B·Sc Sem VI.

Paper XV

Q. What is Soil Profile? Write an account on the formation of Soil.

Q. Write short notes on

(i) Weathering

~~(ii) Pedogenesis~~

Formation (Origin) of Soil

The whole process of soil formation is generally divided into two stages (i) **weathering** — breakdown of bigger rocks into fine, smaller mineral particles, and (ii) **soil development** or **pedogenesis**— modification of the mineral matter through interaction between biological, topographic and climatic effects, which ultimately lead to the development of any of a great variety of potential soil types.

Weathering process

Bare rock surfaces are exposed to various types of physical, chemical and biological processes which lead to **physical** and **chemical disruption** of their components. Physical processes of weathering include action of water, temperature, glaciers, gravity etc., which cause weathering of rocks through processes as wetting-drying, heating-cooling, freezing, glaciation, solution and sand blast etc. The chemical processes of weathering include hydration, hydrolysis, oxidation-reduction, carbonation, chelation etc., which are due to chemical composition of rocks, chemicals in the atmosphere, as well as those produced as a result of living organisms, such as lichens, fungi, bacteria, blue-green algae, bryophytes etc.

In biological processes lichens are able to extract nutrients from bare rocks. Lichens, fungi and bacteria on rock surface retain the water for a long period during which the chemical processes can proceed, splitting the rock alumino-silicates by hydrolysis and carbonation into the simpler clay alumino-ilicates. Algal partner of lichen through photosynthesis, increases the amount of available organic matter at rock surface. Various exudates from these organisms and the respiratory carbon dioxide accelerate the process of weathering, as some of the lichen acids (organic acids) generally dissolve mineral components. Rock weathering is, therefore, for a short time, a physico-chemical process but soon it becomes biogenic, increasing in its rate.

The weathering processes are physical as well as chemical. Physical processes may be of the following types:

Wetting-drying

It is the disruption of layer lattice minerals which swell on wetting.

Heating-cooling

It is disruption of heterogeneous crystalline rocks in which inclusions have differential coefficients of thermal expansion. It occurs particularly in dry climates, where due to sun heating large boulders flake at surfaces.

Freezing

This is the disruption of porous, lamellar or vesicular rocks by frost shatter due to expansion of water during freezing.

Glaciation

Larger masses of snow and ice-glaciers, while falling may cause physical erosi rocks through grinding process.

Solution

Some more mobile components of rocks, such as calcium chlorides, sulphates etc., are simply removed by agents like water.

Sand blast

In arid, desert conditions the rocks are disrupted by physical action of wind, sand etc.

Chemical processes include the following:

Hydration

As a result of taking water, due to reversible change of haematite to limonite ($Fe_2O_3 \rightleftharpoons Fe_2O_3 3H_2O$), the rock swells. This swelling causes the disruption of sandstones etc.

Hydrolysis

In this process, components like alumino-silicates of rock breakdown, during which elements such as potassium and surplus silicon are washed out which give rise to simpler mineral matter like clay alumino-silicates. For example, hydrolysis of orthoclase ($K_2Al_2Si_6O_{16}$) to kaolinite (Al_2O_3. $2SiO_2$. $2H_2O$).

Oxidation-reduction

Some oxidation-reduction chemical reactions, such as reversible change of Fe^{3+} to Fe^{2+} cause disruption of rocks, because Fe^{2+} is more soluble than Fe^{3+}.

Carbonation

Some chemicals, produced in the atmosphere and those during the metabolism of microorganisms bring about carbonation. As for example reversible change of $CaCO_3$ to $Ca(HCO_3)_2$ leads to solution loss of limestone or disruption of $CaCO_3$ cemented rocks as the hydrogen carbonate is more soluble than the carbonate.

Chelation

Some chemical exudates, produced through biochemical activity of microorganisms like lichens, bacteria, etc., are able to dissolve out mineral components of the rocks. These metals dissolved with organic products of microbial activity are known as **chelates**. For example, acids produced by lichens and bacteria have strong chelating properties.

