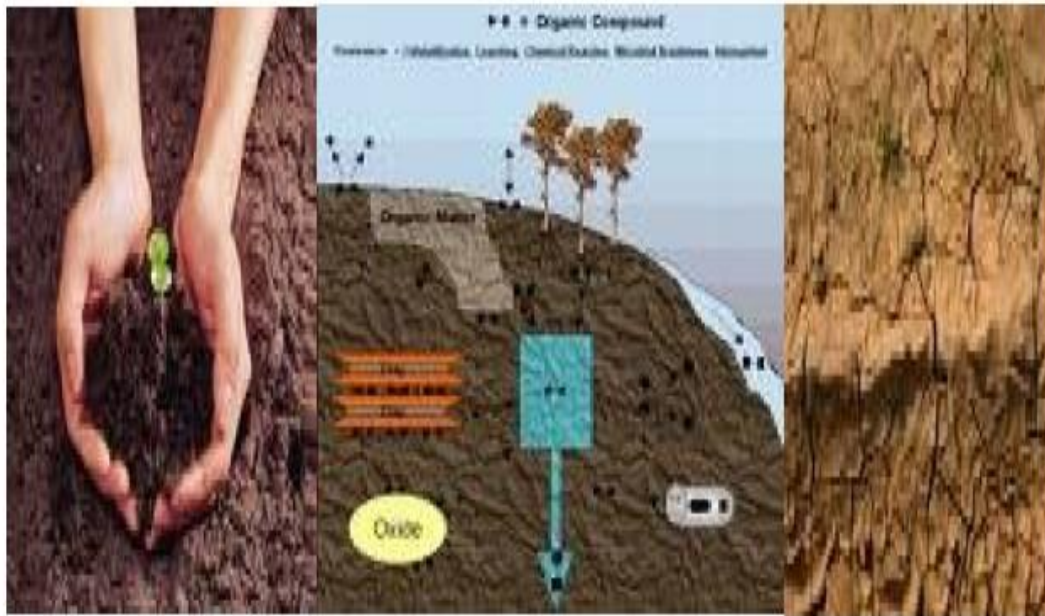


SOIL POLLUTION



CHAPTER TWO ***SOIL ORIGIN***

For Post graduate Students 2020\2021
Faculty of Engineering
Mustansiriyah University
Environmental Engineering Department

Origin, Monitoring & Remediation

Soil is defined as sediments or other accumulation of mineral particles produced by the physical or chemical disintegration of rock, plus the air, water, organic matter, and other substances that may be included. Soil is typically a non-homogeneous, porous, and earthen material whose engineering behavior is influenced by changes in moisture content and density. To understand and appreciate the characteristics of any soil deposit require an understanding of what the material is and how it reached its present state. This requires consideration of rock and soil weathering, the erosion and transportation of soil materials, depositional processes, and postdepositional changes in sediments.

1- Physical or Mechanical Weathering

Physical and biological agents, such as wind, running water, temperature changes, and living organisms, perpetually modify the Earth's crust, changing its upper surface into products that are more closely in equilibrium with the atmosphere, the hydrosphere, and the biosphere. Physical weathering processes cause in situ breakdown without chemical change. Mechanical weathering in the case that the dominant forces are mainly mechanical, such as the eroding action of running water, the abrading action of stream load or the physical action of wind and severe temperature fluctuations. Similarly, one speaks of biological weathering when the forces producing changes are directly or indirectly related to living organisms.

Processes of disintegration, during which mantle rocks are broken down to form particles of smaller size, without considerable change in chemical or mineralogical composition are known as physical weathering processes. Changes of this type prevail under extreme climatic conditions as in deserts or

arctic regions. They are also prevailing in areas of mountainous relief. The most prominent agents of physical weathering are:

- Differential stress caused by unloading of deep-seated rocks on emerging to the surface.
- Differential thermal expansion under extreme climatic conditions.
- Expansion of interstitial water volume by freezing, that leads to rupturing along crystal boundaries.

