2.6 Soil-forming processes

Soil-forming processes, commonly called **pedogenic processes**, change the soil parent material into a soil body of specific morphological and genetic characteristics (soil profile). Every soil profile and soil body is a reflection of one or more combination of processes, each of which has persisted for some time. Soil formation can be considered as two overlapping steps—

formation or accumulation of parent material, and horizon differentiation. Parent material accumulates through the weathering of rocks in place or the transportation of weathered rock material to other places. These changes are commonly called **geochemical weathering**. Geochemical weathering continues after the soil body is established, and is then called **pedochemical weathering**, a part of pedogenic processes. Weathering processes have already been discussed in section 2.4.

Simonson (1978) characterized soil formation as resulting from four sets of processes: addition to the ground surface, transportation within the soil, vertical up or down transfer within the soil, and removal from the soil. Individual soils are the result of a particular balance of all the possible soil-forming processes. Slight changes in the balance or the intensity of these processes combine to form a vast number of soil individuals.

The soil mantle, as an open system, receives and loses substances. Some are transferred, some undergo transformation. Forms of additions in most soils are organic matter along with its nutrients, rainfall and dissolved constituents, solar energy, gases, and dust falls. Transformations include organic matter decomposition and primary mineral alteration. Transfers involve movement of clay and humus particles, movement of ions, and precipitation of salts upward or downward. Losses are in the form of ions in percolating water, evaporation, oxidation of organic matter, and removal by erosion.

Some soil-forming processes promote horizon differentiation, while others retard it. Two simultaneously operating trends in soil development are horizonation and haploidization. **Horizonation** includes the processes that promote differentiation of horizons into A, B, and C: addition of organic matter, losses of carbonates, transfers of silicate clay minerals, and decomposition of organic matter with formation of humus. **Haploidization** includes the processes that inhibit soil horizon formation or destroy horizons that exist, such as erosion or deposition mixing of soil materials by burrowing animals, addition of airborne sediments, and churning of soils by frost or shrinkage.

Boul et al. (1980) lists a number of important soil-forming processes under the four main categories—additions, losses, transfers, and transformations within a soil body. For the purpose of discussion, these processes can be classified as general and specific. A **general process** simply means a reaction or process which contributes to profile development, wherever it occurs. A **specific process** is generally considered as a combination of general processes that operate noticeably under certain defined conditions of climate, vegetation, parent material, or relief. Specific processes such as podzolization or calcification are essentially concepts which explain major kinds of soils like podzols or chernozems. Although these specific terms are not precisely as used in the USDA Soil Taxonomy System (Soil Survey Staff

1975), they throw light on the historical aspects of soil genesis, and they continue to be used in their original senses in other countries (e.g. Russia).

Any general soil-forming process can gain special significance under a certain set of soil-forming conditions, and become as important as a specific one. Some terms for simple general processes are given here as an introduction to the discussion of specific soil-forming processes.

2.6.1 General soil-forming processes

Eluviation is the mobilization and translocation of certain constituents, viz. clay, Fe_2O_3, Al_2O_3, SiO_2, humus, $CaCO_3$ and other salts from one point of the soil body to another. **Illuviation** is the immobilization and accumulation of the eluviated constituents at some depth beneath the soil surface. **Leaching** is a general term for washing out or eluviating soluble materials from the solum. Leaching of soluble salts is a prerequisite to translocation of colloids. **Enrichment** means addition of material to a soil body from the surrounding area by erosion, or from a distance by air movement. The materials may be nutrients or salts. Depressional soils may be enriched or leached, depending upon their moisture balance. **Lessivage** is the mechanical migration of small mineral particles from A to B horizons of a soil, producing fine clay enrichment in the B horizon. This process will be discussed in detail later. **Melanization** is the darkening of light-coloured initial unconsolidated mineral materials by the admixture of organic matter, as in a dark A, or mollic epipedon.

