖ These quinones are condensed with low molecular weight microbial products to form humic molecules.

❖ The microbial products are amino acids, nucleic acid and phospholipids.

Properties of Humus

1. The tiny colloidal particles are composed of C,H, and O_2.

2. The colloidal particles are negatively charged (-OH, -COOH or phenolic groups), has very high surface area, higher CEC (150 – 300 cmol/kg), 4 - 5 times higher WHC than that of silicate clays.

3. Humus has a very favorable effect on aggregate formation and stability.

4. Impart black colour to soils.

Cation exchange reactions are similar to those occurring with silicate clays

Clay – Humus Complex

Humus, the organic amorphous colloid supplies both basic and acidic ions which is transitory and ultimately disappears from soil. Clay, the inorganic crystalline colloid supplies chiefly the basic nutrient ions is more or less stable. Both these colloids form the soil colloidal complex and are extremely active and form important sources of plant nutrients.

It is believed that humus and clay exist in the soil as clay – humus complex, the two being held together by cations like Ca, Fe, etc. Depending upon the nature of binding cation, two types of Clay – humus complex have been recognized. The

colloidal complex bound by Ca ions is more stable and is responsible for the favorable physical condition of the soil, particularly its structure. The other type where Fe acts as the binding agent creates a poor physical condition of the soils.

Maintenance of Humus (Soil organic matter)

❖ Maintenance of humus at a higher level is difficult.

❖ This is due to the reason that the loss of carbon from the soil increases as the organic matter content is raised.

❖ No attempt should be made to increase the organic matter content over that the soil plant-climate control mechanism can permit.

❖ There is a strong linkage between soil Nitrogen and soil organic matter.

❖ To maintain adequate level of organic matter in the soil the N level should be maintained by inclusion of legumes in crop rotation and judicious application of N fertilizers.

❖ Loss of N from the soil is also to be minimized.

❖ To maintain the organic matter level continuous addition of organic materials is essential.

❖ These include animal manure, organic wastes and crop residues.

❖ Incorporation of green manure will add to the organic carbon level of soil.

❖ Ensuring vigorous crop growth by removing constraints in crop production will result in addition of root and top residues to the soil.

❖ Conservation tillage (minimum tillage) should be followed to the extent possible.

❖ This will reduce the decay of residues.

❖ Keeping the land fallow to encourage natural vegetation is also advisable.

****

## Carbon cycle – C: N ratio. Soil biology – Biomass – Soil organisms – Their beneficial and harmful roles.

Carbon cycle

Carbon is a common constituent of all organic matter (plant and animal residues).carbon is continually being fixed into organic form by photosynthetic organisms under the influence of light and once bound, the carbon becomes unavailable for use in the generation of new plant life. Therefore, it is essential for the carbonaceous materials to be decomposed and returned to the atmosphere for the survival of the higher organisms.

The decomposition of plant and animal remains in soil constituents a basic biological process in that carbon (C) is recirculated to the atmosphere as CO_2, nitrogen (N) is made available as NH_4 and NO_3 and other associated nutrient elements like P, S, Fe, Mn, Cu and Zn etc, appear in plant available forms. In the process, part of the nutrient elements is assimilated by micro organisms and incorporated into microbial tissues (Soil biomasses). The conversion of organic forms of C, N, P and S into inorganic or mineral forms is called mineralization and the conversion of inorganic forms of those elements to their organic forms is known as immobilization.

The carbon cycle revolves about CO_2 and its fixation and regeneration. Chlorophyll containing plants utilize the gas as their sole carbon source, and the carbonaceous matter thus synthesized serves to supply the animal world with preformed organic carbon. Upon the death of the plant or animal, microbial world with performed organic carbon. Upon the death of the plant or animal, microbial metabolism assumes the dominant role in the cyclic sequence. The dead tissues undergo decay and are transformed into microbial cells and a large amount of