2- Chemical Processes of Weathering

All types of chemical reactions that occur between the minerals of the rock and the environment (air, water ---et.) and will end up by disintegration of parent rock into fine grain particles; these products have different properties from the parent rock. Chemical weathering transforms one mineral to another or completely dissolves the mineral. Practically all chemical weathering processes depend on the presence of water. Hydration, that is, the surface adsorption of water, is the forerunner of all the more complex chemical reactions, many of which proceed simultaneously. Its products called coarse grained soil e.g. (silt and clay), which are cohesive materials, and its properties do not reflect the same properties of the parent rocks. The effect of chemical weathering is the most decisive in the geologic cycle, whereby dramatic changes may completely obliterate the parent rock and vast geomorphologic changes may occur. Under these conditions, pedogenesis consists of the following categories of processes:

Oxidation. Where the most processes leading to soil formation take place, the availability of oxygen, water, and dissolved gases leads to a dominance of

oxidation reactions, leaving their marks on the formed soil horizons, represented by the characteristic colours of the resulting Products. The typical yellow, brown, or red colour of soil in some warm areas (e.g. Mediterranean terra rossa) is due largely to the oxidation of ferrous iron in the minerals pyroxene, amphibole, and olivine into ferric iron. Besides Fe^{2+} , Mn^{2+} and S^{2+} are the most commonly affected elements by oxidation. They are normally oxidized to Mn^{4+} and S^{6+} . Other examples are V, Cr, Cu, As, Se, Mo, Pd, Sn, Sb, W, Pt, Hg, and U. A good example of oxidation reactions during weathering is the oxidation of pyrite to form sulphuric acid, which attacks the rocks (see Eq. 1.1), developing solution pits and stains.



Hydration and hydrolysis. Hydration and hydrolysis are the most important processes encountered during soil formation by weathering. While in hydrolysis a proper chemical reaction between water and the mineral substance takes place to produce or consume a proton (H^+) or an electron (OH^-), water in hydration forms an envelope around the cations to form a hydrate – a compound in which it is integrated within the crystalline structure of the substance. A typical example of hydration is the conversion of anhydrite (CaSO_4) into gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

Clays that, together with organic substance and other colloidal matter, give soil its characteristic nature, are typical products of hydrolysis processes steering the change of aluminium or iron silicates into clay minerals and/or iron oxides. An example of this is the reaction of the mineral albite in the course of weathering (see Fig. 1.1) with weak acids to yield kaolinite (clay), silica and sodium ions (Na^+).

The protons involved in this reaction are generally provided by naturally occurring acids, such as carbonic acid or by the rather abundant humic acids. The released Na-cations will be sorbed on the surface of colloidal particles or released to the solution. SiO₂ precipitates as colloidal silica or quartz.

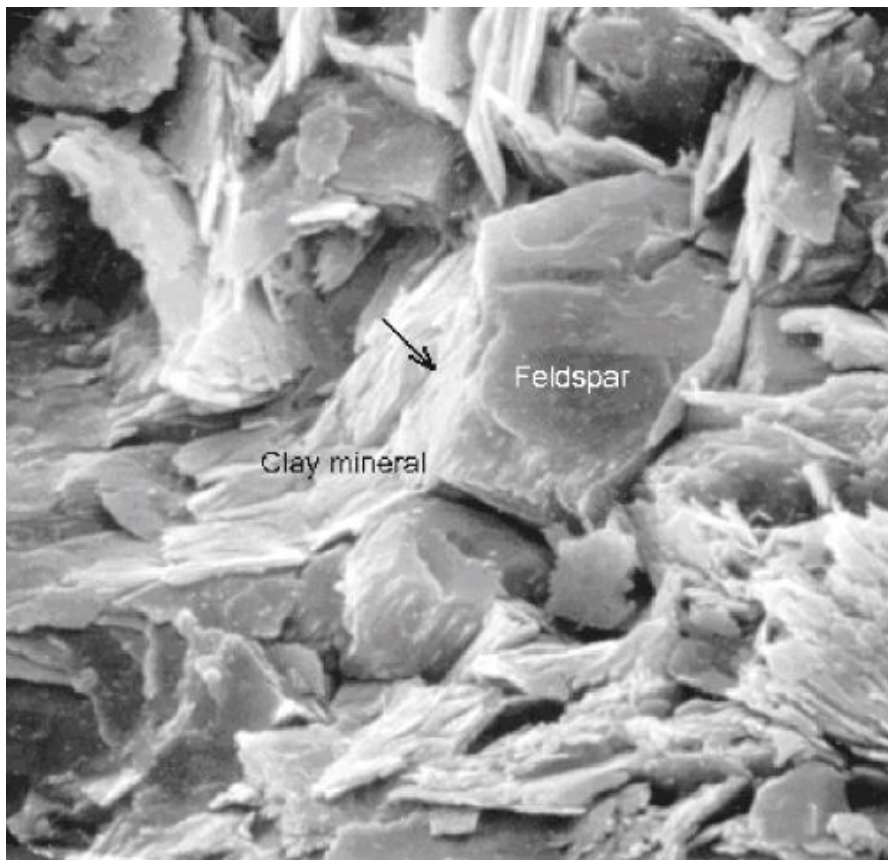
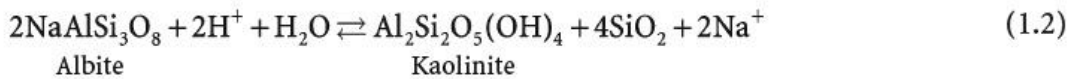


