Soil and Mineral Resources

Soil development occurs as rock weathering alters rocks exposed on the terrestrial surface of the Earth's lithosphere. Weathering is the principal process that acts upon the earth's primary minerals to form the smaller and finer particles that we call "soil." Weathered rock materials and sediments undergo further differentiation during the process of soil formation.

Mechanism of soil formation

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. Earth scientists sum up all the processes through which these alterations take place under the collective term ***weathering.***

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.

Other mechanical agents enhance the effect of mechanical weathering. These may include processes such as gravity, abrasion by glacial ice or windblown particles.

2. Chemical Weathering – The Gate to Pedogenesis

Chemical weathering is the fundamental natural process underlying the group of processes collectively known as *pedogenesis* or *soil-forming processes.* It depends principally on the presence of water and is largely initiated by the preceding physical weathering, since disintegration of the solid material leads to activation of the solid phase and eventually to more favourable energetic conditions for subsequent chemical alterations. 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.

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 the emergence and evolution of soil. One needs only to consider the mechanical forces exerted by intruding roots, or the enormous work of worms and rodents in mixing and disintegrating rock bodies in the upper surface environment, to realize how important this factor is for soil formation and its later evolution. The chemical dimension of biological weathering varies 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.

Soil composition

The basic components of soil are minerals, organic matter, water, and air. The typical soil consists of approximately 45% mineral, 5% organic matter, 20-30% water, and 20-30% air (Fig. 1). These percentages are only generalizations at best. In reality, the soil is very complex and dynamic. The composition of the soil can fluctuate on a daily basis, depending on numerous factors such as water supply, cultivation practices, and/or soil type.

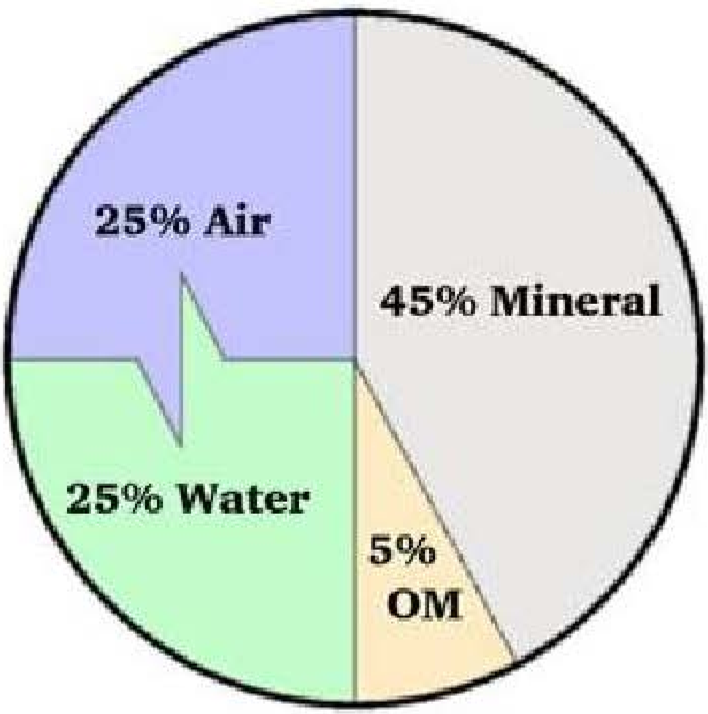

Fig.1: Approximate composition of soil

The solid phase of soil, which includes minerals and organic matter, are generally stable in nature. Yet, if organic matter is not properly managed, it may be depleted from the soil. The liquid and gas phases of the soil, which are water and air respectively, are the most dynamic properties of the soil. The relative amounts of water and air in the soil are constantly changing as the soil gets wet or dry.