heterogeneous carbonaceous compounds togetherly known as humus ar as the soil organic fraction. The cycle is completed and caron made available with the final decomposition and production of CO_2 from humus and the rotting tissues.
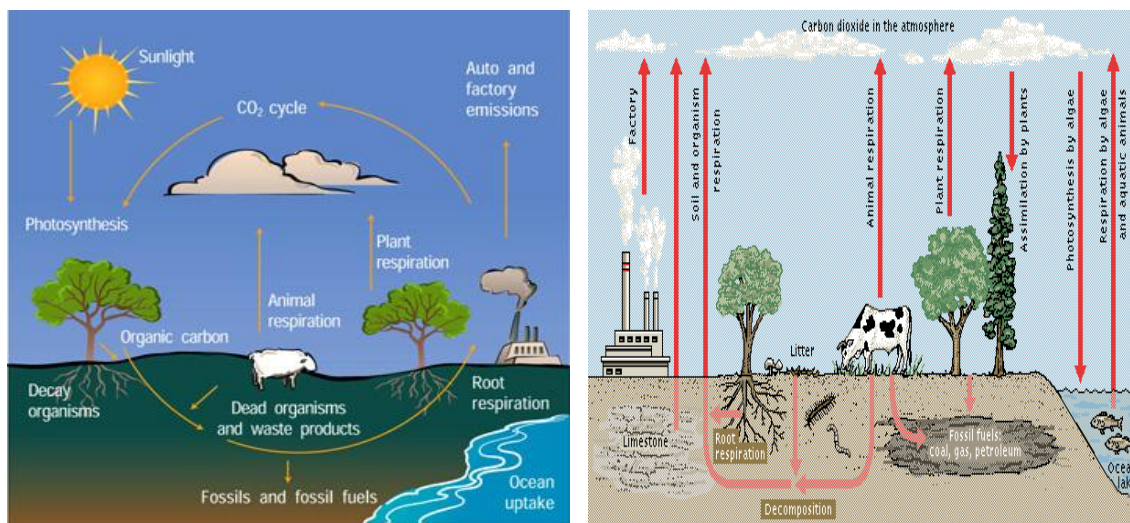
C: N ratio

- ❖ The ratio between the nitrogen content in the microbes and in the organic residues and to the carbon content is called as C:N ratio.
- ❖ When fresh plant residues are added to the soil they are rich in carbon and poor in N.
- ❖ This results in wider C: N ratio (40:1) decomposition of the organic matter in the soil changes to humus resulting in a narrow C: N ratio (10:1).
- ❖ When materials high in carbon are added to the soil the microbial population increase due to the plentiful supply of food material.
- ❖ A lot of CO2 is released.
- ❖ During this process the micro organisms utilize the soil N for their body build up and there is a temporary block of N.
- ❖ When the decomposition of fresh organic residues reaches to the stage where the C: N ratio is 20:1 there is an increase in the availability of N.

- ❖ The C: N ratio of cultivated soils ranges from 8:1 to 15:1.
- ❖ Average: 10:1 to 12:1.
- ❖ Legumes and Farm manure: 20:1 – 30:1.
- ❖ Straw   : 100:1
- ❖ Saw Dust   :   400:1
- ❖ In micro organisms   : 4:1 to 9:1
- ❖ There exists a relationship between the organic matter and N content. Soil carbon has a definite proportion of the organic matter.
- ❖ Hence the C to N ratio in soils is fairly constant.
- ❖ The C: N ratio is lower in soils of arid regions than humid regions.
- ❖ C: N ratio is smaller in subsoils.

It is the intimate relationship between organic matter and nitrogen contents of soils. The ration of the weight of organic carbon to the weight of total nitrogen in a soil or organic material is known as C: N ratio. The importance of C: N ratio in controlling the available nitrogen, total organic matter and rate of organic materials decomposition is recognized in developing appropriate soil management practices.

Ratio in soils:

The C: N ratio of soil is one of its characteristics equilibrium values, the figure for humus being roughly 10:1 although values from 5:1 to 15:1 are generally found in most arable soils. The critical ratio (10:1) is a reflection of the dynamic equilibrium that results from the dominating presence of a microbial population, the ratio being similar to the average   chemical composition of microbial cells. As a rule microbial protoplasm contains 5 to 15 parts of carbon to 1 part of nitrogen , but 10: 1 is a reasonable average for the predominant aerobic of fractions resistant to further decomposition can modify the C:N equilibrium value of humus. Such C: N ratio of soils can vary with the climates i.e. rainfall, temperature etc. the C:N ratio is generally lower in warmer (arid soil conditions) regions than that of cooler

ones (humid soil conditions) inspite of having the same rainfall under both the soil conditions. The ratio is also narrower for sub soils as compared to surface soil horizons.

Ratio in plants and microbes:

The carbon and nitrogen (C:N) ratio in plant material is variable and ranges from 20:1 to 30:1 to legumes and farm yard manure to as high as 100:1 in certain straw residues. On the other hand C: N ratio of the bodies of micro organisms is not only more constant but much narrower between 4:1 and 9:1. Bacterial tissue in general is somewhat richer in protein than fungi and consequently has a narrow C: N ratio.