Fig. 1.1 Chemical weathering of Feldspars (*arrow*) by percolating waters to form clay minerals. Scanning electron photomicrograph of a sample collected near Marburg (Germany). 1 cm = 2 μm

3. Weathering by Biological Agents

Biological effect is a factor, which has never been absent in any soil forming process during weathering. It is always there, whether the dominant processes were mechanical or chemical; it always accompanies emergence and evolution

of soil. The chemical dimension of biological weathering vary from simple dissolution reactions, occurring at the extensive acidic environment at root tips, to complex biochemical processes by which certain elements are extracted, concentrated or bound into complex by plants or by bacterial action. As an example, we may take the oxidation of iron and sulphur or the fixation of nitrogen by bacteria

3.1 The Pedogenic Cycle – A Cycle within the Global Sedimentary Cycle

One of the most fundamental definitions of soil is that it is the relatively thin upper layer of the unconsolidated mantle of disintegrated and decomposed rock material, which overlies the consolidated bedrock. It is composed of organic material derived from the surface and mineral particles, which were contained in the parent material forming the bedrock. Soil matter, thus formed, seems in most cases to have been recycled in place, without being transported for long distances. Generally the unconsolidated material (soil mantle) is zoned from above downward, forming the so-called soil zones (see below). This leads to the conclusion that pedogenic cycles are minor cycles within the main sedimentary cycle, modifying the Earth's crust (see Fig. 1.2). It is governed by the forces demonstrated by the typical stages leading to the formation of sedimentary rocks in all terrestrial environments.