Soil Minerals

Soil minerals play a vital role in soil fertility since mineral surfaces serve as potential sites for nutrient storage. However, different types of soil minerals hold and retain differing amounts of nutrients. Therefore, it is helpful to know the types of minerals that make up your soil so that you can predict the degree to which the soil can retain and supply nutrients to plants. There are numerous types of minerals found in the soil. These minerals vary greatly in size and chemical composition.

Soil Mineral Particle Size

Particle size is an important property that allows us to make distinctions among the different soil minerals. Soils contain particles that range from very large boulders to minute particles that are invisible to the naked eye. To further distinguish particles based upon size, particles are separated into two categories: the coarse fraction and the fine earth fraction.

Table 1: General classification of soil based on size fraction

Class	Size	Texture	Characteristics
Sand	0.05 mm - 2.0 mm	gritty	Sand is visible to the naked eye, consists of particles with low surface area, and permits excessive drainage.
Silt	0.002 mm - 0.05 mm	buttery	Silt is not visible to the naked eye and the moisture-holding capacity of soil is more than sand.
Clay	< 0.002 mm	sticky	Clay has a high surface area, high moisture-holding capacity, many small pores, and possesses charged surfaces to attract and hold nutrients.

Soil Organic Matter

Soil organic matter not only stores nutrients in the soil, but is also a direct source of nutrients. Some of the world's most fertile soils tend to contain high amounts of organic matter. Soil organic matter includes all organic (or carbon-containing) substances within the soil.

Important Functions of Organic Matter

Although surface soils usually contain only 1-6 % organic matter, soil organic matter performs very important functions in the soil. Soil organic matter:

- Acts as a binding agent for mineral particles.
- This is responsible for producing friable (easily crumbled) surface soils.
- Increases the moisture holding capacity of soil.
- Provides food for organisms that inhabit the soil.
- Humus is an integral component of organic matter because it is fairly stable and resistant to further decomposition.

Soil Moisture

In nutrient management, a proper balance between soil water and soil air is critical since both water and air are required by most processes that release nutrients into the soil. Soil moisture is particularly important in nutrient management. In addition to sustaining all life on Earth, it provides a pool of dissolved nutrients that are readily available for plant uptake. Therefore, it is important to maintain proper levels of soil moisture.

The amount of water in the soil is dependent upon two factors:

- First, soil moisture is intimately related to the climate, or the long-term precipitation patterns, of an area.
- Secondly, the amount of moisture in the soil depends upon how much water the soil may hold.

Water holding capacity

Since water is held within the pores of the soil, the water holding capacity depends on capillary action and the size of the pores that exist between soil particles. Sandy soils have large particles and large pores. However, large pores do not have a great ability to hold water. As a result, sandy soils drain excessively. On the other hand, clayey soils have small particles and small pores. Since small pores have a greater ability to hold water, clayey soils tend to have high water-holding capacity.

Soil Air

Soil aeration influences the availability of many nutrients. Particularly, soil air is needed by many of the microorganisms that release plant nutrients to the soil. An appropriate balance between soil air and soil water must be maintained since soil air is displaced by soil water. Air can fill soil pores as water drains or is removed from a soil pore by evaporation or root absorption. The network of pores within the soil aerates, or ventilates, the soil. Soil air is very different than the above-ground atmosphere. A significant difference is between the levels of carbon dioxide. Since the soil contains high amounts of carbon dioxide, oxygen levels may become limited. Since plants must have oxygen to live, it is important to allow proper aeration in the soil.

Soil Profile

The soil profile is an important tool in nutrient management. By examining a soil profile, we can gain valuable insight into soil fertility. As the soil weathers and/or organic matter decomposes, the profile of the soil changes. For instance, a highly weathered, infertile soil usually contains a light-colored layer in the subsurface soil from which nutrients have leached away. On the other hand, a highly fertile soil often has a deep surface layer that contains high amounts of organic matter. With clues provided by soil profile, we can begin to predict how a soil will perform under certain nutrient management conditions.