Therefore, it is usually found that most of the applied fresh organic materials in soils carry large amounts of carbon with relatively very small amounts of total nitrogen .As a result , the value C:N ratio for soils are in between those of higher plants and the microbes.

Implications of the C: N ratio:

The C: N ratio in soil organic matter is important for two major reasons:

The keen competition for available nitrogen results when organic residues of high C: N ratio are added to soils and because this C: N (10:1) is relatively constant in soils, the maintenance of carbon and hence soil organic matter is dependent to no small degree on the level of soil nitrogen. So the C: N ratio obviously has practical implications on the availability of nitrogen in soils as well as in plants. As for example, large amount of fresh organic materials having wide C: N ratios (50:1) are incorporated into the soil under favourable soil conditions for decomposition. A rapid change will found. The heterotrophic micro organisms – bacteria, fungi and actinomycetes become active and increases their population with the production of large amounts of CO_2. Under these conditions, nitrate nitrogen (NO_3-N) disappears from the soil because of the urgent needs by the

micro organisms, and for the time being, little or no nitrogen is available to plants. As the decomposition precedes, the C: N ratio on the organic materials decreases with the loss of carbon and conservation of nitrogen.

Reasons for the stabilization of C: N ration to a constant value

As the decay process proceeds, both carbon and nitrogen are now subject to loss as CO_2 and nitrates respectively. It is only a question of time until their percentage rate of disappearance from the soil becomes more or less the same, *i.e*, the percentage of the total carbon being lost. At this point the C: N ratio becomes more or less constant 10:1 to 12:1 always being somewhat greater than that of the ratio in microbial tissue.

C: N ratio and the level of organic matter

Since carbon and nitrogen are reduced to almost a definite ratio, the amount of soil nitrogen largely determines the amount of organic carbon present when stabilization occurs. Thus, the greater the amount of nitrogen present in the original organic material, the greater will be the possibility of an accumulation of organically bound carbon. Since a definite ratio (1:17) exists between the organic carbon and the soil humus, the amount of organic matter to be maintained in any soil is largely conditional on the amount of organic nitrogen present. The ratio between nitrogen and organic matter is thus constant (organic matter: nitrogen, 20; 1 for most soils).

Soil biology

Soil biology is the study of microbial and faunal activity and ecology in soil. These organisms include earthworms, nematodes, protozoa, fungi and bacteria. Soil biology plays a vital role in determining many soil characteristics yet, being a relatively new science, much remains unknown about soil biology and about how the nature of soil is affected.

Scope

> - Modelling of biological processes and population dynamics.
> - Soil biology, physics and chemistry: occurrence of physiochemical parameters and surface properties on biological processes and population behavior.
> - Population biology and molecular ecology: methodological developnment and contribution to study microbial and faunal populations; diversity and population dynamics; genetics transfers, influence of environmental factors.
> - Community ecology and functioning processes: interactions between organisms and mineral or organic compounds ; involvement of such interactions in soil pathogenecity; transformation of mineral and organic compounds,cycling of elements ; soil structuration

Complementary disciplinary approaches are necessarily utilized which involve molecular biology, genetics, ecophysiology, biogeography, ecology, soil processes, organic matter, nutrient dynamics and land scape ecology.

Biomass

Biomass, as a renewable energy source, refers to living and recently dead biological material that can be used as fuel or for industrial production. In this context, biomass refers to plant matter grown to generate electricity or produce. For example, trash such as dead trees and branches, yard clippings and wood chips are biofuel, and it also includes plant or animal matter used for production of fibers, chemicals or heat. Biomass may also include biodegradable wastes that can be burnt as fuel. It excludes organic material which has been transformed by geological processes into substances such ascoal or petroleum.