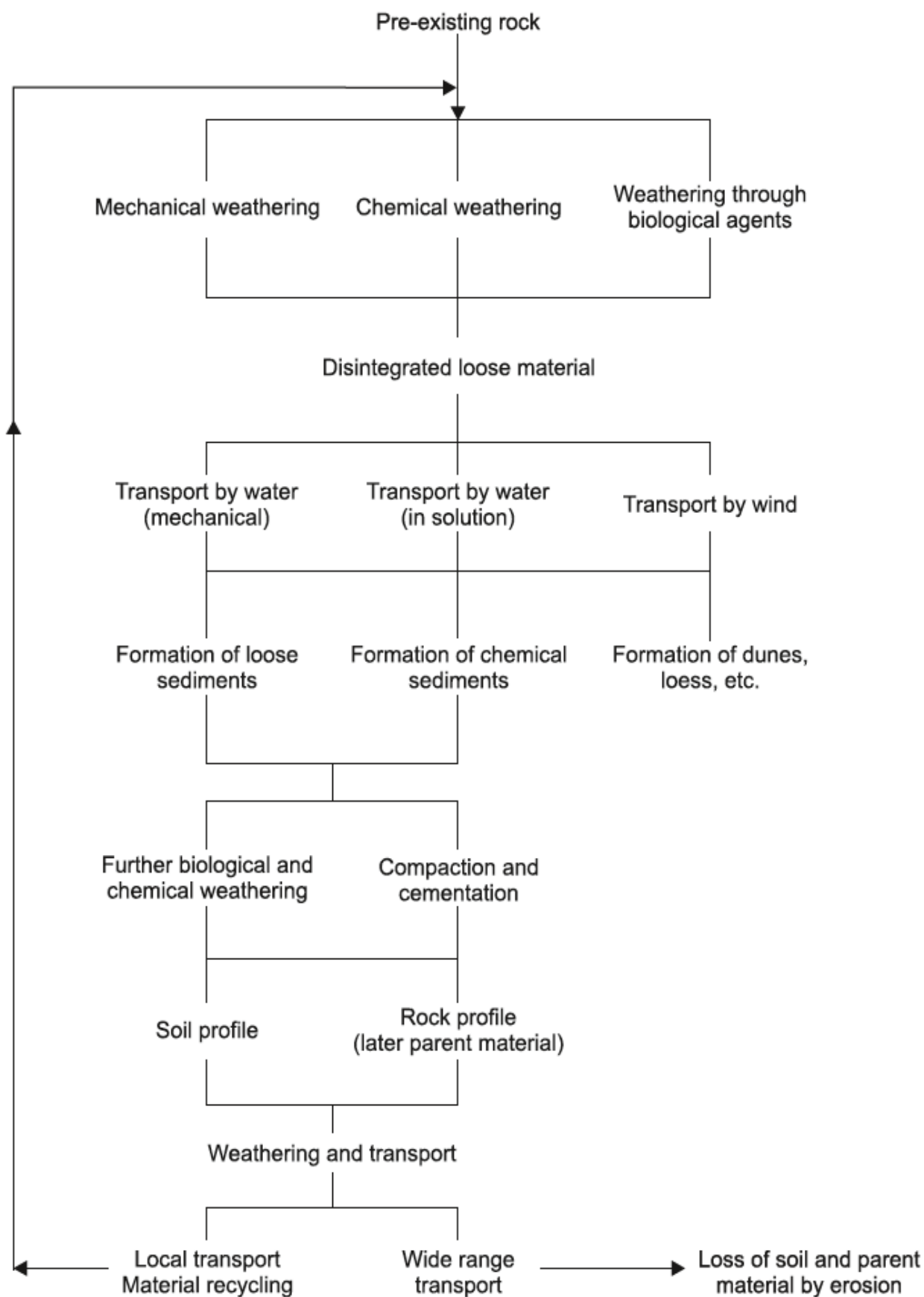


Fig. 1.2 The position of pedogenic processes within the main sedimentary cycle

3.2 Transport Routes and Material Transfer within the Soil Body

Once a soil body is formed, material flows within the body, whether in suspension or in solution they will contribute to the maturing of this body into a well zoned soil profile as that shown in Fig. 1.3. Routes and patterns of flows in a landscape prism run actually in all horizontal and vertical directions according to the physical conditions prevailing in the soil body (grain size, porosities or also concentration gradients in the soil water). A general pattern, however, was recognized and summarized by many authors, the most well known simpler pattern is that of Kozlovskiy (1972). He identified, according to direction of flow, three types of transport routes as shown in Fig. 1.3.

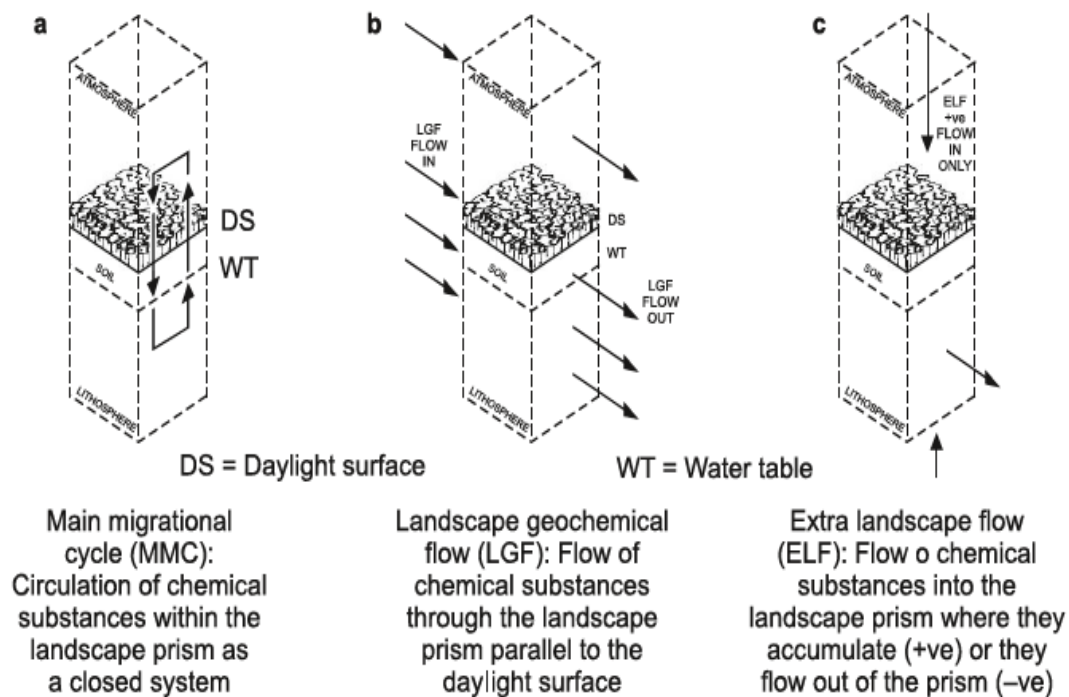


Fig. 1.3 Illustration of the three flow patterns according to Fortescue (1980)

