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NAAC ACCREDITED 'A' GRADE

Topic:	**THE STORY OF SOIL FORMATION**
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Name of the Department:	Environmental Science

Introduction:

Soil: the crucible of life on the Terrestrial Earth can be defined as a finely divided layer of weathered minerals and organic matter on which plants grow. It is both an ecosystem in itself, and a critical part of the larger terrestrial ecosystem.

If you look around and dealt into the past, soil is not always looked at as an entity, rather it is considered to be the matrix of productivity. At the time of hunters and foragers, when for the first time people learnt the growing crops or using the surface for grazing of their domesticated animals, the concept of land developed. Consequently, the productivity came into question and we felt the existence of the matter that built up the land – the Soil. Thousands of years passed, and in the 19th century, discipline oriented concepts based on the background and interests of the scientists of different disciplines developed (Arnold, 2006). While geologists refer to soils as the straight line function of rocks to soils, on geomorphologists recognise it as the upper most layer of the earth with surface features. Similarly, chemist, biologists, agricultural scientists etc. found their own interest in the subject from different viewpoints. However, more recently, the study of soil comes as an inter-disciplinary subject of soil science and pedology. With time pedologic concepts and terminology of soil horizons, solum, profile and weathering layers have developed and come into existence and been adopted to meet both the scientific and societal needs (Arnold, 2006).

Chemically, soil is a mixture of minerals, organic matters, air and water to form a tissue thin layer over the lithosphere. Component wise, soil can be positioned at the interface of lithosphere (soil particles, i.e. minerals and organic matters), atmosphere (soil air) and hydrosphere (soil water or soil solution) where biosphere (soil micro organisms and other biota) play their role as facilitator of interactions. In other form, soil can be dealt with in three different aspects like, physical aspets that includes soil structure and texture, Chemical aspects including organic and inorganic matters i.e., different types of salts etc. and soil biology including the mass of biota and their ecosystem interactions.

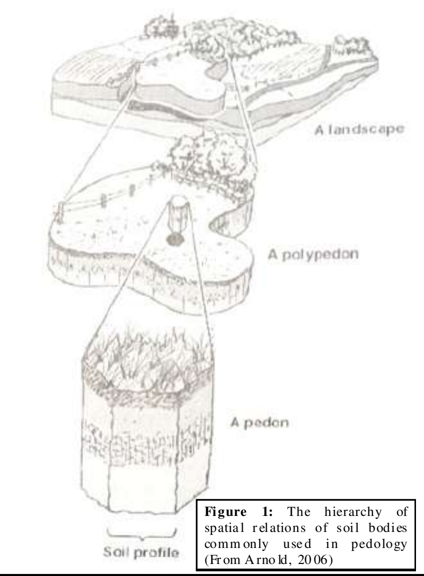


Figure 1: The hierarchy of spatial relations of soil bodies commonly used in pedology (From Arnold, 2006)

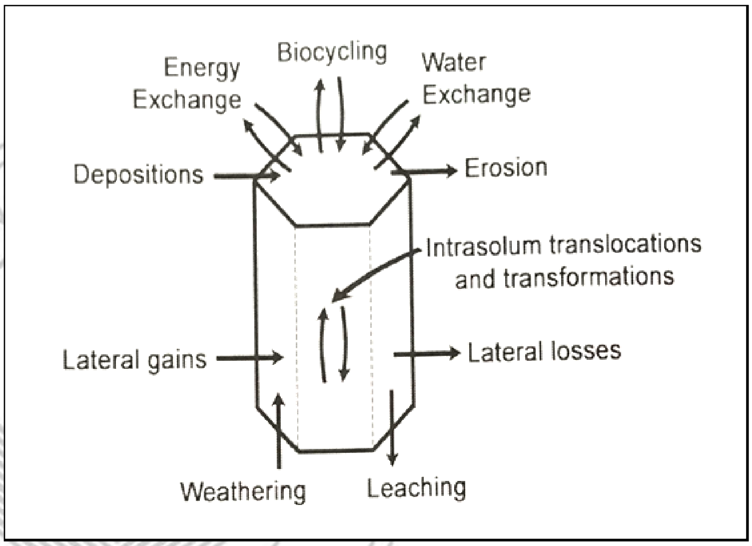
The conservation and protection of soil, need for basic units of classification and for mapping was evident. Based on the 'neo-Dokuchaev paradigm of pedology' that relates factors – processes – properties there arose two major pedological concepts of soil represented by *Pedon* and *Polypedon.* Pedon is an arbitrary volume that represents the smallest three dimensional unit of soil, while Polypedon is a small unit of landscape which may otherwise be called as a broader unit made up of more than one pedon together (Fig. 1). In fact, the vertically arranged two dimensional representation of a pedon may be termed as 'soil profile'.