Components of the Soil Profile

A **soil horizon** makes up a distinct layer of soil. The horizon runs roughly parallel to the soil surface and has different properties and characteristics than the adjacent layers above and below. The **soil profile** is a vertical section of the soil that depicts all of its horizons. The soil profile extends from the soil surface to the parent rock material.

The **regolith** includes all of the weathered material within the profile. The regolith has two components: the **solum** and the **saprolite**. The solum includes the upper horizons with the most weathered portion of the profile. The saprolite is the least weathered portion that lies directly above the solid, consolidated bedrock but beneath the regolith.

Master Horizons

There are **5 master horizons** in the soil profile. Not all soil profiles contain all 5 horizons; and so, soil profiles differ from one location to another. The 5 master horizons are represented by the letters: O, A, E, B, and C.

O: The O horizon is a surface horizon that is comprised of organic material at various stages of decomposition. It is most prominent in forested areas where there is an accumulation of debris fallen from trees.

A: The A horizon is a surface horizon that largely consists of minerals (sand, silt, and clay) and with appreciable amounts of organic matter. This horizon is predominantly the surface layer of many soils in grasslands and agricultural lands.

E: The E horizon is a subsurface horizon that has been heavily leached. Leaching is the process in which soluble nutrients are lost from the soil due to precipitation or irrigation. The horizon is typically light in color. It is generally found beneath the O horizon.

B: The B horizon is a subsurface horizon that has accumulated from the layer(s) above. It is a site of deposition of certain minerals that have leached from the layer(s) above.

C: The C horizon is a subsurface horizon. It is the least weathered horizon. Also known as the saprolite, it is unconsolidated, loose parent material.

