SOILS AND THE ENVIRONMENT

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Contents

Summary

Soil is one of humanity's most important resources, not only is it important in agriculture but it is an important construction material. Soil is derived primarily from the breakdown of rocks by weathering and erosion processes. The resultant material may undergo varying amounts of transport before being deposited or may accumulate in places. Soil also usually contains some amount of organic material, with peat soils being composed mainly of organic matter. Time also is an important factor in soil development in that soils need time to reach maturity. Different types of soils develop under different climatic and vegetative regimes, and these are characterized by different horizons within the different soil types. Individual horizons or zones differ in character. The fertility of soils is influenced by a number of factors, the availability of nutrients for plant growth being one of the most important. Physically soil consists of solid particles and void space, the voids being occupied by air or water or both. In this context, the particle size distribution is important since it governs the size of the voids and therefore whether soils are well or poorly drained. Depending upon its moisture content, a clayey soil may be solid, semi-solid, plastic, or liquid. These states are defined by the consistency limits, namely, the shrinkage limit, the plastic limit and the liquid limit. Two notable properties of soil in terms of construction are the amount and rate of consolidation a soil undergoes when a load is placed upon it, and the strength of the soil, that is, the load it will carry immediately prior to failure. Soil erosion is a natural process but it commonly is accelerated by man as a result of unsuitable farming practices. Although it can occur in any climatic regime, it is most frequently associated

with semi-arid and arid regions. Soil erosion is brought about by the action of water or wind. Water erosion may be splash erosion (i.e. due to the action of raindrops), sheet erosion or gully erosion. Wind erosion can only remove soil particles beneath a certain size and is influenced by the nature of the ground over which the wind blows, particularly the amount of vegetation cover. Erosion control and soil conservation measures such as contour farming, strip cropping, crop rotation or the use of mulches or geotextiles can be used to reduce or prevent soil erosion. Windbreaks normally are used to reduce wind erosion. There are many types of soil that can present problems in relation to construction. One of the most notable is expansive clay, which expands when wetted and shrinks as it dries. Hence, low-rise buildings in particular may be subject to ground movements when constructed upon such soils. Dispersive soils erode in water without it having to flow and collapsible soils may collapse on wetting. Sabkha soils occur in arid regions and contain notable proportions of corrosive salts. Quicksands liquefy when subjected to dynamic loading, that is, vibration, and quick clays lose much of their strength on remoulding as, for example, happens when they are involved in landsliding. Peat soils contain large moisture contents, lack strength and suffer considerable consolidation if loaded. Soils may be permanently frozen in tundra climates, only the upper meter of so thawing out in summer. This can give rise to thaw-settlement beneath buildings if precautions are not taken. When this soil refreezes, it then experiences heave due to the water content expanding when it changes to ice. |Soil surveys are undertaken to determine soil types and properties, and to help assess land-use. Soil types are represented on soil maps.

1. Origin of soil

Soils are one of humanity’s most important resources. Although they are of most value in terms of agriculture, they also play an important role as construction materials. In the broader sense, soil supports the great majority of higher plants and therefore is essential to biodiversity and global cycles of energy and nutrients.

Soil is derived from the breakdown of rock material by weathering and/or erosion. It may accumulate in place or have undergone some amount of transportation prior to deposition. It may contain organic matter or, in the case of peat, consist mainly of organic material. The type of breakdown process(es) and the amount of transport undergone by sediments influence the nature of the macro- and micro-structure of the soil. The same type of rock can give rise to different types of soils, depending on the climatic regime and vegetative cover under which it has been developed. Time also is an important factor in the development of a mature soil, especially from the agricultural point of view.

Probably the most important methods of soil formation are mechanical and chemical weathering. The agents of weathering, however, are not capable of transporting material. Transport is brought about by gravity, water, wind or moving ice. If sedimentary particles are transported, then this affects their character, particularly their grain size distribution, sorting and shape.