Genesis of Soil (Pedogenesis):

The entire volume of material defined as soil is actually a single layer in a largest context of the lithosphere, where soil is considered to be the tissue thin outermost part of Earths' crust. The soil gets its organic matters from the above in form of basically plant materials and less frequently along with decaying organic zoogenic matters. However, in both the cases the organics are actually the assimilated carbon in the ecosystem. As it is already discussed, the soil is finely divided or weathered rock fragments which supplies the inorganic or mineral portions of it. Hence, the soil is can be seen as an open system where materials can be added, transformed, translocated and removed.

The process of soil horizonation and formation therefore include an array of processes as described in following paragraph. The pedogenesis includes (as per Buol, 2006),

1. Energy exchange as soil surface is daily heated and being cooled.
2. Exchange of water and moisture through the processes of precipitation and evapo-transpiration.
3. Biocycling, the cyclic process of essential plant nutrient uptake, assimilation of the nutrients and carbon for growth, storage as biomass and receiving those material back to soil surface as vegetation dies.



4. Erosion and deposition of surface soil materials by wind and water.
5. Weathering processes altering minerals. Some elemental compounds of primary minerals are removed and some are restructured into secondary minerals as soil wet and dries.
6. Leaching processes remove soluble organic and inorganic compounds as water percolates beyond the root zones.
7. Lateral transfer of soluble and suspendable material takes place in the flow of groundwater adjacent to soil.
8. Intrasolum translocation processes represent the movement of mineral and organic substances and particles within the soil. During this process the materials within soil physically moves and get mixed up by action of air, water, flora, fauna, frost, salts, vibration, human activities etc. through the generic process of pedoturbation (Box 1).

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BOX 1

Pedoturbation

The term ***Pedoturbation*** is synonymous to soil mixing. Or it can be defined as the process of **soil mixing** accomplished by a number of vectors like plants, animals, gravity, impacts from meteoroids, water, shrink-swell clays human activities etc.The process affects the soil generation and its developmental pathways almost continually, but is **not always synonymous to homogenisation**. Some consider it as a process that helps in soil formation from disordered parent materials, while others think this churns the layers of soil.

Accordingly, pedoturbation is classified in two groups:

Proisotropic pedoturbation: The kind of pedoturbation processes that **disrupt, blend or destroy horizons**, or genetic layer and/or impede their formation to cause morphologically simplified profiles.

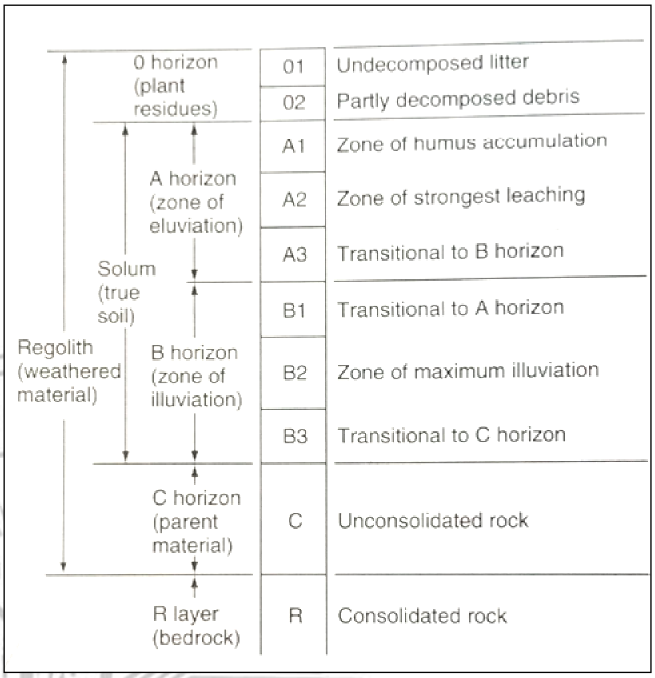
Proanisotropic pedoturbation: The processes that aid the **formation or maintenance of the horizons**, subhorizons or genetic layers and/pr cause an overall increase in the profile order.