Pedoturbation is the process of soil mixing by fauna and flora and by physical churning and cycling of soil materials. Faunal pedoturbation is mixing by organisms such as earthworms, ants, termites, and rodents. Floral pedoturbation is mixing of soil by plants while argilli-pedoturbation is soil mixing by the shrinkage and swelling of clay accompanying drying and wetting cycles. **Homogenization of alluvium (stratified sediment) by earthworms is the most important soil-forming process in the alluvial plain of Pakistan.**

Mineral transformations within the soil body may be simple or complex. In simple mineral transformations a large part of the structure of the original mineral remains structurally intact throughout the transformation. Examples are transformation of mica to vermiculite or smectite and trioctahedral chlorites to expansible 2:1 minerals. In complex mineral transformations, minerals go totally into solution, and new minerals are precipitated. The synthesis of kaolinite from decomposed products of feldspars is an example of this.

Organic matter transformation includes both mineralization and humification of organic matter. The release of mineral components of organic matter through decomposition is the complex process of mineralization.

Humification is the transformation of raw organic material into humus by microorganisms in the presence of O_2. Carbohydrates are decomposed into simple sugars, proteins into amino acids, and lignin and waxes into phenols. Further polymerization results in humus, which is a complex stable intermediate product of organic matter transformation with a narrow carbon:nitrogen ratio. Anaerobic decomposition of organic matter results in organic matter accumulation and formation of bog and peat materials.

2.6.2 Specific soil-forming processes

Lessivage. Lessivage is a specific process related to movement of clay-sized particles within the soil solum. The downward transfer of silicate clay minerals is responsible for the argillic horizon formation (clay accumulation in the B horizon) diagnostic for Alfisols and Ultisols and present in some Aridisols and Mollisols. Quantities transferred need not be large, but some transfer is required. Formation of a clay-enriched B horizon is common in the oldest landscape in temperate to subtropical climates with a pronounced dry season, and more frequently under forest than under grass vegetation. Maximum clay content is often at the top of the B horizon, decreasing with depth. Possible causes of such a distribution are formation of clay minerals in place, movement and reunion of soluble weathered products into clay particles, and movement of clay particles in water flowing from the A to the B horizon. Of these, the movement of clay particles in water seems the explanation most likely to account for the bulk of the phenomenon. Oriented clay skins on mineral grains and on peds in the form of **clay cutans,** and a higher fine clay:total clay ratio in the B horizon than in the A horizon are the main indications of the migration of clay particles.

The sudden wetting of a dry soil by heavy rain after a period of drought favours the dispersion of clay particles. After the first hours of rain, the electrolyte concentration responsible for clay flocculation is reduced. The concentration of calcium becomes lower than required for equilibrium, and CO_2 pressure is also reduced with lessened biological activity. So the pH of the surface horizon becomes very high. The result of the temporarily elevated pH is a considerable increase of the surface potential of the clay particles because of the dissociation of H^+ Si–OH and Al–OH groups at the edges of the particles. The increase of the electrical charge of the clay, and the low electrolyte concentration promote the mobility of clay. Consequently, clay migration during the first hours after the start of rain should not be neglected as a possible process even in calcareous soils.

The presence of cracks and wide pores in the matrix facilitates the percolation of the dispersed clay percolation. Subsequently the percolating water is halted by capillary withdrawal of moisture by the dry soil. If soluble salts are present in the soil, the clay remains flocculated; thus the leaching of salts is necessary before clay can be translocated. The formation of an argillic horizon needs thousands of years. Even exchangeable Na^+ dominated dispersed clays required at least 1000 years for sufficient translocation to form a Natric B horizon. In Pakistan, soils with an argillic horizon (Alfisols) have developed on stable Pleistocene surfaces in subhumid/humid regions such as the Pothwar Plateau, Peshawar Vale, and the northern intermountain valleys.

Calcification. The **calcification** process involves weak eluviation and formation of secondary calcium carbonates in the subsoil horizon, and leads to the formation of the chernozemic soils or Pedocals of the old USDA classification system. In the new Soil Taxonomy, the order of well-drained Mollisols represents most of the soil properties developed by the process of calcification. However, many Aridisols, Inceptisols, and soils of other orders having extremely calcareous parent materials also typically display features attributable to calcification. Calcification is the major process of soil formation in calcareous parent material in arid and semiarid to subhumid climates. Calcium is the dominant cation on the exchange complex of soils containing secondary carbonate minerals. The $CaCO_3$ of carbonate horizons may come from several sources: Ca^{2+} released by weathering of calcareous parent materials, from carbonate minerals added as atmospheric dust, and from weathering of Ca-bearing silicates. Sometimes a perched high water table rich in Ca also leads to the accumulation of $CaCO_3$ by capillary rise. The natural vegetation under ideal conditions is grasses and shrubs, which help to retain Ca in the system by nutrient recycling.