Plants affect the soil in several ways. For instance, when their roots die and decay, they leave behind a network of passages that allow air and water to move through the soil more readily. Roots, especially those of grasses, help bind soil together and so reduce erosion.

But perhaps the major contribution to soil made by plants is the addition of organic matter. The total organic content of soils can vary from less than 1% in the case of some immature or desert soils to over 90% in the case of peat. Micro-organisms occur in greatest numbers in the surface horizons of the soil where there are the largest concentrations of food supply. They are particularly important in terms of the decomposition of organic matter, which leads to the formation of humus.

Changes occur in soils after they have accumulated. In particular, seasonal changes take place in the moisture content of sediments above the water table. Volume changes associated with alternate wetting and drying occur in cohesive soils with high plasticity indices. Exposure of a soil to dry conditions means that its surface dries out and that water is drawn from deeper zones by capillary action. The capillary rise is associated with a decrease in pore water pressure in the layer beneath the surface and a corresponding increase in effective pressure. This supplementary pressure is known as capillary pressure and it has the same mechanical effect as a heavy surcharge. Therefore, surface evaporation from very compressible soils produces a conspicuous decrease in the void ratio of the layer undergoing desiccation. If the moisture content in this layer reaches the shrinkage limit, then air begins to invade the voids and the soil structure begins to break down. The decrease in void ratio consequent upon desiccation of a cohesive sediment leads to an increase in its bearing strength. Thus if a dry crust is located at or near the surface above softer material it acts as a raft. The thickness of dry crusts often varies erratically.

Chemical changes that take place in the soil due, for example, to the action of weathering, may bring about an increase in its clay mineral content, the latter developing from the breakdown of less stable minerals. In such instances, the plasticity of the soil increases while its permeability decreases. Leaching, whereby soluble constituents are removed from the upper, to be precipitated in the lower horizons, occurs where rainfall exceeds evaporation. The porosity may be increased in the zone undergoing leaching.

2. Soil horizons

With continuing exposure soil develops a characteristic profile from the surface downwards. A soil profile is divided into zones or horizons, which differ in character from the parent material to the soil surface. The master horizons are denoted by a capital letter as follows:

H: Formed by the accumulation of organic material deposited on the soil surface. Generally, contains 20% or more organic matter. May be saturated with water for prolonged periods.

O: Formed by the accumulations of organic material (plant litter) deposited on the surface. Contains 35% or more of organic matter. Is not saturated with water for more than a few days of a year.

A: A mineral horizon occurring at or adjacent to the surface that has a morphology acquired by soil formation. Generally, possesses an accumulation of humified organic matter intimately associated with the mineral fraction.

E: A pale colored mineral horizon with a concentration of sand and silt fractions high in resistant minerals from which clay, iron or aluminium or some combinations thereof have been leached. E horizons, if present, are eluvial horizons, which generally underlie an H, O or A horizons and overlie B horizons.

B: A mineral horizon in which parent material is absent or faintly evident. It is characterized by one or more of the following features:
  (a) An illuvial concentration of clay minerals, iron, aluminium, or humus, alone or in combinations.
  (b) A residual concentration of sesquioxides relative to the source materials.
  (c) An alteration of material from its original condition to the extent that clay minerals are formed, oxides are liberated, or both; or a granular, blocky, or prismatic structure is formed.

C: A mineral horizon of unconsolidated material similar to the material from which the solum is presumed to have formed and that does not show properties diagnostic of any other master horizons. Accumulations of carbonates, gypsum or other more soluble salts may occur in C horizon.

R: Rock that is sufficiently coherent when moist to make hand digging impracticable.

Not all the horizons mentioned above necessarily are present in a given soil profile. The H, O and A horizons tend to be dark in color because of the presence of plentiful organic matter. The E horizon is light in color due to leaching of iron oxides from it. Sometimes notable changes in color may be displayed by the B horizon, varying from yellowish-brown to light reddish-brown to dark red. This depends primarily on the presence of iron oxides and clay minerals. The presence of carbonates may lighten the colors. Well drained soils are well aerated so that iron is oxidized to give a red color. On the other hand, wet poorly drained soils generally mean that iron is reduced, which may give rise to a yellow color.