Industrial biomass can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, and a variety of tree species, ranging from eucalyptus to oil palm (palm oil). The particular plant used is usually not important to the end products, but it does affect the processing of the raw material. Production of biomass is a growing industry as interest in sustainable fuel sources is growing.
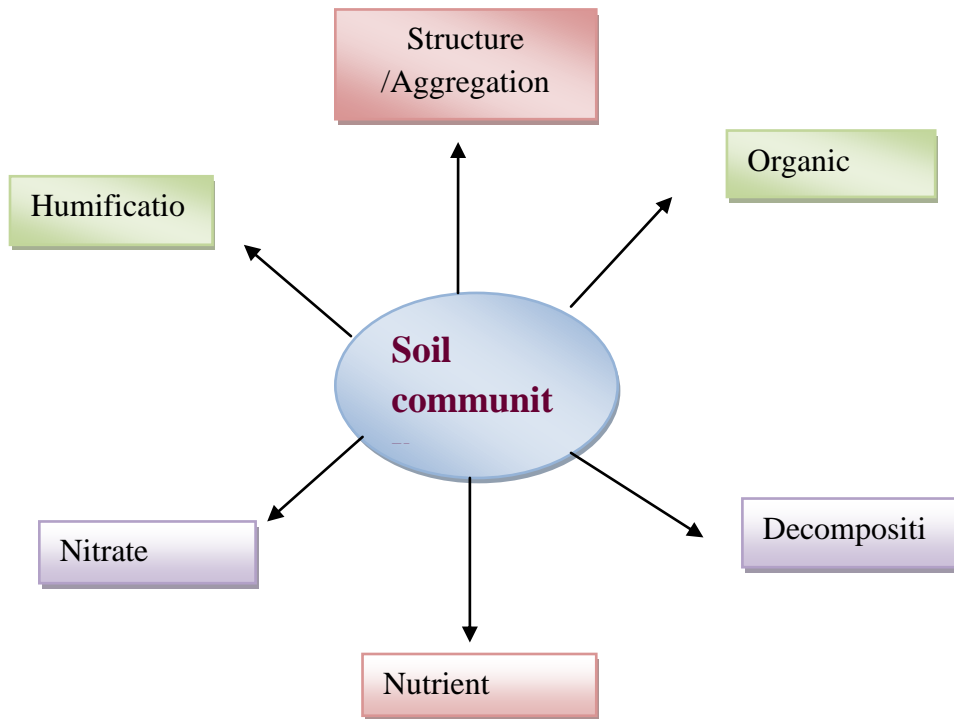
Although fossil fuels have their origin in ancient biomass, they are not considered biomass by the generally accepted definition because they contain carbon that has been "out" of the carbon cycle for a very long time. Their combustion therefore disturbs the carbon dioxide content in the atmosphere. Plastics from biomass, like some recently developed to dissolve in seawater, are made the same way as petroleum-based plastics. These plastics are actually cheaper to manufacture and meet or exceed most performance standards, but they lack the same water resistance or longevity as conventional plastics.

Soil organisms – Their beneficial and harmful roles.

Role of soil organisms are:

- ❖ Soil N utilization by plants

- ❖ Dead organic matters decomposed

- ❖ Nutrient transformation

- ❖ Physical and chemical properties of soil.

- ❖ The CO_2 content

- ❖ Soil formation

Soil organisms are involved in nearly every aspect of soil quality

Structure /Aggregation

Organic

Humificatio

Soil communit

Nitrate

Decompositi

Nutrient

Soil organism

```
Soil organism
├── Soil
│   ├── Soil Macro flora
│   └── Soil Micro
│       ├── Bacteria
│       │   ├── Heterotropic
│       │   │   ├── Symbiotic
│       │   │   ├── Non symbiotic
│       │   │   ├── Ammonifiar
│       │   │   └── Cellulose Decomposer
│       │   └── Autotropic
│       │       ├── Nitrite
│       │       ├── Nitrate
│       │       ├── Denitrifer
│       │       └── S Oxidiser
│       ├── Actinomycete
│       ├── Fungi
│       │   ├── Moida
│       │   ├── Yeast
│       │   └── Mushroom
│       │       └── Cellulose, protein, lignin decomposers humus formers
│       └── Algae
│           ├── BGA
│           ├── GA
│           ├── YGA
│           └── Di atoms
└── Soil Fauna
    ├── Macro
    │   ├── Earthworms
    │   ├── Moles
    │   ├── Ants
    │   └── Others
    └── Micro
        ├── Protozoa
        ├── Nematode
        └── Rotrifier
```

Micro organisms are also classified based on their ability to grow in the presence or absence of molecular oxygen as aerobes and anaerobes.

Based on temperature

❖ Psychrophiles

- ❖ Mesophiles

- ❖ Thermophiles

- ❖ Micro organisms are also classified based on morphology, shape, size, biochemical transformations they carryout.

- ❖ Soil organism are classified broadly soil flora and soil fauna.

- ❖ These again may be subdivided into micro and macro.

- ❖ Micro flora again is classified into Bacteria, actinomycetes, fungi and Algae.

Bacteria:

- ❖ Single celled.

