SOILS

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Contents

Summary

Two entries are merged in this chapter: a discussion of soil-forming processes and associated soil functioning, and a typology of diagnostic horizons and soil profiles as proposed by the US Soil Taxonomy and the World Reference Base for Soil Resources (WRB). In addition, soil-forming factors are presented with an emphasis on the human impact on soils. The difficulties of classifying and mapping soils are discussed in the final section of the chapter.

1. Introduction

At the beginning, some billions of years ago, igneous and volcanic rocks as well as materials from outer space were altered by hydrolysis into secondary products, essentially clays. When life emerged on Earth, an ecosystem developed on these products of weathering—the soil ecosystem. This ecosystem became the richest of the terrestrial ecosystems in terms of its biodiversity as well as of its biomass. In the present as in the past, soils play a prominent role in the Earth system (Figure 1) which is, however, to some extent ignored by other Earth scientists. Soils form a continuum covering all emerged surfaces, except bare rock and ice on glaciers.

Ever since our appearance on Earth, humans have relied heavily on soils and have modified them. We already depended on their fertility when we were only hunters and gatherers. With the onset of Neolithic times, humans began to clear forests for agriculture, modifying soil functioning, for example, by inducing soil erosion. Soils also supplied us with raw materials (e.g., for dwellings and for ceramics). Since the industrial revolution and consequent exponential increase in the world's population, the human impact on soils has increased considerably. The use of heavy agricultural machinery degrades the physical properties of the soil thus encouraging erosion. Humans have polluted soils as well as surface and groundwater by applying pesticides, herbicides, and, to a lesser extent, chemical fertilizers, considerably impoverishing the soil ecosystem. Humans also use soils to filter water and to recycle waste. The soils are a product of different weathering processes—for complementary information, see*Weathering*.