Types of Pedoturbation:

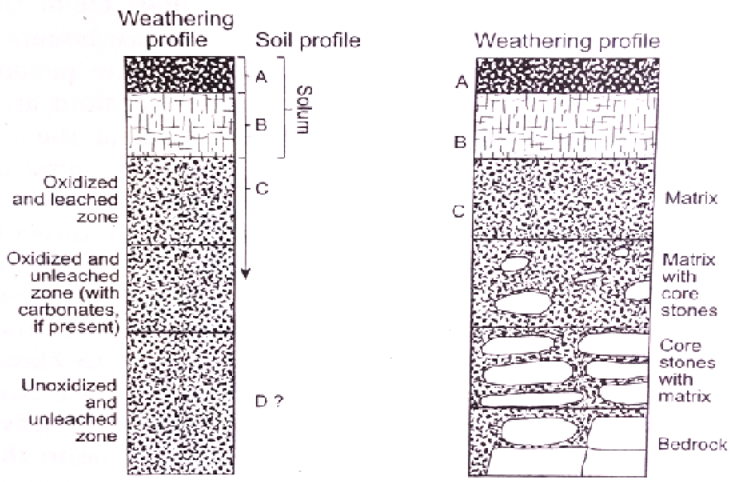
1. **Aeroturbation:** This includes minuscule form of mixing by gases, as are given off by various forms of microorganisms, roots and different faunals inhabitants.
2. **Aquatrubation:** Movement of water in soil usually at a microscopic scale causes **dissolution** and **translocation of ions and colloids**.
3. **Faunalturbation:** Soil fauna – termed as *infauna* are the most discussed vector of pedoturbation. The main pedogenic activities of soil fauna includes **Mounding, mixing, void formation, formation and destruction of peds,** facilitating **air and water movement, nutrient cycling** etc.
4. **Floralturbation:** This process usually takes place through **root expansion, decay and infilling of root channels, root movement** caused by agitation by wind and **uprooting.**
5. **Cryoturbation:** This is a subset of the larger term frost action in soils, also known as *Geliturbation* or *Congelliturbation*. Cryoturbation is common in areas with soil freezing, but minimal at the areas of dry permafrost. The sheer stress experienced by freezing and melting with within soil layer results in turbation process.
6. **Argilliturbation:** Silicate clays like smectite etc. having higher linear extensibility undergo significant volume changes under wetting. This leads to turbation of soil particles through frequent swelling and shrinking under influence of water.
7. **Graviturbation:** Downslope transport of sediments and soil by action of gravity is known as mass-wasting. The turbation of Regolith during transport is a function of mass-wasting or mass-movement and termed as graviturbation.
8. **Anthroturbation:** Mixing of soil by human activities like grazing, ploughing and different other soil based activities are most common form of turbation. It has a subset as *urbanthroturbation* that exclude the agricultural activities.
9. **Crystalturbation:** Crystal growth of Sodium chloride (NaCl), Gypsum ($CaSO_4 . H_2O$), Calcite ($CaCO_3$) etc. although is insignificant turbation vectors, but may be destructive when in specific cases their volume become large compared to the matrix.
10. **Sismiturbation:** Sismic activities may play importantly in moving, shaking and crushing of rocks and regolith on the earth crust. It, may trigger the mass wasting and may even directly take part in large scale pedoturbation.

It seems for the short time being that the soil is permanent or stable with its properties, but actually the process of change remains dynamic and perhaps no one has seen a mature soil form in *toto* (Buol, 2006). All soils move vertically in space and time and this movement occurs as erosion and dissolution remove mateirals. In contrast, in some locations upward movement occur as material is deposited by flooding water and volcanic depositions.

The pedogenesis begins with physical disintegration of exposed rock formation, which provides the soil its parent materials. The loose unconsolidated material at the Earth surface is called *Regolith.* It can be formed in place as bedrock weathers and is then called residual regolith or simply *Residuum,* or regolith may be may be transported to a site by action of gravity, water, wind or any other vector (Schaetzl and Anderson, 2005) to form ex-situ soil. Gradually the loosened materials are colonised by living organisms and consequent accumulation of the organic residues below the surface brings about the development of a discernible 'A' horizon. Although, this horizon is quite stabilized and has aggregated structure, but continued chemical weathering may bring about the formation of clay which tend to move downward along with other transferable materials like soluble salts. This movement and consequent accumulation leads to formation of the intermediate zone called 'B' horizon. the deeper parent materials below this zone is called 'C' horizon (Hillel, 2008).