- ❖ The cells may be rod shaped or spherical.

- ❖ The rods may be about 1 µm wide and up to 3 µm long and about 2 µm in diameter.

- ❖ Bacteria are the most abundant group of micro organism in the soil.

- ❖ Their population in the soil is not uniform.
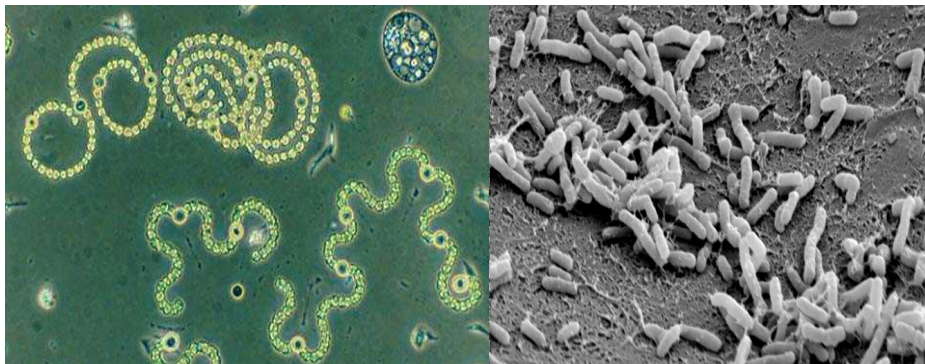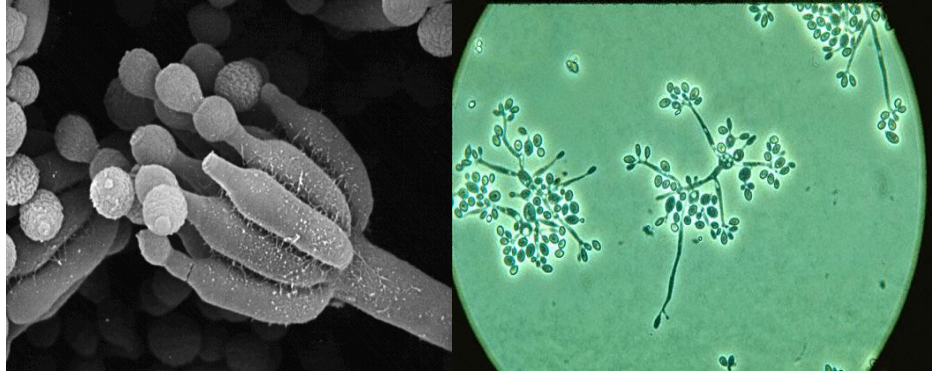
Classification of bacteria

> Based on O_2 requirement

Aerobic and anaerobic

Based on temperature

> Facultative

> Psychrophiles

> Mesophiles

> Theromophile

Based on their food preparation

❖ Autotroph

❖ Heterotroph

❖ Chemoautotroph

❖ Obligate chemoautotrophs: Prefer specific substrates

❖ Nitrobacter – Nitrite as substrate

❖ Nitrosomonas – Ammonia as substrate

❖ Thiobacillus - Converts sulphur compounds to SO4

❖ Ferrobacillus – Converts ferrous to ferric

Based on symbiotic relationship:

Symbiotic N fixers:

❖ Associated with a host plant.

❖ Both the host and the bacteria get the benefit.

❖ Fix atmospheric N.

Non symbiotic N fixers:

❖ Bacteria present without the association of a plant.

❖ But fix atmospheric N.

❖ Symbiotic, non symbiotic and cellulose decomposers come under Heterotrophs

❖ Nitrifiers, denitrifiers Nitrate formers and sulphur oxidizers are autotrophs.

Role of Bacteria:

❖ Bacteria carryout the decomposition of organic matter and synthesis of humus

❖ Enzymatic transformations are carried out by bacteria

❖ Bacteria oxidize or reduce many chemical reactions such as N fixation, sulphur oxidation nitrification etc.

Conditions affecting the growth of bacteria:

❖ Oxygen

❖ Moisture

❖ Temperature

❖ Organic matter

- ❖ Exch.Ca and pH
- ❖ High Ca concentration and pH 6.0-8.0 optimum. Some bacteria function at pH <3.0.
- ❖ Exchangeable Ca is more important than pH . The bacterial population may be 10-8 - 10-9/gram.
- ❖ The biomass may vary from 450-4500 kg/ha.