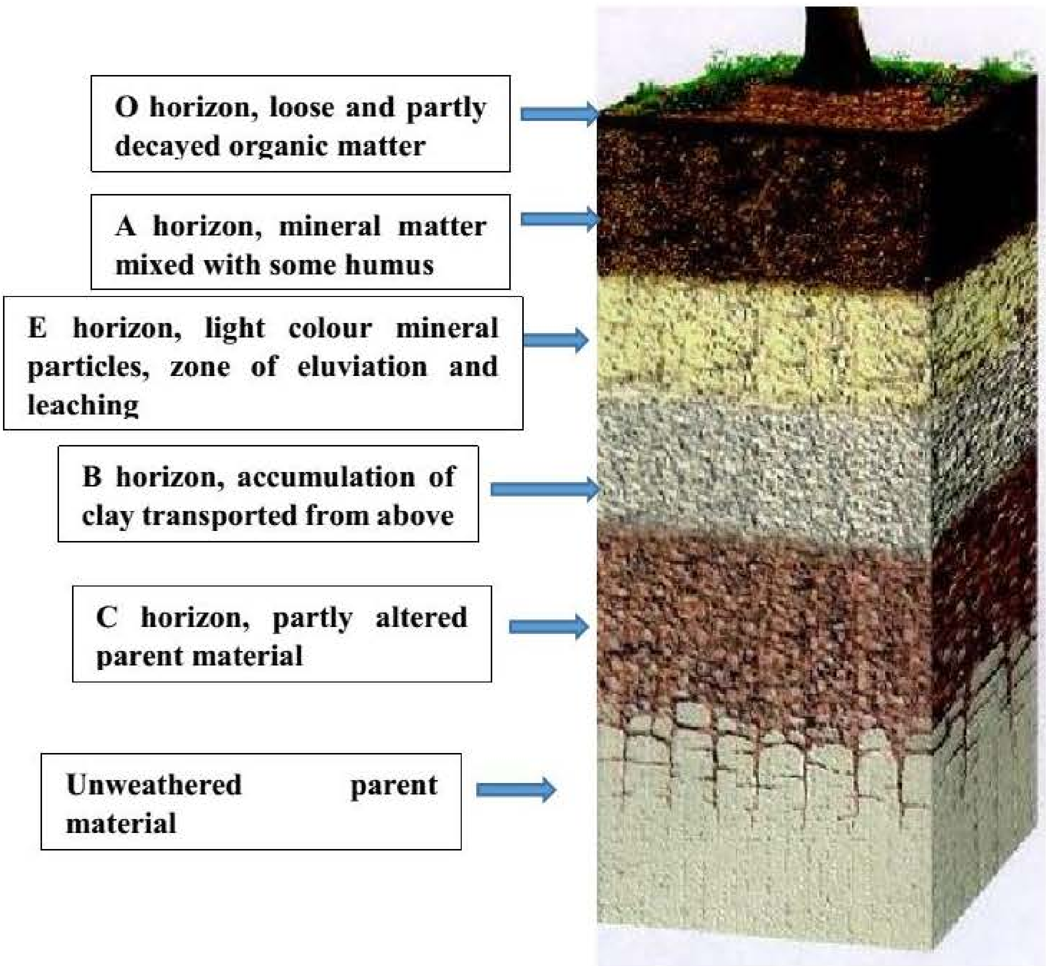

Fig.2: A portrayal of the horizons within the profile of a typical forest soil.

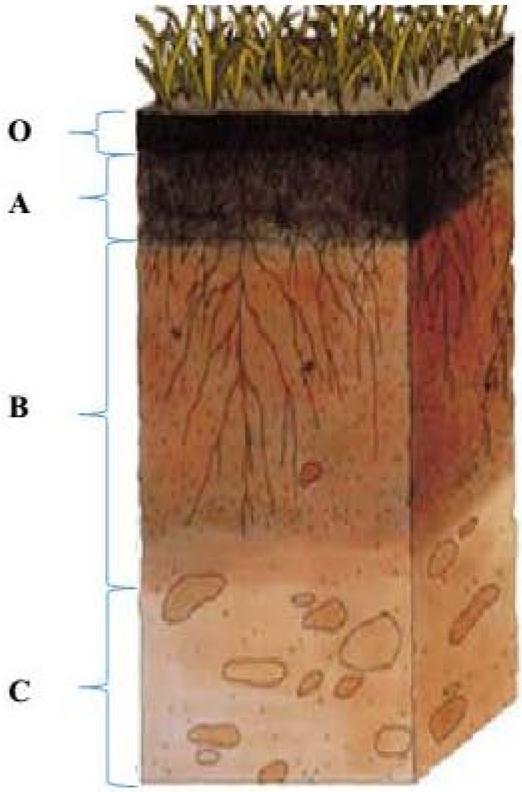

Fig.3: Grassland soil profile.

Soil erosion

Soil erosion: movement of soil components, especially litter & topsoil, from one place to another.

- Losing topsoil makes soil less fertile & reduces their water holding capacity;
- While soil is a potentially renewable resource, it takes long periods of time to form topsoil, typically 200– 1000 years to form 2.5 centimeters (1 inch) of topsoil;
- Topsoil is eroding faster than it forms in about one–third of the world's cropland.

Types of soil erosion

- **Normal erosion:** This is caused by the gradual removal of topsoil by natural processes. The rate of erosion is slow.
- **Accelerated erosion:** This is caused by manmade activities. In this case, the rate of erosion is much faster than the rate of formation of soil.

Causes of soil Erosion

- **Running water:** a) Uniform removal of soil b) Rill erosion c) Gully erosion (e.g. northern Punjab, Haryana, Rajasthan, M.P., and U.P)
- **Wind Erosion**: Mainly in the arid and semi-arid regions.
- **Anthropogenic factors:** Farmland can be degraded in several other ways besides erosion. Physical degradation from mechanical tilling can lead to compaction and crusting of soil.

Causes of soil Erosion

- **Biotic agents:** Overgrazing, mining, and deforestation are the major biotic agents causing soil erosion. These processes disturb the topsoil thereby exposing the soil to various physical forces inducing erosion
- **Landslides cause soil erosion**: Construction of dams, buildings, and roads removes the protective vegetal cover leading to soil erosion.

