4. Soil Chemistry

The word **soil** is derived from a Latin word '*solum*' meaning earthy material in which plants grow. The science which deals with the study of soil is called **soil science, pedology** (*pedos*-earth), or **edaphology** (*edaphos*–soil). The study of soil is helpful in practices of agriculture, horticulture, forestry, etc., such as cultivation, irrigation, artificial drainage and use of fertilizers. Pedology is also useful in sciences like geology, petrology, minerology, palaeobotany and palaezoology.

A fully developed or **mature soil** is that state of soil that has assumed the profile features (*i.e.*, succession of natural layers), characteristic of predominant soils on the smooth uplands within the general climate and botanical regions in which is found.

ORIGIN AND FORMATION OF SOIL

Soil is a stratified mixture of inorganic and organic materials, both of which are decomposition products. The mineral constituents of soil are derived from some parent material, the **soil forming rocks** by fragmentation or weathering, while, organic components of soil are formed either by decomposition (or transformation) of dead remains of plants or animals or through metabolic activities of living organisms present in the soil. Before discussing the soil-forming processes, a brief discussion about the nature of soil forming rocks will be highly desirable.

CHEMISTRY OF MINERALS IN SOIL-FORMATION

Rocks are the chemical mixture of numerous kinds of minerals. The chemical nature of certain most common and abundant minerals of soil forming rocks has been listed in below table.

Table

Chemical composition of some common soil minerals

Minerals	Chemical Constituents
A. Sand and silt	
1. Quartz or silica	SiO_2
2. Feldspars	
a. Orthoclase	$K_2Al_2Si_6O_{16}$
b. Calcium feldespar	$CaAl_2Si_2O_3$
3. Micas	
a. Muscovite	$K(OH)_2Al_2(AlSi_3)O_{10}$
b. Biotite	K, Mg, Fe, Al silicate
4. Pyroxene	(Mg, Fe) SiO_3
5. Amphibole	$(Mg, Fe)_7 (Si_4O_{11})_2 (OH)_2$
6. Calcite; magnesite; and dolomite	$CaCO_3$, $MgCO_3$; and ($CaCO_3$, $MgCO_3$)
7. Iron oxides	
a. Haematite	Fe_2O_3
b. Magnetite	Fe_2O_4
B. Clay	
1. Kaolin	Al_2O_3, $2SiO_3$, $2H_2O$

Besides these tabulated minerals following minerals occur in low percentage in soil-forming rocks—Toarmalive (Boron silicas or Aluminium with alkali metals and Iron and Magnesium), Rutile (Titanium oxides), Zircon (Zirconium oxide), and Gauconite (hydrated silicon of iron and potassium).

Process of Soil-formation

The processes which are involved in the formation of mature soil can be studied under following heads:

A. Weathering of Soil-forming Rocks : Soil formation is started by **disintegration** or **weathering** of parent rocks by some physical, chemical and/or biological agents, because of which the soil-forming rocks are broken down in small particles called **regoliths**. Regoliths are the basic materials which under the influence of various other pedogenic processes finally develop into mature soil.

(*a*) **Physical weathering :** The physical weathering agents are primarily climatic in character, exerting a mechanical effect on the substratum with the result that fragments are comminuted into progressively decreasing particle sizes (*i.e.*, regoliths). Such climatic weathering of rocks does not cause any chemical transformation of rock-minerals and commonly occurs in deserts, in high altitudes, in high latitudes, and in localities with marked topographic relief and sparse vegetation cover. The agents which are involved in climatic weathering of rocks, are **temperature, water, ice, gravity** and **wind.**

The **temperature** causes break down of those rocks which have heterogeneous structure, due to the fact of differential expansion and contraction coefficient of materials composing the rocks. Minerals composing the rocks have got different degrees of expansion. The different expansion and contraction of different minerals of rocks set up internal tensions and produce cracks in the rock and consequently, the rocks weather into finer particles.

In its liquid state **water** causes mechanical weathering of rocks by following methods : (*i*) **Rain water**—Natural water falling either in the form of rain drops or hail storm on the surface of rock with beating effect bring about abrasion of massive rocks into smaller particles. (*ii*) **Torrent water**—Rapidly flowing water rolls the heavy rocks masses such as rock boulders along the bottom of stream and grinds them into finer particles. (*iii*) **Wave action**—The wave actions are most effective in sea shores. The rapidly striking water waves dislocate solid particles of varying diameters from sea shore rock and the debris is then settled at the sea bottom to form **marine soil**. Water also acts as a mechanical carrier.

In its freezing and ice-melting states water causes rock-weathering by **frost action** and **glacier formation**. Water in the form of frost or ice, is an extremely effective physical weathering agent of rocks. It steeps into rock crevices, freezes due to sudden fall of temperature of rocks, expands about nine per cent of its original volume, exerts a pressure of approximately 150 ton/ft^2 and eventually cracks the rocks into smaller pieces. Likewise, in summer when ice at mountain tops starts melting and glaciers move downwardly on the slope, then, during the glacier movement, the rock over which they move is gradually worn down to produce fine particles which are deposited as **drift** or **till**, when glacier finally retreats.