Pedogenesis

During weathering, the rocks are broken down into smaller particles. But this is not the true soil and plants cannot grow in this matter. The weathered material undergoes further a number of changes, which is a complex process, known as **pedogenesis** or soil development. Whereas in weathering, mostly physical and chemical factors are involved, pedogenesis is largely a biological phenomenon. During this phenomenon, living organisms such as lichens, bacteria, fungi, algae, micro-arthropods, molluscs etc., as a result of secretion of organic acids, enzymes, CO_2 production and addition of organic matter after their death, bring about geochemical, biochemical and biophysical processes. Due to all this the crusts of weathered rock debris are converted to true soils consisting of a complex mineral matrix in association with a variety of organic compounds, and a rich microorganism population.

Thus during pedogenesis, there are added various organic compounds, dead organic matter and living organisms etc. to the mineral matter. As a result of mineralization of dead organic matter, the minerals are then gradually added to different layers of developing soil. This soil, when fully developed can be seen having a number of layers-horizons of a soil, known as **soil profile,** which will be described later in this chapter.

Factors in Soil Formation

We have seen above that during the whole sequence of soil formation *i.e.*, weathering followed by pedobiogenesis, many factors are involved. The nature and type of soil forming at a particular place is largely governed by **five** soil forming factors: (i) bedrock or the parent material, (ii) local climate, (iii) plants and animals *i.e.*, organisms,(iv) elevation, and (v) the relief *i.e.*, topography and the time over which soil has developed. Out of these, the parent material and the climate are the two most important factors on a large regional scale. Joffe (1936) recognised the climatic and biological factors as **active** factors, whereas the parent matter, topography and the time as **passive** factors of soil formation.

Parent material

Physical constitution of parent material influences the aeration, leaching rate and texture of the developing soil, whereas chemical composition influences the chemical characteristics of soil. The rates of physical and chemical weathering of parent rocks are different depending upon their structure, degree of hardness and the climate. Some rocks weather easily and other decay at a slower rate. Such characteristics make rocks like shale, a better soil-former than the limestone which is a poor soil-former. Faster the rate of weathering as in hot and wet climate, faster is the rate of soil formation.

Topography and time

It influences soil formation through drainage and retention of water. Soil aeration is also governed by topography which affect solifluction and insolation of chemicals. Local site (topography) affect soil deposition, degree of its erosion and the rate of run-off of water. Only a thin and coarse soil is left on steep rocks on which it is formed. That's why this is called **residual soil.** The elevation and nature of slope also influence the rate of weathering and drainage of water. Most soil from slope is carried away by several agents. Such soils are called **transported soils. Mature soils** are developed over a long time reflecting the influence of organic matter and climate. They have well-developed soil profile. It tells us the influence of time factor.

Climate

Rainfall, temperature, humidity/evaporation and wind are the climatic factors that strongly influence soil formation. Rainfall determines the direction of solute translocation according to precipitation/evaporation (P/E) ratio. Rainfall in combination with other factors also determines depth of water table, that would affect the level of capillary water and aeration. Temperature governs P/E ratio. Through its influence on physico-chemical processes, it also controls the rate of organic turnover in soil. Humidity/evaporation interaction influences rainfall and amount of water movement. Thus climate of an area is a major factor in soil formation. It tends to reduce differences caused by the parent material. That is why two different parent materials may develop the same soil in one type of climate regime. Likewise, the same parent material may produce different types of soil in different types of climates. Crystalline granites produce laterite soil in relatively moist parts of the monsoonal region and non-lateritic towards its drier margins. Hot summer and low-rainfall develops black soil as found in some districts of Tamil Nadu, irrespective of the parent rock.

Organisms

Plants, animals and microbes exert the so-called **biosphere effects** on soil formation. Thus, **phytosphere** (direct plant activities such as secretion of organic acids, enzymes, respiratory CO_2; input of organic matter after death; micrometerological influence of vegetation cover), **zoosphere** (direct interaction between primary production and consumption by animals with consequent effect on input of organic matter to the soil; soil-dwelling micro-arthropods, molluscs, lumbricids etc. have a direct influence on organic matter turnover and incorporation) as well as **microorganisms** (bacteria, fungi etc. involved in geochemical, biochemical and biophysical process of pedogenesis) are important factors in soil formation.