Actinomycetes

- ❖ Unicellular like bacteria. Have same size as bacteria.
- ❖ Filamentous and profusely branched.
- ❖ Mycelial threads are smaller than those of fungi.
- ❖ No nuclear membrane as in bacteria.
- ❖ Also called as filamentous.
- ❖ Sensitive to acid soils.
- ❖ Potato scab a disease due to actinomycetes can be controlled by lowering the soil pH by applying sulphur.
- ❖ Heterotrophic optimum temperature 25-30°C, pH 6.5 – 8.0.
- ❖ Actionomycetes are important for organic matter decomposition.
- ❖ Chitin and phospholipids are reduced to simple compounds.
- ❖ The aroma of freshly ploughed land at certain times of the year is probably due to actinomycetes as well as certain molds.
- ❖ Actinomycete population in soil exceed all other organisms except bacteria.
- ❖ Their proportion increases with soil depth. Their population and biomass are almost equal to that of bacteria.

Fungi:

- ➢ Soil fungi may be parasitic or saprophytic.

- They possess filamentous mycelium composed of individual hyphae which are 5-20 μm in diameter and several centimeters in length.
- Most fungi are heterotrophic and hence they depend on the organic matter content of the soil.
- They are dominant in acid soils some can tolerate a pH upto 9.0.
- Fungi are strictly aerobic.
- Fungi are classified into phycomycetes, Ascomycets, Basidiomycetes and fungi imperfecti.

Soil micro organism
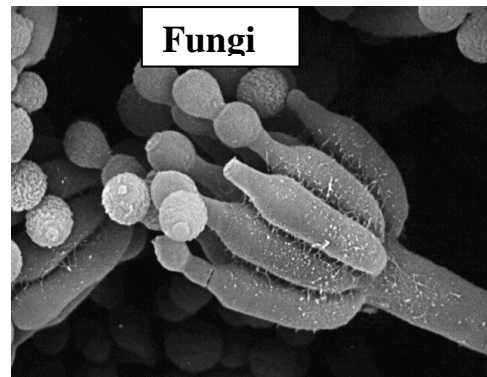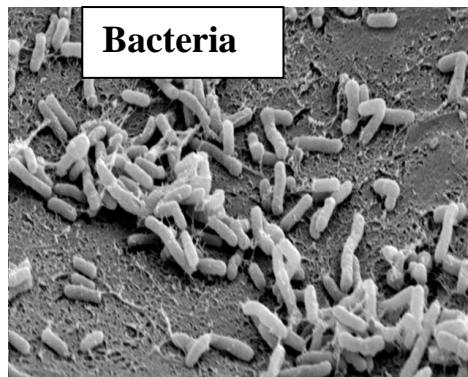
Fungi may also may be classificied as molds:

Molds,Yeast,Mushrooms

- **Molds:** Molds are filamentous microscopic molds develop vigorously in all types of soils
- In acid forest soils - decomposing organic matter.
- The common genera - mucor, Fusarium and Aspergillus.

- Their average population - 10-200 billion / m^2.
- In humus formation and aggregate stabilization molds are more important than bacteria.

❖ They continue to decompose complex organic substances after bacteria and actinomycetes have stopped function.

Yeast

❖ Yeast is a group of fungi which exist as an unicellular organism.

❖ Reproduce by fission or budding.

❖ Used as food supplement and also for the production of alcoholic beverages.

❖ Yeast is not common in soils.

❖ They produce several plant diseases.

Mushroom:

❖ Mushrooms are present in forests and grasslands where there are ample moisture and organic residues.

❖ Some mushrooms are edible.

❖ Mushrooms are also not common in cultivated soils.

❖ Their fruiting body is above the ground.

Algae

❖ Algae are filamentous u-10µm in diameter. Population in soil around 1-10 billion / m2.

❖ Their mass in soil may be 50-600 kg/ha of furrow slice.

❖ Algae are photo autotrophs

❖ They are divided into 4 general groups. Blue green,Green, yellow green and diatoms.

❖ Blue green algae are numerous in rice soils

❖ Blue green algae growing within the leaves of aquatic Fern.

❖ Azolla can also fix atmospheric N.