As it takes time to develop a mature soil, different grades of soil profiles may be recognized from immature to mature. A poorly developed immature soil profile is one in which the A horizon may overlie the C horizon directly, and the C horizon may show signs of oxidization. In a moderately developed soil profile the A horizon may rest upon an argillic B horizon (i.e. one that contains illuvial clay and in which the peds may be coated with clay) that, in turn, is underlain by the C horizon. At times a carbonate B horizon also may be present. A mature well developed soil profile possesses a good soil structure in which the B horizon may contain a notable amount of clay material.

3. Soil fertility

Soil fertility refers to the capacity of a soil to supply nutrients needed for plant growth. More or less all soils have a certain inherent fertility. For example, soils that are acidic, alkaline, waterlogged or deficient in particular elements can support specific plant communities and, as such, can be regarded as fertile in relation to those communities. However, when humans attempt to cultivate such soils, the inherent fertility may be unsuitable for the particular crop(s). It then becomes necessary to alter the fertility by, for example, the addition of fertilizer or, installation of drainage or irrigation measures, to suit the needs of the crop(s).

Be that as it may, there are a number of factors that influence plant growth. These include soil aeration and moisture content, soil temperature, pH value and essential elements. Good aeration usually is facilitated by a granular or crumb structure and free drainage. An adequate and balanced supply of moisture is essential for plant growth. The particle size distribution, texture, organic content and structure of a soil affects its retention of moisture.

Generally, clays and organic soils have the highest moisture retaining capacity, while organic soils have the highest available moisture. The moisture retained in the soil is lost mainly by evapotranspiration so that the rate of loss depends upon temperature and plant cover; as they increase, moisture losses increase. On the other hand, wet or waterlogged soils need drainage for satisfactory cultivation of most crops. Drainage is beneficial to agriculture as it improves the soil structure, facilitates aeration, increases the rate of decomposition of organic matter, leads to an increase in soil temperature and increases the bacterial population in the soil. In addition, the thickness of soil available for root growth and penetration is very important.

Two important moisture characteristics of soil are the field capacity and the permanent wilting point. When soil is saturated and the excess water drains away, the soil is described as being at its field capacity. Plants extract moisture from the soil until, as the soil dries out, it becomes impossible for them to continue doing so, they then wilt and die if the soil is not rewetted. The point at which permanent wilting starts is known as the permanent wilting point. The field capacity and permanent wilting point have been defined in terms of soil suction, the pF values being 2.0 and 4.2 respectively. The permanent wilting point varies from soil to soil and plant to plant. Water held between the field capacity and the permanent wilting point is the water available to plants, and similarly the amount varies considerably from soil to soil.

The pH value for soils ranges between 3 and 9, although the range for cultivated soils is more limited, tending to vary from 5.5 to 7.5. Very low values sometimes can be found in swamps where breakdown of organic material produces humic acid and sulphides give rise to sulphuric acid. At the other extreme, very high pH values may be attributable to the presence of sodium carbonate. This may be the case in some salinas or sabkhas. Generally, pH values about neutral are associated with large amounts of exchangeable calcium and some magnesium. High acidity may lead to increasing amounts of manganese and aluminium in the pore water, with little formation of ammonia or nitrate, low availability of phosphorus and molybdenum deficiency.

A number of elements are essential for healthy plant growth. However, they must be present in the soil in the correct proportions. If there is an excess or deficiency in any one element, plant growth can be affected seriously, plants developing symptoms of toxicity or nutrient starvation. Of the essential elements, calcium, carbon, hydrogen, magnesium, nitrogen, oxygen, phosphorous, potassium, and sulphur, should be present in soil in relatively large amounts whereas boron, chlorine, cobalt, copper, iron, manganese, molybdenum, and zinc are necessary in small amounts. Most of these elements (i.e. except those obtained from the air) are derived initially from the breakdown of minerals within the parent rock, and are taken up by the plant roots. They subsequently are returned to the soil in the plant litter when it decomposes, thereby releasing the elements into the soil for the cycle to begin again.