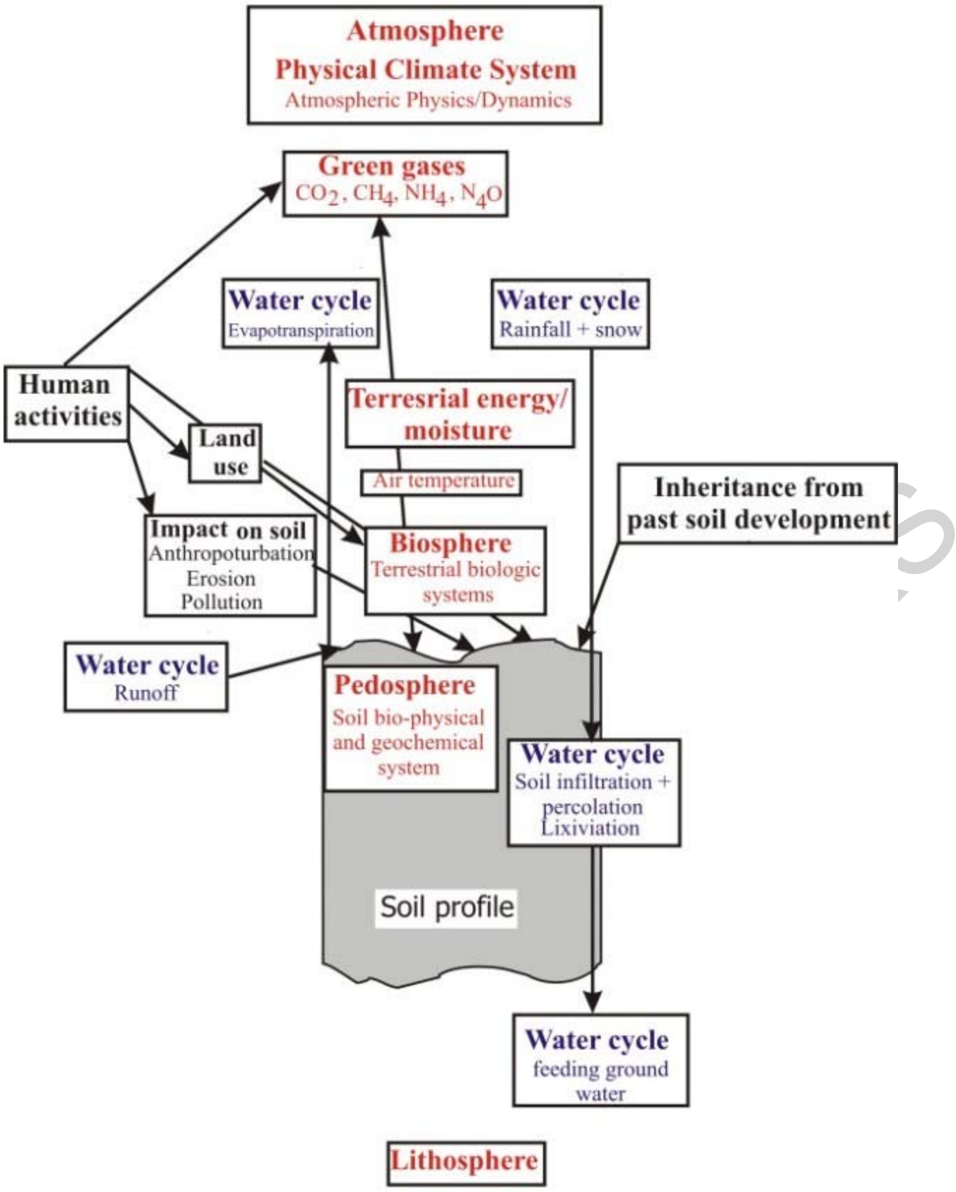

Figure 1. The pedosphere (the soil profile), interface between atmosphere and biosphere and the lithosphere

2. Definitions

Varied definitions are given to soils. Farmers usually restrict the term "soil" to the plowed layer, which they also call the arable layer. For civil engineers, a soil is simply a substrate on which to build or a material to be used as a filling material. Archaeologists consider a soil to be a surface on which people lived in the past. The broadest scientific definition for soils might be: "*a soil is the upper part of the lithosphere altered by climatic factors and transformed by biological activity*," for which the term pedosphere is sometimes also used. However, most soil scientists set the lower limit of the soil to the depth of penetration of biological activity. Moreover, in the US Soil Taxonomy, the lower boundary of the soil is arbitrarily set at 200 cm. We will, in this chapter, adopt as our definition of soil the limit of present penetration of biological activity, while in the article on Weathering we deal with the whole layer affected by past and present climatic factors as well as biological activity.

Different levels of organization are recognizable in the soil cover:

(a) At low levels (Figure 2, panels 2 and 3), soil organization consists of grains (occasionally crystals), clay platelets (Figure 2, panel 2), organic particles, and living organisms while at the lowest nanometric level, the crystal structure is investigated (Figure 2, panel 1). Two main size fractions are distinguished: (i) a coarse fraction, also called the skeleton, which consists of sand- and silt-sized grains, usually dominated by quartz; and (ii) a fine fraction, also called the plasma, consisting dominantly of clay particles. Coarse and fine fractions combine in ground masses characterized by various assemblages.

(b) The soil fabric (Figure 2, panels 3 and 4) deals with the total organization of a soil expressed by the spatial arrangements of the soil constituents (solid, liquid, and gaseous). A fabric unit is a part of the soil material, homogeneous at the scale of observation. A partial fabric comprises all identical fabric units. Pedological features, supposed to be the result of soil forming processes, are the most common fabric units, but inherited parental material features may also be present. Only a few pedological features are recognizable with the naked eye. Identification and analysis of most of them requires thin-section investigations under a polarizing microscope. Pedological features are discrete fabric units distinguishable from an adjacent material by a difference in concentration of one or more constituents (e.g., a granulometrical fraction, organic matter, crystals) or by a difference in internal fabric.

(c) The soil profile (Figure 2, panel 5) described in the field, is divided into soil horizons. From top to bottom, it consists of: (i) The soil surface, which is the interface between raindrops (and other climatic factors) and soil material on the one hand, and between organic residues and soil material on the other hand. (ii) Organic horizons (see also Section 3.5.4 on humus types), which exist only on acid, unplowed soils in which soil fauna is unable to mix organic residues with soil material. (iii) A horizons (see also Sections 3.5.4 and 3.5.5), which are characterized by an appreciable content of soil organic matter (SOM), from under 1% to some 10%, and by abundant and active soil biota, whose effects decrease exponentially from the soil surface to the base of the A horizon. In some soils, below the SOM-rich horizon but still considered as belonging to the A horizon, there is a pale, weakly structured, or structureless horizon, mainly consisting of silt and occasionally of sands with low organic content. It is designated as A2 or E and named the eluvial horizon. (iv) B horizons, which are subsurface horizons that mainly result from chemical and physical soil forming processes. The different types of B horizons are described in Section 3 of this chapter. (v) C horizons, corresponding to weakly transformed or nontransformed soil parental material. A soil profile is a bidimensional unit, the corresponding tridimensional unit (Figure 2, panel 6) being the pedon, a volume in which all the characters of the pedological profile are supposed to be similar according to USDA classification published in1975. (d) According to the US Soil Taxonomy, the soil cover consists of a juxtaposition of pedons. Frequently, however, especially on old cratons in the tropics, pedons do not have a vertical limit (i.e., the A horizon has a different extension from that of the underlying B horizon). In order to overcome this problem, Boulet et al. proposed to deal with a tridimensional unit, the pedological volume (Figure 2, panel 6), instead of horizons.