Microorganism

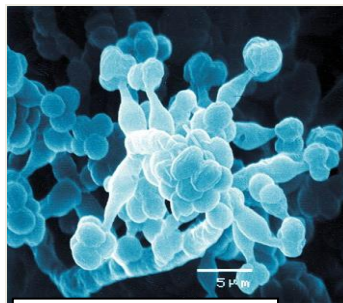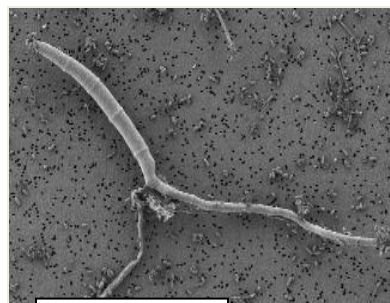## Bacteria
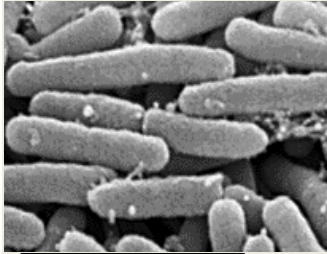
Pseudomonas
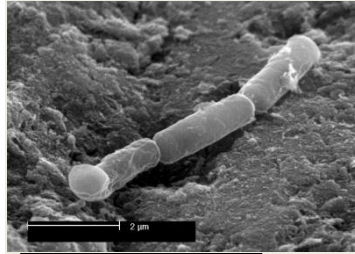
Arthrobacter
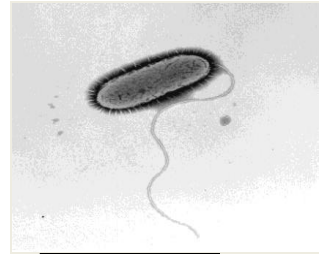
Bacillus

Fungi
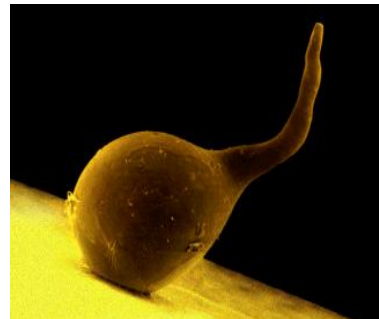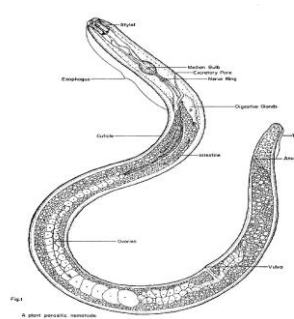

Aspergillus

Trichoderma

Fusarium

Nematodes

SOIL FAUNA - Macro Fauna-   Earthworm

❖ About 1800 species of earthworms are known.

❖ There are 293 species in the genus pheretima. The common earthworms found in India are pheretima posthuma, P.elongater Lampita mautritii etc.

❖ Their population may vary from 1,25000 to 1000000/ha.

❖ They are active in monsoon season. The worms prefer organic matter as their food.

❖ They also consume larvae of small animals and bacteria mixed with earth.

❖ They ingest soil in large quantities which pass through the alimentary canal which has many grinder gizzard

❖ The ingested soil and organic matter are ejected in the form of castings.

❖ They make crores of burrows which make the soil porous.

❖ Earth worms prefer warm (21°C) well aerated soils. The casts have low C:N ratio.

❖ The burrows left in the soil increase aeration and drainage. They increase the size and stability of soil aggregates.

❖ The factors influencing the earth worm population and activity in the soil are availability of organic matter, soil pH, temperature and soil moisture.

❖ The biomass or live weight of earth worm may range from 110-1100 kg/ha.

Soil Animalia

Termite

Pseudo Scorpion

Earthworm

Centipede

Snail

Vole

Ants

- ❖ They have local effects. Some have the ability to break down woody materials.
- ❖ Some ants produce mounds and some have under ground nests.
- ❖ There is considerable turn over of the soil due to these.
- ❖ The ants and termites can modify soil structure and till the soil.

Nematodes

- ❖ Commonly called as thread worms or eelworms. Present in almost all soils.
- ❖ They are microscopic most of the nematodes are Saprophytes
- ❖ They may feed on other nematodes, bacteria, algae and protozoa.
- ❖ The genus Heterodera can infest the roots of all plants.
- ❖ Heavy infestation may cause severe damage in vegetable crops.

Protozoa

- ❖ Single celled, larger than bacteria and are more complex.

- Soil protozoa may be amoeba, celiates and flagellates.
- Soils have more than 250 species. Live weight in soil ranges from 15-175 kg/ha.
- They cause a number of serious diseases in animals and plants.
- They thrive well in moist and well drained soils and on the surface.
- They are not abundant in soils to play a major role in the organic matter decomposition and nutrient release.