4. Pedological soil types

A comprehensive pedological classification of soils has been developed by the Food and Agriculture Organization (FAO) of the United Nations (Anon, 1980). Accordingly, the following description of major soil types is from that of the F.A.O.

The gleysols of tundra regions are characterized by a thin accumulation of organic matter at the surface, beneath which there is a dark greyish brown mixture of mineral and organic material lying on top of a wet mottled horizon about 500 mm thick. Then follows a sharp change to permafrost. The upper horizons freeze in winter and thaw in summer.

South of the tundra there are extensive areas of histosols with marshy vegetation dominated by peat soils. Peats tend to be acidic and peaty soils need to be drained and limed if they are to be cultivated.

The podsols tend to coincide with the coniferous forest regions and some heathlands. They are characterized by an accumulation of plant litter at the surface, below which there is a layer of dark brown, partially decomposed plant material (Figure 1a). This grades into very dark brown amorphous organic matter. A dark grey layer of mixed organic and mineral material occurs beneath the organic matter. This is followed by a pale grey horizon, which has been leached of iron compounds and organic matter by downward percolating water. The leached material is precipitated beneath this horizon to form sesquioxides. A layer of hard pan may be present at this level. Finally, the unaltered parent material occurs below this horizon. Podsols may be up to 2 m in thickness. These soils are usually acid, with pH values of less than 4.5 at the surface, increasing to about 5.5 in the lowest horizons. They also are very deficient in plant nutrients except in the surface organic matter, which releases them upon decomposition.