Harmful Effects of Soil Erosion

- Loss of fertile topsoil leading to gradual loss of soil fertility and agricultural productivity.
- Loss of mineral nutrients from the soil through leaching and flooding.
- Loss of soil ability to hold water and sediment
- Sediment runoff can pollute water courses and kill aquatic life
- Lowering of the underground water table and decrease in the percentage of soil moisture.
- Drying of vegetation and extension of arid lands.
- Increase in frequency of droughts and floods.
- Silting of river and canal belts.
- Recurrence of landslides.
- Adverse effect on economic prosperity and cultural development.

Mineral Resources

A naturally occurring concentration of solid, liquid, or gaseous material in or on Earth's crust that can be processed into useful materials at an affordable cost.

Energy resources: coal, oil, natural gas, uranium, geothermal energy sources;

Metallic mineral resources: iron, copper, aluminium. Ore is a metal–yielding material that can be economically extracted. To make profitable, copper must be concentrated 86 times, gold 1,000 times, & mercury 100,000 times the crustal average.

Nonmetallic mineral resources: salt, gypsum, clay, sand, phosphates, water, & soil.

Types of mineral resources

On the basis of chemical and physical properties, minerals may be grouped under two main categories: i.e. metallic and non-metallic which may further be classified as follows:

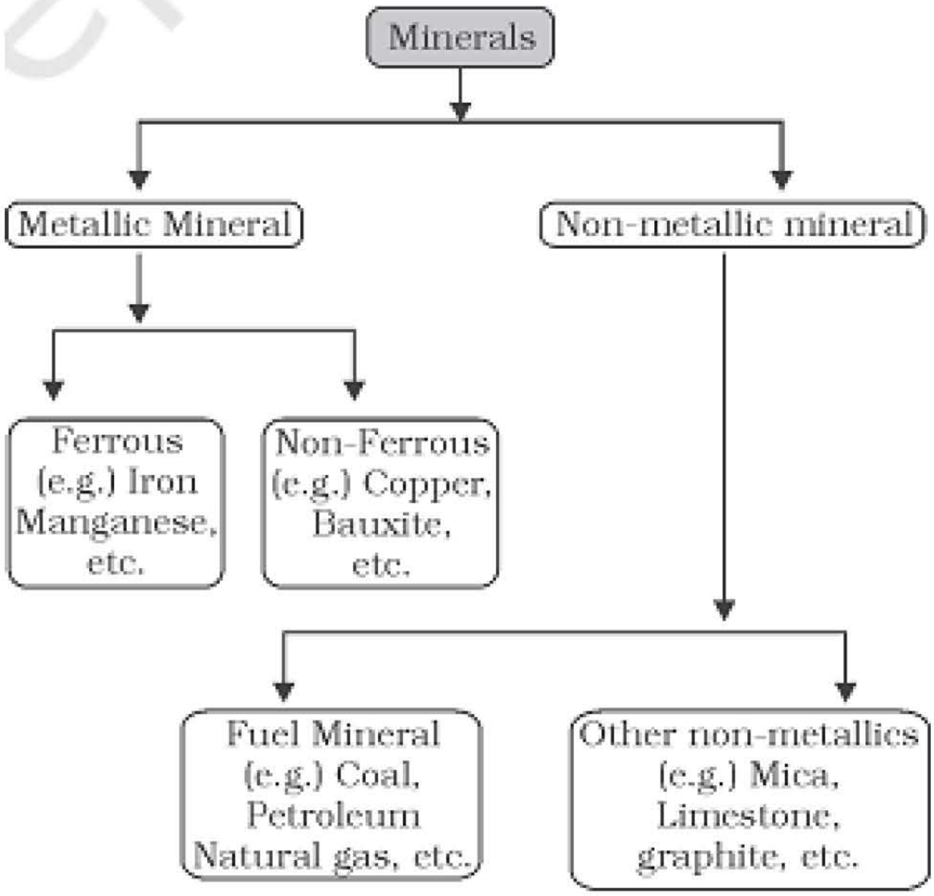

Fig. 4: Classification of Minerals

Mineral Resources Problems

- Non-renewable resources
- Finite amount of mineral resources and growing demands for the resources
- Supply shortage due to growing global industrialization
- With more developed countries consuming disproportionate share of mineral resources
- The uneven distribution of the resources and consumption of the resources.