A short description of the different patterns of flow can be given as follows:

- 1. Main migrational cycle** (Fig. 1.3a). This has a predominantly vertical movement and corresponds to the narrower concept of biogeochemical cycle in a more or less closed loop. It may, however, include the transport of fine material suspended in water from the upper parts of the soil body, to

deposit them at the lower parts – illuviation– forming coatings or skins on the coarser grains (sometimes known as clay skins· see Fig. 1.4). Besides forming coats on coarser grains, clay skins, may in many cases form fine linings in the interstitial space between coarser grains (see Fig. 1.5). In the latter case, however, the clays in the interstitial space may be chemical (diagenetic products formed in place along the boundaries between feldspar grains, due to increased solution activities following the pressure arising along these boundaries due to compaction (pressure solution).

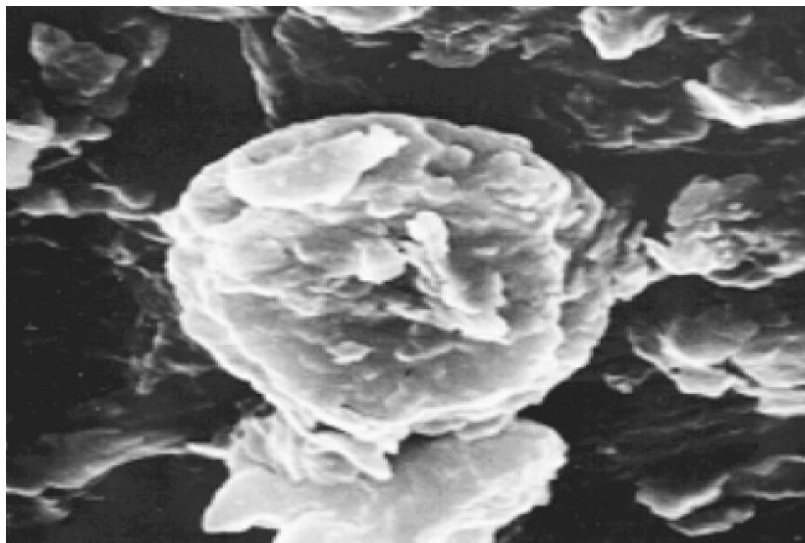
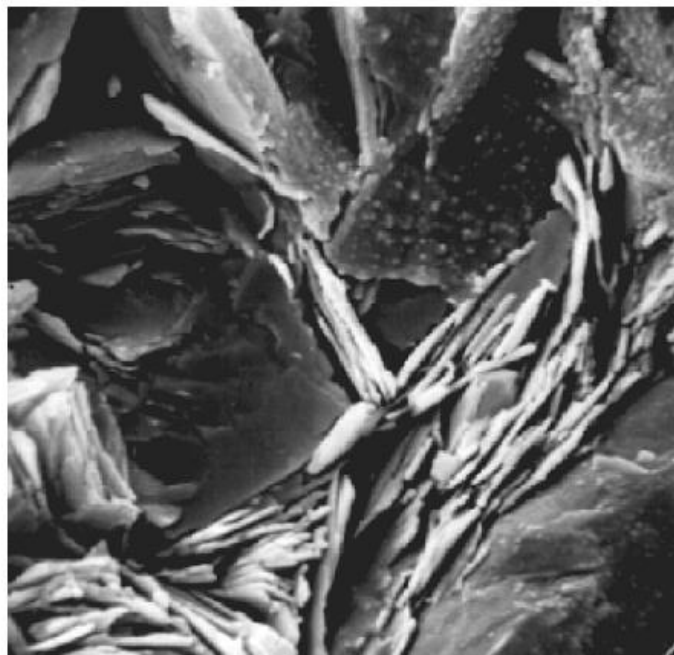


Fig. 1.4 Formation of grain coats by illuviation (SEM)