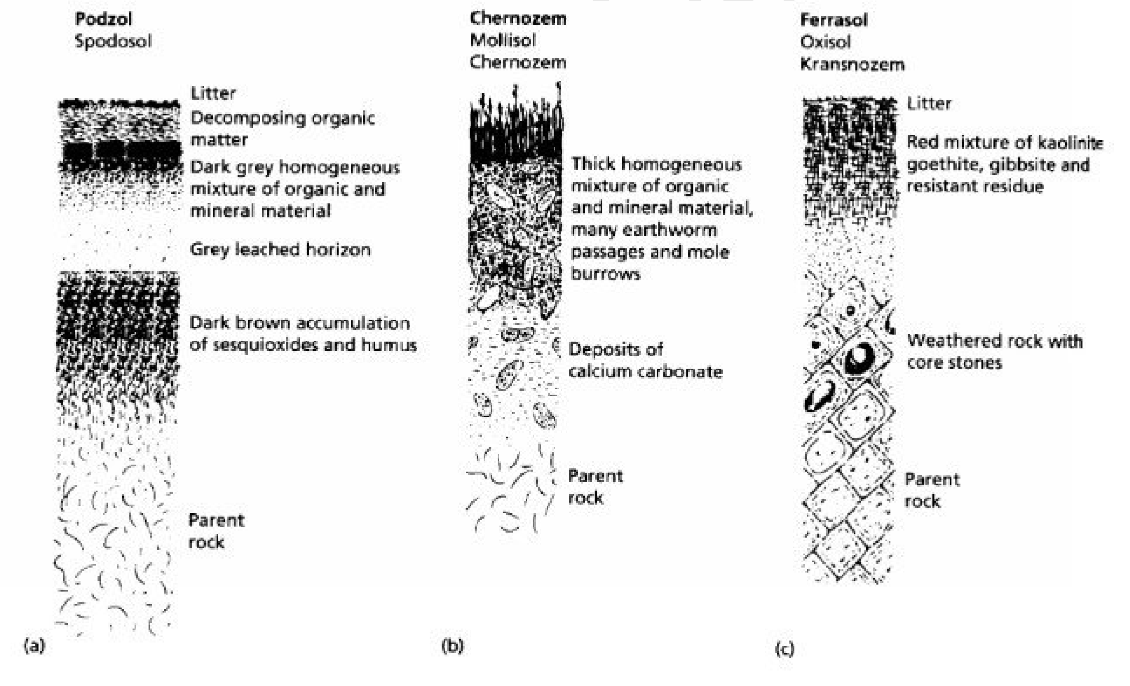

Figure 1. Soil profiles (a) a podsol (b) a chernozem and (c) a ferrasol.

The cambisols, commonly known as brown earths, occur beneath some deciduous woodlands of the cool temperate regions. There is a continuous gradation from podsols to cambisols. At the surface of a cambisol there is a loose layer of plant litter resting on a brown or greyish brown horizon of mixed organic and mineral material. This overlies a brown, friable, loamy B horizon, which grades into unaltered material. This parent material at times is basic or calcareous and gives the soil a high base saturation. These soils generally are slightly acid to mildly alkaline. Organic matter is rapidly broken down and incorporated into the soil, giving it a high natural fertility.

Luvisols also are found in cool temperate regions beneath deciduous forests or mixed deciduous and coniferous forests. A thin layer of loose plant litter rests on a greyish brown mixture of organic and mineral material. This changes into a grey sandy horizon, beneath which occurs a sharp change to a brown blocky or prismatic horizon that has a high content of clay. Then there is a gradation to the unaltered material. These soils have a middle horizon that contains more clay than those above or below (argillic B horizon), due to clay particles being washed from the upper horizons. Luvisols are weakly acid at the surface with medium base saturation, which means that they have a moderate natural fertility.

As the precipitation declines to less than 400 mm on moving towards the equator, then the deciduous forests are replaced by grasslands. Here are found the black earths or chernozems. These soils have a root mat at the surface that overlies a thick black horizon with a high humus content that may be up to 2 m in thickness (Figure 1b). Thin thread-like deposits of calcium carbonate occur in the lower part of this horizon, as well as below. Concretions of calcium carbonate also may be present. The black horizon grades into yellowish brown material. Chernozems have neutral pH values, very high base saturation, and a very high inherent fertility. These soils have a well developed crumb structure and high water holding capacity due to their high organic content from annual increments of dead grass.

With further decrease in precipitation, the vegetation changes from tall grass, to short grass, to bunchy grass, and then to species that can withstand long dry periods. Accordingly, there are similar changes in the soils with the thick black horizon becoming lighter in color and shallower, and the calcium carbonate horizon approaching the surface. Generally three soil types can be recognized, namely, the kastanosems, the xerosols and the yermosols. The kastanozems are typically covered with short grass. They have a dark brown horizon, which may be up to about 300 mm thick, below which the calcium carbonate horizon is present, followed by the unaltered material. Xerosols are developed beneath bunchy grass and possess a thinner brown upper horizon than the lower calcium carbonate horizon. Yermosols are covered with sparse xerophytic desert type vegetation. They have a thin brownish grey upper horizon that rests on a carbonate or sometimes a gypsiferous layer. These three soils frequently have a high inherent fertility but, unless irrigated, crop production usually is restricted by the lack of moisture.

Soils with high salinity or alkalinity are found in semi-arid or arid regions where evapotranspiration greatly exceeds precipitation. Ions such as calcium, chloride, magnesium, potassium, sodium and sulfate accumulate in the soils. Solonchaks are saline soils, which often have salt efflorescences on the ped surfaces and on the ground surface. The soil profile often has an upper grey organic mineral mixture that rests on a mottled horizon, beneath which is a grey or olive completely reduced horizon. Many solonchaks are potentially useful for agriculture if the excess ions can be dissolved and removed by large amounts of water provided by irrigation. One of the problems in such regions is salinization. This occurs when irrigated soils are not well drained. Solonetz soils also occur in arid and semi-arid areas. A thin layer of litter may occur at the surface, to be quickly followed by a thin very dark mixture of organic and mineral matter, and then a dark grey, frequently sandy horizon. Below this is a distinctive middle horizon with a marked increase in clay. The latter is characterized by a prismatic or columnar structure. These soils have pH values that are often above 8.5 due to high exchangeable sodium and magnesium but generally have a low salt content. The high pH is harmful to plant growth and must be reduced if arable farming is to be practised. This usually is brought about by adding calcium sulfate.