Soil Macrofauna

| Nematodes | Mites | Springtail |

Rotifers:

- About 100 species have been studied. They thrive under moist and swampy lands.
- Activities are confined to peat bogs and wet areas of mineral soils.

Roots of higher plants

- Since the roots grow and die in the soil they supply food and energy for the soil microflora and fauna.
- They physically modify the soil as they push through cracks and make new openings.
- By removing moisture from the soil the plant roots create physical stress that stimulates soil aggregation.
- Plant roots exudates several chemicals which stabilize the soil structure.
- They decay and supply the material for the synthesis of humus.

❖ Roots constitute about 15-40% that of above ground crop.

Mycorrhizae

➢ The symbiotic association between numerous fungi and the roots of higher plants is called mycorrhizae which means fungus roots".

➢ This association increases the availability of several essential nutrients to plants especially from low fertile soils

➢ This association provides sugars and other organic exudates from higher plants as food to the fungi.

➢ The fungi in turn provide an enhanced availability of several essential nutrients including P, zn, Cu, Ca, Mg, Mn and Fe

➢ There are 2 types of mycorrhizal associations. Ecto mycorrhizae and endo mycorrhizae

➢ The vesicular asbuscular mycorrhizae (VAM) is the most important endo mycorrhizae.

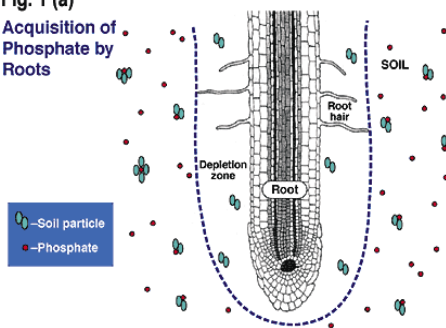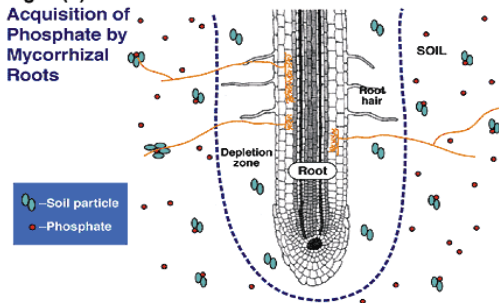Fig. 1 (a) Acquisition of Phosphate by Roots

Fig. 1 (b) Acquisition of Phosphate by Mycorrhizal Roots

Injurious effects of soil organisms on higher plants.

❖ Some rodents and moles may severely damage crops.

❖ Snails and slugs in some climates are dreaded pests.

❖ Ants transmit aphids which are major pests. Nematodes infest roots of all plants which in severer cases result in crop failure.

❖ Microflora exerts the most devastating effect on plants.

❖ Fungi are responsible for most soil borne diseases wilt, damping off, root rots and club root of cabbage are caused by fungi.

❖ Actinomycetes and bacteria also cause several diseases.

❖ Some bacteria are involved in the denitrification of NO_3 to, elemental N which is a loss.

❖ Beneficial effects include N fixation, increased nutrient availability, improvement in soil physical properties oxidation and reduction of Fe and Mn.

❖ Oxidation of S. Conversion of ammonia to Nitrate form.

SSAC 121 - INTRODUCTION TO SOIL SCIENCE (2+1)

1. Soil – Pedological and edaphological concepts –

2. Origin of the earth – Earth's crust – Composition -

3. Rocks and minerals –

4. Weathering –

5. Soil formation factors and processes – Components of soils –

6. Soil profile –

7. Soil physical properties – Soil texture – Textural classes – Particle size analysis –

8. Soil structure – Classification –

9. Soil aggregates – significance – Soil consistency – Soil crusting – Bulk density and particle density of soils & porosity - their significance and manipulation –

10. Soil compaction – Soil Colour – Soil water –

11. Retention and potentials – Soil moisture constants –

12. Movement of soil water – Infiltration, percolation, permeability – Drainage – Methods of determination of soil moisture –

13. Thermal properties of soils – Soil temperature – Soil air – Gaseous exchange – Influence of soil temperature and air on plant growth –

14. Soil colloids – Properties, nature, types and significance –

15. Layer silicate clays – their genesis and sources of charges –

16. Adsorption of ions–Ion exchange–CEC& AEC – Factors influencing ion exchange - Significance.

17. Soil organic matter – Composition – Decomposability –

18. Humus – Fractionation of organic matter –

19. Carbon cycle – C: N ratio. Soil biology – Biomass – Soil organisms – Their beneficial and harmful roles.