Fig. 1.5 Clay flakes (booklets) lining interstices between coarse feldspar grains (SEM). Sample collected near Marburg (Germany)



Acid waters may, on their way downwards, leach cations from upper horizons to precipitate them as chemical sediments in the form of newly formed chemical sediments in the lower parts, as it is the case with the formation of carbonate rich horizons in some soils. In the course of material flow during an active pedogenic cycle, the vertical flow forms one of the main routes for the development of mature soil horizons, as well as the distribution of organic and mineral components among these horizons. Examples of these are numerous, among which we may mention the following:

Flow of organic material down the profile of an active pedogenic cycle may result in the transfer of organic material – from the surface – to be deposited, either unchanged in the form of organic debris (roots, animal rests, etc.), or completely changed after being decomposed and homogenised by several organic reactions to form typical humic substances.

2- **Landscape geochemical flow** (Fig. 1.3b). This involves a progressive transport of material parallel to soil surface (see Fig. 1.3b). It takes place within a prism of the landscape, including portions of the atmosphere, the pedosphere, and the lithosphere as shown in Fig. 1.3b. It also includes among others air (gas) migration. An example of chemically active air migrant in the LGF is carbon dioxide and other gases that would dissolve in soil water, causing a shift in its chemical constitution and in some cases precipitation of new chemical compounds (e.g. carbonates. (Complex organic compounds under conditions, prevailing during this type of flow)e.g. oxidation during air flow) may be decomposed allowing cations that form the bases for plant nutrients such as Ca^{2+} , Mg^{2+} , and K^{+} to be released, forming salts (carbonates, sulphates, etc.) in a process fundamental to pedogenesis is known as mineralization.

This process may occur at any time of the cycle, yet it is characteristic to changes taking place during landscape geochemical flows. Mineralization processes may be reversed in subsequent changes to form simple organic compounds, as it will be shown later when polymerization processes will be explained.

3.Extra landscape flow (ELF) (Fig. 1.3c). A third type of material flow in landscapes is the Extra Landscape Flow. Applying this to soils as a portion of the landscape prism we may define it as the flow of chemical substances into the soil, where they would be accumulated (+ve flow), or out of it (-ve flow), where they would cause material loss from the site (see Fig. 1.3c). This type of flow characterises two main types of pedogenic processes, namely: **additions and losses**.

Additions prevail during positive flows, i.e. when substances flow into the soil profile, where they would be accumulated – a process that may occur in vertical as well as in horizontal directions, either at the surface or in lower parts within the soil body. Soil additions may involve plant debris, animal bodies or their parts as well as organic material formed by decomposition of pre-existing molecules, whereby such detrital material could indicate – according to its degree of erosion or decomposition – whether it was locally derived or transported from distant regions other than the site of direct pedogenesis.

Following the addition of organic or inorganic material to the soil body, further chemical reactions continue driving the energetic conditions of the system towards chemical equilibrium, by transforming those elements of the system that might be metastable (under the prevailing environmental

conditions) to stable ones. These transformations involve inorganic as well as organic soil material.

Losses. In the case of negative flows, losses from the soil body characterise the net result of material flow. In this case, the site of pedolisation loses material to its surroundings both at the surface and in the lower parts of the landscape prism.

Speaking about loss, would call to mind soil erosion in the first place. However, this conclusion is not completely right, even though it describes a great deal of the reality when loss is mainly defined on a physical or mechanical basis. Material loss during negative flows occurs mainly in four forms: gases, solutes, and particulate material, to which we may also add removed plants Ellis and Mellor.(1990)

Particulate material loss may occur due to water or wind erosion, while gaseous material may be lost from soil either due to degassing, by changing partial pressure gradients between a soil and its surroundings, or due to oxidation of organic compounds. Loss of nutritive material can follow after harvesting or removing plants from the soil. In deeper parts of the soil column, subsurface flow may carry dissolved material, leading to its loss in a portion of the soil. It might be later deposited outside the site of pedolisation. Thus leading to a net loss of soil material through extra landscape flow (ELF).

4. Factors Controlling Soil Formation

Climate: Weathering in general, and soil formation processes in particular, are dependent largely on climatic factors. These, not only control the main processes and directions in the main cycles of material flow, but also affect organic addition, and the rate of mineral transformation via crystal lattice

break down. Ross (1989) found that, in such transformations, the rates of chemical reaction double for every 10 °C rise in temperature, and that the maximum rate of organic matter decay takes place in the temperature range from 25–35 °C. This may also follow from the observation that, on a global level, the rate of mineral transformation and organic matter decay increases from high to low latitudes.