The overall process of dissolution and precipitation of $CaCO_3$ can be represented by the equation:

$$CaCO_3 + 2H^+ \ (H_2CO_3) \rightleftharpoons Ca^{2+} + CO_2(g) + H_2O$$

An increase in CO_2 gas content in the soil or a decrease in pH (high H^+ ion activity) will increase the dissolution of $CaCO_3$ and the concentration of Ca^{2+}. Dissolution is also favoured by increasing the amount of water moving through the soil. Precipitation of $CaCO_3$ will occur when CO_2 pressure is low or pH is high, and when the soil solution is saturated by evapotranspiration of soil moisture. Under grassland, biological activity is highest in the A horizon because of root respiration and organic matter decomposition, resulting in high CO_2 pressure and low pH, conditions under which $CaCO_3$ dissolves. Soluble Ca^{2+} diffuses downward with percolating water and arrives in horizons where the CO_2 pressure is lower than in the A horizon. The concentration of Ca^{2+} is then lowered, and $CaCO_3$ precipitates.

The mixed sediments of the Indus and its tributaries, as well as loess deposits, contain finely distributed $CaCO_3$ (about 5–>15%). When rainfall or flood water percolates into the soil, some $CaCO_3$ is dissolved, which precipitates along pores and voids, and probably along old root channels and worm tracks as water is lost by evaporation or used by plants. With time, repeated solution and re-precipitation causes concentration into larger crystal aggregates at places in the soil where the rate of evaporation is relatively high, and small nodules begin to form. Once this process has started, the solubility of the very fine crystals and aggregates of $CaCO_3$ is somewhat higher than that of the larger aggregates, which causes very slow growth by precipitation on the larger concentrations at the expense of the very fine crystals every time the soil is wet. Similarly, soft aggregates and nodules of $CaCO_3$ have been formed in the subsoil horizons, wherever ground water evaporates, precipitating dissolved Ca^{++} slowly but gradually in the pores and voids.

Most soils of Pakistan contain secondary $CaCO_3$ in the form of lime specks or pseudomycelia, soft aggregates, and nodules of various sizes (even greater than 5 mm in diameter), depending on the stage of soil development and the underground water level. In some areas, where finer solum material has been eroded away, coarse lime *kankars* are present on the soil surface or in the plough layer. A calcic horizon, a subsurface diagnostic horizon, occurs only in the soil profiles of subhumid to humid areas.

Podzolization. Podzolization is the process leading to the formation of podzolic soils with a spodic horizon. *Podzol* is a Russian word, composed of *pod* 'under' and *zola* 'ash', which reflects the fact that the spodic horizon is under 'ash', the albic or bleached E horizon. Podzolization is a complex process including many general soil-forming processes such as removal of soluble salts, disintegration of clay and translocation of the decomposition products iron and Al by simple organic substances, new formation of amorphous minerals, and translocation of organic substances with high molecular weights. Podzols are found in cold humid regions, usually with slightly acid or weakly calcareous parent material, often under coniferous forests. Giant podzols in Australia and New Zealand are reported to be formed under the litter of kauri trees. In Pakistan, climatic conditions are not conducive to the podzolization process, and hence no podzols have been observed even in the northern forest regions.

Podzolic soils are characterized by pronounced downward translocation of iron and aluminum. In many podzols, however, the conditions for translocation in soluble ionic form are not favourable. In such soils, pH is in the range 4–5, where iron and aluminum are insoluble. Under these conditions, fulvic acids with strong chelating properties are formed in the O, A and E horizons. These acids complex Fe and Al as they are released from primary mineral weathering, and the soluble complexes so formed are leached downward. These soluble complexes precipitate in the B horizon, releasing Fe, Al, and even humus in the form of bands. Possible causes of this are increase in ionic strength at lower depths which causes flocculation, or degradation of chelate molecules by microorganisms.