Sometimes the transported regoliths are little weathered, especially if buried deeply. Thus immediately below the soil profile, there may present a zone of transported regolith slightly altered by leaching and/or oxidation. This comparatively unweathered and unmodified zone is sometimes known as 'D' horizon marking the lowermost layer of the profile (Schaetzl and Anderson, 2005). Together, the active horizons and 'D' horizon constitute weathering profile and are known to have basically three zones like, 1) oxidised and leached, 2) oxidized and



Source: Schaetzl and Anderson, 2005

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unleached and 3) unoxidized and unleached (Bettis, 1998 as cited in Schaetzl and Anderson, 2005).

Important aspects of soil formation and profile development are the twin processes of eluviation (washing out) and illuviation (Washing in), whereby clay and other substances emigrate from overlying eluvial 'A' horizon and accumulate in the underlying 'B' horizon. Throughout the processes, the profile as a whole deepens and the upper part of 'C' horizon is gradually transformed. Eventually a quasi-stable condition is approached in which the counteracting processes of soil formation and soil erosion are more or less in balance (Hillel, 2008). However, the soil profile or more specifically the soil horizons can be seen as the pages of books, that describe the history and characteristics of the soil itself. The soil horizon is described as 'working aggregates of whole soil system, and like the organs of an organism, generally are adapted for the performance of specific functions (Anderson, 1987 as cited in Schaetzl and Anderson, 2005). The major soil horizons are discussed in the 'Box 2'.

BOX 2

Major / Master Soil Horizons are:

O : Organic Horizon that forms above a mineral horizon.

A: Top soil layer reach in decomposed organic matters and minerals. Characterized by intimately mixed mineral fractions with humified organic matters. Properties influenced by anthropogenic surface disturbances.

E: Light colour eluvial horizon, in which the main feature is loss of weatherable materials.

B: Subsurface mineral horizon, characterized by i) illuvial accumulation of clay, Fe, Al, humas ii) removal of primary carbonates, iii) distinct non-geologic features and brittleness.

C: Mineral soil layer excluding hard base rock and retains some rock structures.

D: An informal zone of comparatively unaltered material deposited as transported regolith.

R: Hard continuous bedrock

Weathering: the forerunner of pedogenesis:

The formation of soil starts with the disintegrated fragments of rocks – also called 'residuum', which is actually a product of weathering. Weathering consisting of physical fragmentation of exposed rocks and chemical decomposition and recomposition of their mineral constituents, is a feeble but relentless process capable of breaking down strong, dense and massive bedrocks like granite, basalt etc.

Exposed rock surface are subjected to continuous expansion and contraction owing to diurnal and seasonal temperature fluctuations. Wetting and drying of porous rocks, freezing and thawing of water in cracks, pressures from growing roots, abrasion the particles carried by wind and water etc. put further stress on the rocks. In addition, soluble compounds of minerals present in the rocks are dissolved and transported by recurrent rain, percolate into the fragmented rocks and re-precipitate at various depths. Superimposed upon these physical processes numerous chemical reactions tend to modify the minerals present in the original bed rocks. These reactions include, hydration, oxidation, reduction, acidification and alkalization. However, the types of weathering are given below.

WEATHERING		
Physical/ Mechanical	**Chemical**	**Biological**
1. Frost Action 2. Thermal Expansion 3. Wetting & Drying 4. Salt Decay	1. Dissolution i. *Congruent* ii. *Incongruent* 2. Oxidation 3. Hydration 4. Hydrolysis 5. Carbonation	1. Chemical modifications in pH, moisture etc. 2. Activities of burrowing animals. 3. Physicochemical changes by Lichens

The factors influencing the weathering process are:

- **Slop gradient:** It controls the force of weathering agents like water and hence is a control itself.
- **Bedrock condition:** The depth and nature, i.e. consolidation and composition of bed rock is one of the main control of weathering.
- **Precipitation:** The amount of down pouring is vital factor of the rate of weathering.
- **Temperature:** The range and fluctuation of temperature is important for physical weathering.
- **Evaporation:** It is another important factor for physical weathering processes.
- **Litter fall:** Addition of organic matter influence the biochemical process of weathering.