Biota: Actually, the role of organisms cannot be discussed apart from the climatic control effect, since these are generally related to bio-geographical conditions. Aside from the mechanical work done by rodents and burrowing animals, the chemical reactions triggered off by bacteria and plant roots play, as mentioned before, a crucial role in the process of soil formation.

Parent material: Since the principal source of soil is the pre-existing rock or parent material, the main control on soil formation will be directly related to the susceptibility of this material to weathering processes, and the chemical and physical changes accompanying them.

Physical properties (such as hardness, cleavage, porosity and grain size) form primary factors in determining whether water can percolate into a rock layer to initiate its disintegration into an unconsolidated material, or its decomposition into a different mineralogical constitution; the properties and characteristics of the resulting soil will also be directly related to parent material. Soils formed on parent material highly resistant to weathering will normally have relatively less thickness than those formed on easily weathered landscapes. They also contain more regolith or stony material than the latter.

5. Morphology of Soil

One of the characteristic properties of soil is the organization of its constituents into layers related to present day surface. Each of these layers,

which may easily be identified in the field through colour or texture, reflects subtle differences in chemical properties and composition, of which the most significant are pH, organic matter content, mineral assemblages, and metal concentrations, especially iron and manganese.

Soil layers, normally referred to as horizons, may range from a few centimetres to a metre or more in thickness. They are classified according to their position in profile, which is also closely related to their mineralogical constitution and grain size into few basic types (as shown in Fig. 1.6)

At the top of the profile, a layer of partially decomposed organic debris is referred to as the O-horizon (also A₀). It contains about 20–30% organic matter, derived from plant and animal litter. It is in this region that the principle process of soil formation, known as humification, i.e. complete change of organic debris into soil organic matter, takes place. The resulting material, humus, made up of a mixture of organic substances, is characterized by its dark colour and rather acidic nature. It is mainly produced by the work of consumers and decomposers among the microorganisms, living in the site of the soil formation. In the best-developed soils, which render ideal profiles, three main horizons follow.

They form a transition between the O-horizon and the base of the profile, made of the parent material, which is given the name R-horizon. This may be rock in situ, transported alluvial, glacial or wind blown overburden, or even soil of a past pedological cycle.

The three middle horizons, identified by the letters A, B, and C, are composed of sand, silt clay and other weathered by-products (Table 1.1 presents a description of grain size). They represent two main subsequent stages of soil formation, whereby the lowest one, C-horizon, represents the stage nearest to the parent material. It is made up of partially or poorly weathered bedrock having minimum content of organic matter and clay. The A- and B-horizons

are viewed together as representing the real soil emerging from the complete weathering of the C-horizon; they are collectively known under the name solum.

The A-horizon, which is generally a dark coloured horizon, rich in organic matter, may in some cases have a structure made up of three identifiable subdivisions known as A1, A2 and A3. Marked colour differences, resulting from leaching processes, make it possible to identify these subdivisions in the field. In fact, the resolution of the A horizon into a dark upper layer containing humus with mineral grains (A1) and an underlying light coloured horizon with little organic matter, is due to leaching processes, initiated by water percolating downward through the rich organic material on the top of the A-horizon. On its course downwards, water carrying in solution organic acids and complexing agents, generated in the humus by bacterial action, performs a process of leaching known as eluviation – a word from Latin meaning “to wash out.”

Eluviation, enhanced by carbonic acid, resulting from the decay of humus, displaces bases (calcium, sodium, magnesium, potassium) from the exchange sites of clay minerals.

These bases move down the soil profile as colloidal particles, dissolved ions or as free ions complexed with hydroxyl. Silica is also leached in the course of eluviation. It is largely dissolved as silicic acid or colloidal silica. Resistant primary mineral matter, however, remains behind in the upper soil (Rose et al. 1979).

Material dissolved in the A-horizon finds in some cases its way to the saturated zone of groundwater, yet the greatest part of it is normally re-deposited in the underlying layers forming the B-horizon. In this process, known as illuviation (from the Latin to wash in), colloidal material and metal oxides are deposited or precipitated in the B-horizon, resulting in an

enrichment of its layers in clay and aluminium oxide. Iron oxides, if present, give the horizon its red or yellow brown colour.