Gravitation weathering action is most effectively demonstrated by land slides and rock slippages caused by earth quakes and faulting during which the rock is fragmented by abrasion and the forces of impact. Lastly, the rapid stormy **wind** carrying suspended sand particles causes the abrasion of exposed rock. It acts like a mechanical carrier in moving the particles over the surface of earth as **dunes** or **drifts** and in transporting large quantities of fine suspended particles long distances.

(*b*) **Chemical weathering :** The physical disintegration produces a greater surface area of rock exposed to the **chemical weathering**, which occurs simultaneously with physical weathering and continues much beyond that. During chemical weathering, a chemical transformation or decomposition of parental mineral materials into new mineral complexes or secondary products occurs. Because chemical weathering requires the presence of moisture and air as essential factors, therefore, chemical weathering is not effective in deserts. It includes following reactions :

1. Solution : Water is the most potent chemical weathering agent in most kinds of rocks through its solvent action. Solution helps in the removal of water-soluble minerals of weathered rocks. For example, soluble rocks like gypsum, limestone and those with a calcareous content get weathered by the solvent action of water which increases in the presence of CO_2 and organic acids formed by decay of organic remains of plants and animals. The solution of these minerals may become absorbed on the surface of negatively charged colloidal particles or are removed by leaching.

2. Hydrolysis : Hydrolysis involves an exchange of constituent parts between water and minerals such as the chemical union of water with strong bases producing hydroxides of iron, magnesium, calcium, aluminium, etc. Hydrolysis mostly acts in combination with other reaction such as oxidation/ reduction or carbonation as in the production of secondary kaolinitic clay minerals from primary orthoclase. The release of calcium, magnesium, potassium, sodium, and silicates into the soil solution, as a result of hydrolysis, enhances the availability of these ions to plants.

3. Oxidation : Oxidation results when oxygen is added to minerals to produce oxides which when dissolve in water weaken the rock and bring about weathering. It occurs in well-aerated, well drained soil. Because iron is especially reactive with water and oxygen, iron-bearing minerals are prone to rapid decomposition. Further, oxides and sulphides of Iron, Aluminium, Manganese, etc., are easily oxidised and cause into the weathering of rocks.

4. Reduction : Reduction occurs in wet, badly drained, poorly aerated sites such as deep zones of earth crust. It means removal of oxygen from minerals. For example, red ferric oxide may be reduced to the gray ferrous state.

5. Carbonation : In carbonation water and carbon dioxide combine to form carbonic acid which reacts with hydroxides of calcium, magnesium and other minerals of rock to form carbonates and bicarbonates. The slightly soluble carbonates of these minerals either accumulate deeper in the rock material or are carried away, depending upon the amount of water passing through. The solubility of these carbonates, leaves gap in rocks and consequently makes them weak enough for weathering process.

6. Hydration : During hydration water molecules become chemically attached to particular rock mineral, due to which the volume of parental material increases and hydrated minerals become soft and more readily weatherable.

(c) Biological Weathering : Though the surface of bare rock is unsuitable for many forms of life, even then a number of micro-organisms (bacteria, protozoans, fungi, nematodes, etc.), lichens and mosses can gain a foothold. These early colonizers transform the rock into a dynamic system, storing energy and synthesizing organic material. Their activities alter the mineral composition as well as the physical structure of the rock. For example, lichens are present in the initial stages of biological succession and their growth may cause cracking or flaking, exposing greater area of rock to further weathering. These elements are combined with organic complexes, and eventually return to the developing soil when the vegetation decomposes.

Products of Weathering

The soil which is formed by weathering of soil-forming rocks is called **embryonic** or **primary soil**. It may mature into following types of soils :

(i) **Residual soil or Sedimentary Soil :** This is the mature soil lying immediately over the parent rocks.

(ii) **Skeletal Soil or Immature Soil :** This is only partly weathered material in which maturation has not occurred.

(iii) **Secondary Soil or Transported Soil :** The transported soils are those in which the weathered parent material has been shifted to different places by the agency of glacier (**moraine soils, glacial drift** and **till**), streams and rivers (**alluvial soil**), the gravitational forces as land slides (**colluvial soil**), wind (**aeolian soil**), sand storms (**sand dunes**), standing water and wave action (**lacustrine soil**) and the oceanic waves (**marine soil**).

On the basis of profile development, the soils are also classified into zonal, intrazonal and azonal soils. Some soils are called **zonal**, because climate is the foremost control over the process of soil formation and fully developed or mature soils of a given climatic zone tend to the very similar. **Intrazonal soils** result from local geological conditions that preclude the normal pattern of soil formation. One type of intrazonal soils are **hydromorphic soils**, which are formed in areas where the soil becomes waterlogged during formation. Waterlogged soils are not aerated, and the normal aerobic breakdown of detritus cannot take place; thus hydromorphic soils are rich in organic materials. A **halomorphic** is another type of intrazonal soil and it is formed in arid and semiarid regions due to waterlogging. Its chief characteristic is the high salt contents.