Not only the presence or conditions of the factors, but also the intensity and exposure to the weathering agents, viz., nature and concentration of chemicals, contact time with the weatherable material, composition of parent rock and Exposure time to a physical agent, play important role in weathering.

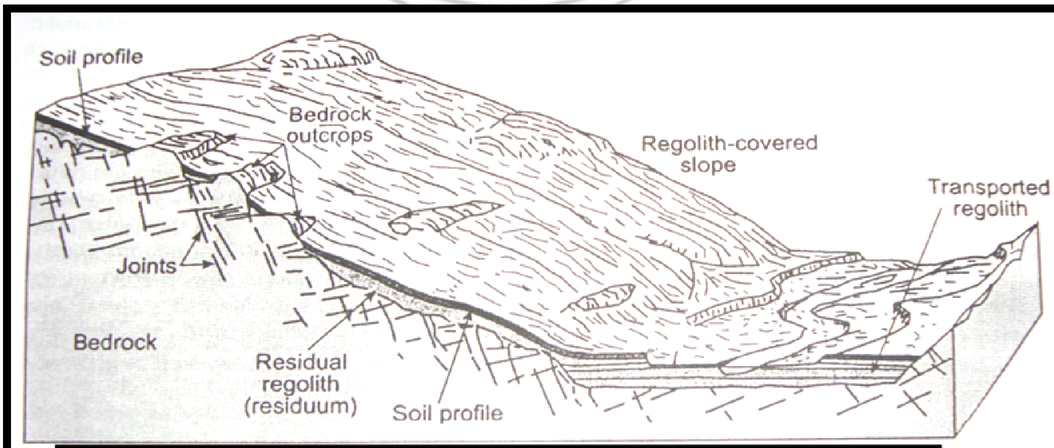

Figure: Diagram of a Regolith-covered slope illustrating the diffrence between bedrock, residual regolith and transported regolith.

(Strahler and Strahler, 1992)

Why do we have different soil types?

Two overlapping trends in soil development are horizonation and haploidization. Simply, stated these are processes that tend to form layers or horizons within soil or mix the soil respectively. In other words the processes have been put forward in the Box 1 of this write up as pro-isotropic and pro-anisotropic pedoturbation. Mixing processes are more prevalent near soil surface and led to generation of surface horizons while the translocation is more active in forming distinctive sub-surface horizons. Most **'surface horizons'** called ***epipedons*** in soil taxonomy (Soil Survey staff 2006 as cited in Buol, 2006) result from the mixing of organic materials and mineral materials. These are also commonly known as **diagnostic horizons.**

The distinctive **surface horizons or epipedons** include.

- **Mollic epipedons,** which are thick dark coloured surface horizons containing more than 1% organic matters and 50% or more base saturation among the CEC at pH 7. This form a calcium rich mineral material generally under grass vegetation.

- **Umbric epipedons,** are similar in organic content to that of mollic epipedons but is having less that 50% base saturation. They are most often formed in acid geologica material and gives organic matter a stability due to low temperature and draining condition.

- **Orchric epipedonsare** having very low organic matter content due to slow growth of plants in moisture and temperature limited climate.

- **Histic epipedons** contains more than 20 to 30% organic matter. They are almost entirely present where the soil is saturated with water much of the year.

- **Plaggen epipedons** are surface horizon with intensive input of manure and organic residues by the human activities. Other distinctive surface horizons created by a shorter term human activity in soil taxonomy is called **anthric epipedon.**

  As per the World Reference base (WRB) there are specific kinds of epipedons depending on specific human activities, like **Anthric** (formed by long term ploughing, liming, fertilization etc.), **Irragric** (formed by use of muddy irrigation water), **Hortic** (formed by deeper than normal cultivation and intensive application of fertilizers and manure) and **Anthraquic** (formed over a 'puddled' slowly permeable plough pan created by long term cultivation of crops like rice in flooded field) (Boul, 2006).

Preferential losses, accumulations and mineral tranfromations of specific soil components are responsible for most subsoil horizons. Water and other physical movement of water is the primary agent for these intrasolum processes. Translocation of minerals, through the processes of congruent and incongruent dissolution and subsequent eluviation or illuviation leads to development of different soil properties. Specific subsoil horizons are identified by the properties they acquire from the relative intensity of eluviations, illuviation and leaching processes that have been and continue to be active at a specific depth.

Subsoil horizons with specific properties and characteristics are defined in modern soil classification system. Some of the subsoil horizons are discussed in the following section (adopted from Buol, 2006).