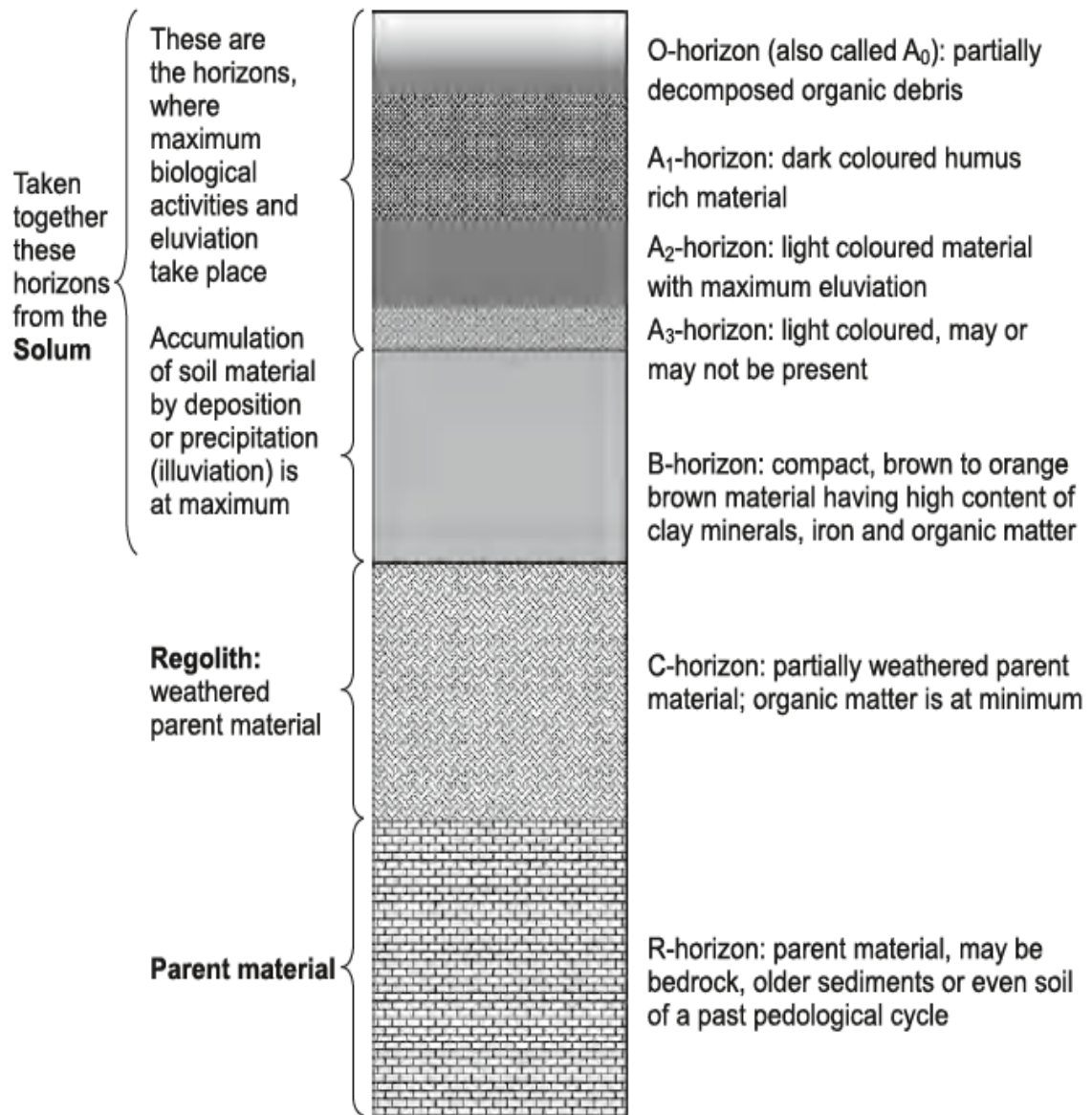


Fig. 1.6 Diagrammatic representation of a hypothetical soil profile

Table 1.1 Grain sizes of clastic sediments and related rock types

Grain size (mm)	Unconsolidated sediment	Lithified rock
>80	Boulders, cobbles	Conglomerate (Breccia if angular)
>2	Pebbles, gravel	
0.5 – 2	Coarse sand	Sandstone
0.02 – 0.5	Medium to fine sand	Sandstone
0.002 – 0.02	Silt	Siltstone (mudstone)
<0.002	Clay	Shale