Soil Profile

As pointed out earlier, due to interaction of various factors influencing the process of pedogenesis, there develop a variety of soil types. It depends upon the nature of parent matter and other factors-climatic, topographic and biological etc., which type of the soil will develop in any area. Different types of soil may be defined by the nature of the mineral matrix, the vertical distribution of organic matter and the movement and redeposition of various inorganic components. Soils are described and identified by reference to their profiles. Soil profile is "the sequence and nature of the horizons (layers) superimposed one above the other and exposed in a pit-section dug through the soil mantle." The smallest three-dimensional volume of a soil needed to give full representation of horizontal variability of soil is termed a **pedon**. A **soil horizon** is defined as "a layer which is approximately parallel to the soil surface and that has properties produced by soil forming processes but that are unlike those of adjoining layers." Horizons may usually be identified visually in the field but they also have chemical and physical characteristics which can be diagnosed in the laboratory.

Although, profiles of different types of soil differ markedly in respect of their physico-chemical and biological properties, Figure 3.1 shows a hypothetical soil profile with its principal horizons. It is not always true that all these horizons are always present in each profile.

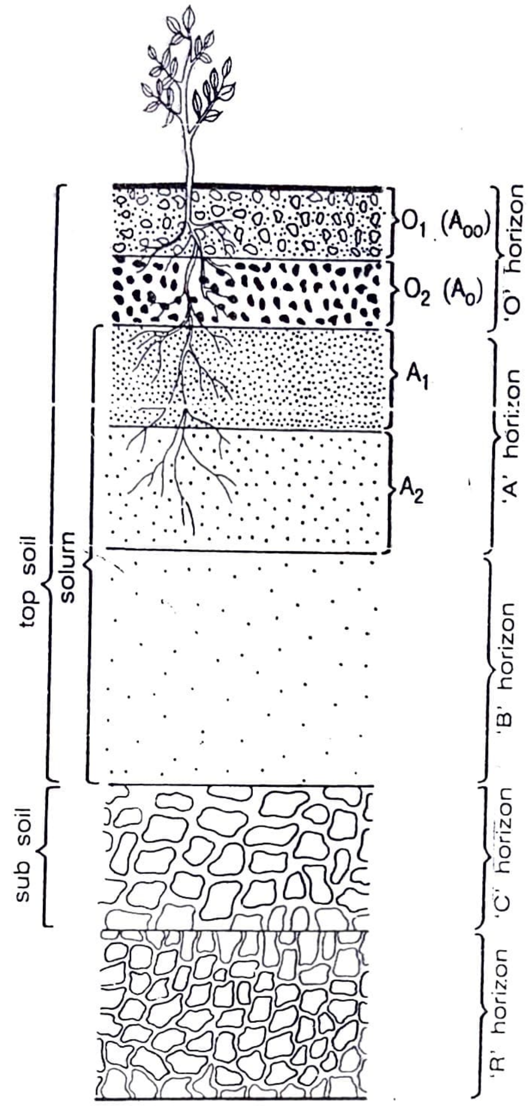

Fig. 3.1. Hypothetical diagram of the soil profile to show principal horizons.

The different horizons of a soil profile historically in Russian terminology, were classified into ABC terminology. However, according to the present one in general use, the soil profile (Fig. 3.1) consists of the following **five** main horizons:

The 'O' horizons

These are the organic horizons forming above the surface of the mineral matrix, mainly composed of fresh or partially decomposed organic matter. This horizon is divided into following two sub-layers:

O_1 (A_{00}) region

This is the uppermost layer consisting of freshly fallen dead organic matter as dead leaves, branches, flowers and fruits, dead parts of animals etc. These do not show evident breakdown.

O_2 (A_0) region

It is just below the O_1 region, in which decomposition has begun. Thus organic matter is found under different stages of decomposition and microorganisms like bacteria, fungi, actinomycetes are frequently found. Upper layers contain detritus in initial stage of decomposition, in which material can be faintly recognised, whereas the lower layers contain fairly decomposed matter, the duff.

The 'A' horizons

These are the mineral horizons formed either at or adjacent to the surface. These are rich in organic matter and/or show downward loss (**eluviation**) of soluble salts, clay, iron or aluminium, being consequently rich in silica or other resistant minerals. This is thus also known as zone of **eluviation**-downward loss or leaching.