Recent research indicates that some podzols may form without the complexing of Fe and Al with organic chelates. Al and Si may form a gel-like substance called **proto-imogolite** that is positively charged, stable, and soluble at pH < 5, and this may represent the form in which Al is eluviated. Mixed Al_2O_3–Fe_2O_3 sols appear to be stable with or without silica, and can also be eluviated. These inorganic sols precipitate to form the spodic horizons of spodosols. Soluble organic matter complexes, being negatively charged, also precipitate on imogolite and are translocated downward. Thus, it appears that both organic-influenced and strictly inorganic eluviation–illuviation phenomena are involved in the formation of the E and B horizons of podzols.

Laterization. The term *laterization* is used in two senses. First, **laterization** describes the overall process of desilication, i.e. the removal of silica and the accumulation of hydroxides, oxy-oxides, or oxides of iron and aluminum (sesquioxides) and formation of 1:1–type clay of the kaolinitic group. This process operates in the hot, humid climatic conditions of the tropical and subtropical regions of the world. A hot, humid climate decomposes organic matter rapidly, producing a high CO_2 level, which also results in complete weathering of the primary minerals. Sesquioxides remain at the site of reaction, while silicic acid leaches down. There are no lateritic soils in Pakistan: although a small coastal portion of Pakistan has tropical climate, it is hot and dry rather than humid.

Two sets of processes operate for the creation of such conditions—laterization and latosolization.

Laterization or lateritization. The word is derived from the Latin word *later* 'brick'. Historically the concept of laterization was associated with iron **accumulation**, from whatever source. In the new terminology, laterization is related to the formation of Oxisols with plinthite. In hardened form, laterite may be referred to as ironstone. The two main stages involved are desilication and plinthization (redistribution of iron oxides). The conditions which produce laterization are a hot and humid climate with alternating dry and wet seasons, associated with slow drainage and fluctuating ground water table, which favor oxidation–reduction reactions. Alternating aerobic and anaerobic conditions favor iron accumulation by producing alternating oxidation–reduction phases of weathering.

Latosolization is the advanced stage of mineral transformation which results in losses of silica and bases by leaching, and the *formation of oxides from residual Fe,* Al, and Ti. In contrast, laterization involves mainly iron oxide *accumulation*. According to Soil Taxonomy, latosolization leads to formation of Oxisols with an oxic horizon without plinthite. Latosols usually occur in very old geomorphic surfaces in mafic parent rocks such as serpentine and basalt. Because of the perfect drainage and rapid permeability and absence of fluctuating ground water tables, oxidation–reduction processes do not operate. The weathering is perfectly aerobic and consists of dissolution, hydrolysis, and hydration reactions. Faunal pedoturbation, such as the intense termite activity in some tropical regions, is expected to prevent the formation of argillic horizons, and favours the formation of an oxic horizon.

The other specific soil-forming processes are:

Salinization	accumulation of soluble salts in soil
Alkalization	accumulation of exchangeable sodium on soil colloids
Desalinization	removal of soluble salts from soil through leaching
Dealkalization	replacement of exchangeable sodium by calcium

They are discussed in detail in Chapter 16 on soil salinity, sodicity, and waterlogging.

STUDY QUESTIONS

1. Define *mineral*. Which are the eight most important rock-forming minerals?
2. List the chemical composition of the earth's crust.
3. Describe briefly how rocks are classified. Give examples of each type. Discuss the types of rocks present in Pakistan.
4. What physical properties are used for identification of minerals?
5. Classify the silicate minerals.
6. Differentiate between physical and chemical weathering. Describe physical weathering processes in detail.
7. Discuss the processes of chemical weathering.
8. Describe hydrolysis and its significance in weathering.
9. Group the minerals according to relative stability. Which factors control the relative resistance of minerals to chemical weathering?
10. How are the secondary clay minerals formed or synthesized in the soil environment?
11. Reproduce Jenny's fundamental equation of soil formation. Discuss each of the variables involved.
12. Compare the general effects of arid climate and humid climate on soil formation.