- **Argellic horizons** are clay reach subsoil layer having 1.2 times as much clay as horizons above. Clay that has been in the soil for a longer period often coated with iron oxide and appears less subject to illuviation.
- **Kandic horizons** are similar to Argellic horizon containing primarily kaolite clay and CEC lower than 16 $cmol^{+}$ kg^{-1} clay at pH 7.
- **Albic horizons** are light coloured horizonz below dark coloured surface horizon and sometimes known as 'E' horizon.
- **Calcic horizons** are accumulations of calculum carbonate. They are common in arid climate with little leaching when carbonate minerals are present in the parent materials. Hard calcic horizons containing more silicon are known and **petrocalcic horizon.**
- **Spodic horizons** are formed by aluminium and iron eluviated from O, A and E horizons. Along with Al and Fe, monovalent cations and other ions like Ca^{2+} and Mg^{2+} are also leached down. The process is largely governed by the production of organic acids from the plant materials deposited on the surface of the soil.
- **Cambic horizons** are horizons that have some alterations of primary minerals present in the parent materials. Removal of iron, carbonate and gypsum from parent materials is sometimes act as identifying criteria of cambic horizon.
- **Gypsic horizons** contains 5% or more gypsum accumulation.
- **Natric horizons** contains 15% sodium or more exchangeable sodium plus magnesium than calcium on CEC.
- **Oxic horizons** are sandy loam or finer textured and almost always present in subsoil material that has been previously exposed to weathering in other soils and during previous transports to its present site.
- **Salic horizons** develop in arid climate where there is little or no leaching and soluble salts accumulate near soil surface.
- **Sulfuric horizons** (thionic horizon) are formed as sulphates accumulated in some horizons that are saturated with brackish water.

A few specific processes remains active in formation of subsoil horizons are discussed in following table.

Laterization	Podzolization	Calcification	Salinization	Glaziation
Eluviation of ions other than Fe and Al leads to formation of	Leaching of Cations, Fe, Al to form spodic horizon	Dissolved alkaline salts move upward and Ca^{2+} deposited in B horizon to	Salt deposit happens in surface layer due to upward movement led by	Organic materials accumulates at upper layer due to poor drainage

reddish soil.		form **Caliche** layer.	evapotranspiration.	

There are several schemes of classification of soils used in different parts of the globe. However, one of the most accepted scheme given by NRCS has been discussed in the Box 3.

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Box 3

SOIL CLASSIFICATION (As per Natural Resource Conservation Services)

Oxisols develop in tropical and subtropical latitudes with high precipitation and temperature. The profiles of oxisols contain mixtures of quartz, kaolin clay, iron and aluminum oxides, and organic matter. No clear horizonation. Contain *laterite*.

Aridsols are soils that develop in very dry environments. Poor and shallow soil horizon development. Light colored because of limited humus additions. Salt deposition due to high rate of evaporation causes *Salinisation*.

Mollisols are soils common to grassland environments. Mollisols have a dark colored surface horizon, tend to be base rich, and are quite fertile. Mollisols of arid region often exhibit *Calcification*.

Alfisols form under forest vegetation where with significant weathering. Illuviation of clay occurs in the B horizon, moderate to high concentrations of base cations, and light colored surface horizons.

Ultisols are soils common in warm region that receives high amounts of precipitation. Well leached and highly weathered soil. Dominance of iron and aluminum oxides. Presence of Iron in A-horizon causes red surface.

Spodsols develop under coniferous vegetation and as a result are modified by podzolization. Low base concentration makes it acidic. Iron and Aluminum salts leach down to eluvial layer of B-horizon. Most spodosols have little silicate clay and only small quantities of humus in their A horizon.

Entisols are immature soils lacking vertical horizon development. These soils having recently deposited sediments from wind, water, or ice erosion may develop into another soil type.

Inceptisols are young soils, more developed than entisols. Common characteristics include immature development of eluviation in the A horizon and illuviation in the B horizon, and evidence of the beginning of weathering processes.

Vertisols are heavy clay soils that show significant expansion and contraction due to the presence or absence of moisture.

Histosols are organic soils that form in areas of poor drainage. Their profile consists of thick accumulations of organic matter at various stages of decomposition.

Andisols develop from volcanic parent materials. Volcanic deposits have a unique process of weathering that causes the accumulation of allophone.

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