Environmental Impacts of Mineral Development

The environmental impacts come from

- Mineral exploration and testing
- Mineral mining
- Mineral resources refining
- Mining waste disposal

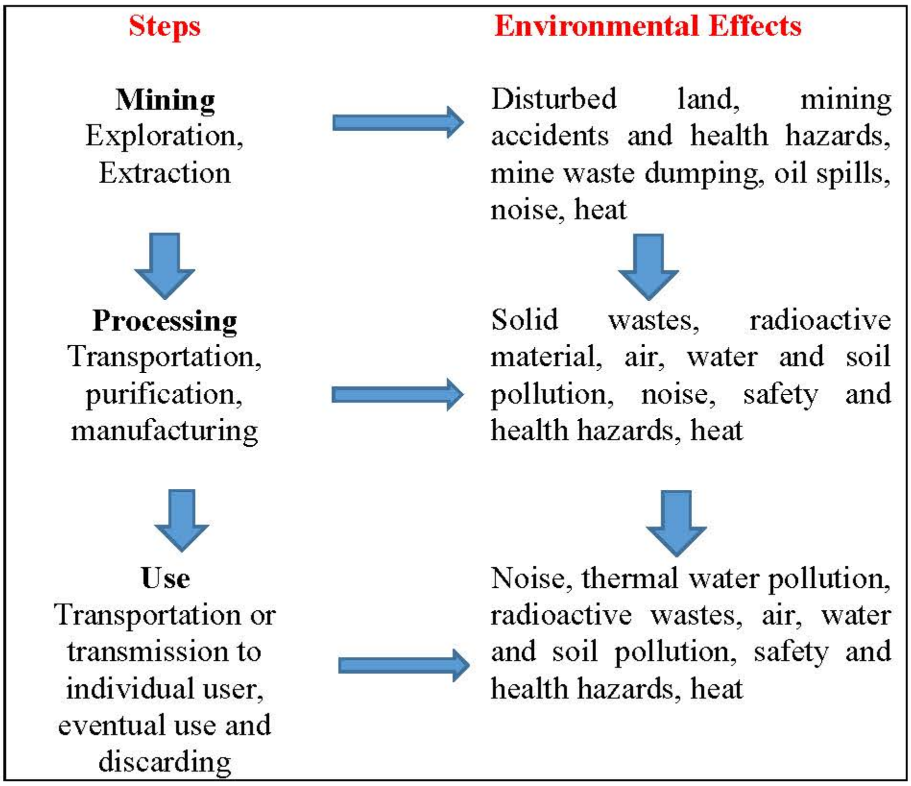

Fig. 5: Environmental impacts of mineral extraction and uses

Impact of Mineral Extraction and Processing

- Direct impact on land, water, air, and biological environment
- Indirect impact on the environment
- Topographic effect, transportation of materials, etc.
- Impact on social environment
- Increased demands for housing and services

Impact from mining operations

- Land disturbances from surface mining
- Waste from mines: 40% of the mining area for waste disposal
- Special mining: Chemical leaching from gold mining
- Mining acid drainage during mining and post mining
- Water pollution, such as smelting emissions of SO_2
- Biological environment

Water Pollution

- Trace elements leaching out into water such as Cadmium (Cd), Cobalt (Co), Copper (Cu), Lead (Pb), Molybendium (Mo), Zinc (Zn)
- Flooding of abandoned mines
- Acid mine drainage from tailings
- Acidic and toxic mining wastewater