This horizon is divided into following two sub-layers:

A_1 region

It is dark and rich in organic matter. The amorphous, finely divided organic matter here becomes mixed with the mineral matter, which is now known as **humus,** which is dark brown or black coloured. This region having a mixture of finely divided organic matter and the mineral matter is also called **humic** or **melanized region.** In forest soils this region is less deeper than those of the grasslands.

A_2 region

This region is of light colour in which the mineral particles of large size as sand are more, with little amount of organic matter. Chiefly in areas with heavy rainfall, the mineral elements and organic chemicals are rapidly lost downwards in this region, making it light-coloured. This is thus also known as **podsolic** or **eluvial zone** or zone of leaching.

The 'B' horizons

These are the mineral horizons forming below the surface in which one or more of the following features can be present (i) enrichment with inwashed clay (lessivation), iron, aluminium, manganese or organic matter, (ii) residual enrichment with sesquioxides or silicate clays which has occurred other than by the removal of carbonates or readily soluble salts, (iii) sesquioxide coatings of mineral grains sufficient to give a more intense colour than horizons above or below, (iv) alteration of the original rock material to give silicate clays or oxides in conditions where (i), (ii) and (iii) do not apply.

This is just below the 'A' horizon, and can also be divided into B_1 (A_3), B_2 and B_3 regions, depending upon the stages of soil development in the area. B_1 (A_3), if present is in the process of successional development, the presence of which depends upon the extent of development of horizons, above and below it.

The 'B' horizon is dark-coloured and coarse-textured due to the presence of silica-rich clay organic compounds, hydrated oxides of aluminium, iron etc. Since, the chemicals leached from A_2 region, become collected in this horizon, it is also known as zone of **illuviation** or **illuvial zone.** This zone is poorly developed in dry areas.

A_1, A_2 and B collectively are also known as mineral soil or **solum.**

The 'C' horizons

These are the **mineral horizons** below the 'B' but excluding true bedrock and without any characteristics of 'A' or 'B' horizons. It consists of incompletely weathered, large masses of rocks.

The 'R' horizons

This is the parent, unweathered bedrock, upon which there is collected water.

Climate and Soil Formation

It is clear from the above account that climate and other factors largely affect the soil formation. The type of soil thus depends upon the nature of interactions between such factors. The characteristics of the soil formed may be analysed through study of their profiles.

Some of the following processes are intimately related with soil formation as influenced by climate and other factors. These are characteristic to a particular type of climate. Some of them which are much pronounced, are as follows:

Laterization

One of the passive factors — **time,** required for soil formation is much variable, since it is strongly influenced by climatic and parent material factors. Under tropical conditions, soil formation may occupy a much longer time-scale. Mohr and van Baren (1959) wrote: "the process of laterisation in the tropics...must be regarded as a geological phenomenon. This is because the time factor, next to climate, is of the greatest importance in determining the final stage in the cycle of weathering." Under high temperature regimes and high rainfall in the tropics, the silicate minerals are very unstable and a large loss of silica, probably as colloidal silicic acid occurs. The ratio of silica/sesquioxide becomes very low. The aluminium and iron sesquioxides of the parent minerals are resistant to decomposition and some are synthesised ***in-situ*** from ionic Al and Fe liberated during alumino-silicate breakdown. This process known as **laterization** is most common on base-rich parent matters and it leaves a residue of primary laterite containing little else but iron and aluminium sesquioxides and a few resistant parent minerals.

Melanization

The process is very common in regions of low humidity where humus formed from the organic matter, alongwith water becomes mixed in the 'A' horizon of the soil. Due to melanization, the 'A' horizon becomes dark-coloured.

Podsolization

In temperate climates, particularly with moderate rain coupled with a nutrient-deficient, well-drained parent material, podsolisation is very common. The chief vegetations are the genera of Ericaceae and conifers, which produce a litter with high lignin and low nutrient (particularly calcium) contents, and rich in phenolic compounds which inhibit microbial activities. The litter layer is thus acidic. The water percolating through such litter, being acidic dissolves out with it minerals and humus content from 'A' horizon. These leached materials reach to the lower horizons, and collected in the form of a hard, distinct