Vertisols or black cotton soils occur in the savannah grassland regions of the tropics and subtropics, which are characterized by alternating wet and dry seasons. They are dark colored, clayey soils in which montmorillonite is an important constituent. The surface horizon usually is granular but can be massive and rests upon a dense horizon with prismatic or angular blocky structure that grades into similar material with a marked wedge structure. This is caused by the montmorillonite shrinking and expanding in response to seasonal drying and wetting. The pH value of vertisols is about neutral. They have a high base saturation and high cation exchange capacity. Vertisols are fertile soils with a high potential for agriculture. Irrigation frequently proves necessary in such regions as they tend to be affected by droughts.

The ferrasols (laterites) occur in the humid tropics, being highly weathered soils that are often red in color. These soils possess a thin layer of plant litter at the surface, followed by a greyish red mixture of organic and mineral matter that is not more than 100 mm in thickness. These grades quickly into a bright red clayey horizon that may be several meters thick, which overlies the underlying rock (Figure 1c). The red horizon consists largely of kaolinite with hydrated oxides of iron and aluminium. The change from lateritic soils to the parent rock can be gradual or sharp. There often is a red and cream mottled horizon beneath the red topsoil or a thick white horizon, known as the pallid zone, may be present. Because of the effectiveness of chemical weathering these soils are deficient in essential plant elements and so can become rapidly exhausted unless fertilizers are applied.

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Biographical Sketch

Fred Bell graduated BSc, MSc from the University of Durham and received his PhD from the University of Sheffield, United Kingdom in 1974. More recently, he received a DSc from the University of Natal. He is a fellow of the Royal Society of South Africa, a fellow of the Institution of Civil Engineers and the Institution of Mining and Metallurgy, and a fellow of the Geological Society, being both a chartered engineer and a chartered geologist. He is the recipient of several awards.

Professor Bell now is a Visiting Research Associate at the British Geological Survey. Previously, he was Professor and Head of the Department of Geology and Applied Geology, University of Natal, Durban, South Africa, during which time he also was a Distinguished Visiting Professor, Department of Geological Engineering, University of Missouri-Rolla, USA.

Professor Bell's research subjects have included ground stability, subsidence, ground treatment, engineering behavior of soils (clays, expansive clays, saprolites, tills, laminated clays, dispersive and collapsible soils, sands), engineering behavior of rocks (sandstones, carbonates, evaporites, shales, basalts, dolerites, granites), cement, lime and PFA stabilization of clay soils, acid mine drainage, mining impacts, landfills, derelict and contaminated ground, rock durability in relation to tunnelling, slope stability, aggregates, building stone, and geohazards.

In his professional activity Professor Bell has been involved in a variety of work in the United Kingdom, southern Africa and Malaysia concerning site investigations; foundations; settlement problems on clays, fills and sands; old mine workings and subsidence; longwall mining and subsidence; ground treatment; groundwater resource assessment; slope stability; use of mudrocks for brickmaking; assessment of various rock types for aggregates; contaminated ground; acid mine drainage; landfills; dam sites.

Professor Bell is author/editor of 17 books, several reprinted, one in its fourth edition, one translated into French, two into Italian and yet another into Malay, and an Indian edition (in English). He is also author of over 200 papers on geotechnical subjects. He has served on the editorial boards of five international journals and has been a series editor for three publishers.