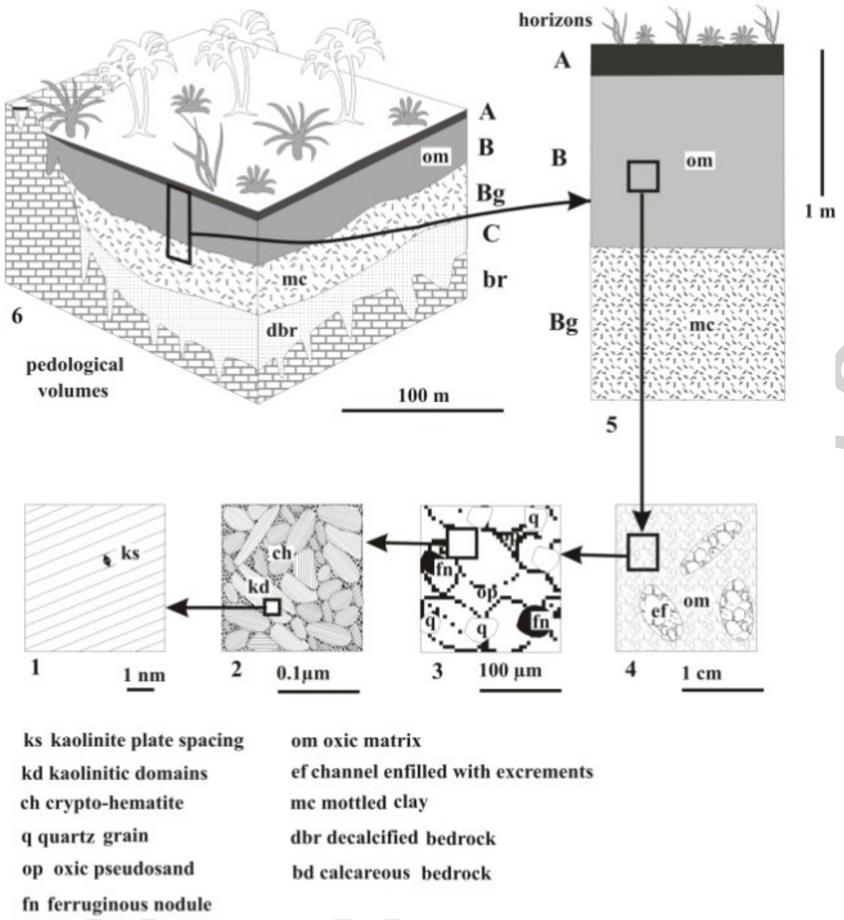

Figure 2. The different levels of soil organizations
Based on soil organizations of the Havana plain (Cuba). Aquic Hapludox (US Soil Taxonomy), Gleic Ferrasol (WRB). (1) Nanometric: elementary clay plates are visible (ultra thin sections under high resolution electron transmission microscope). (2) Submicronic: the clay size constituents of the ground mass and their arrangements are recognizable (ultra thin sections under electron transmission microscope). (3) Micronic: grains and pedological features are analyzed at this scale (thin sections under polarizing microscope; drawing schematized from micrograph 5 in chapter on Weathering and chemically mature soils). (4) Millimetric: overview of the soil fabric (soil microstructure and most pedological structure; large-sized thin sections under lenses). (5)Two-dimensional soil profile description with naked eye and lenses (drawing schematized from photograph 3 in chapter on Weathering and chemically mature soils). (6) Three-dimensional soil descriptions in trenches with naked eye and lenses.

3. Soil-Forming Processes and Associated Soil Functioning

The soil should be considered as a multifunctional and open reactor, physical, chemical, biochemical, and biogenic (Figure 3), which receives from the atmosphere rainwater that may contain some solutes (e.g., from spray) and sometimes dust. Dusts and various organic residues can also be deposited on the soil surface. The functioning of this reactor is essentially regulated by water, but also depends on the parental mineral composition, the stage reached in the soil's development, the vegetation, the soil ecosystem and the impact of man.

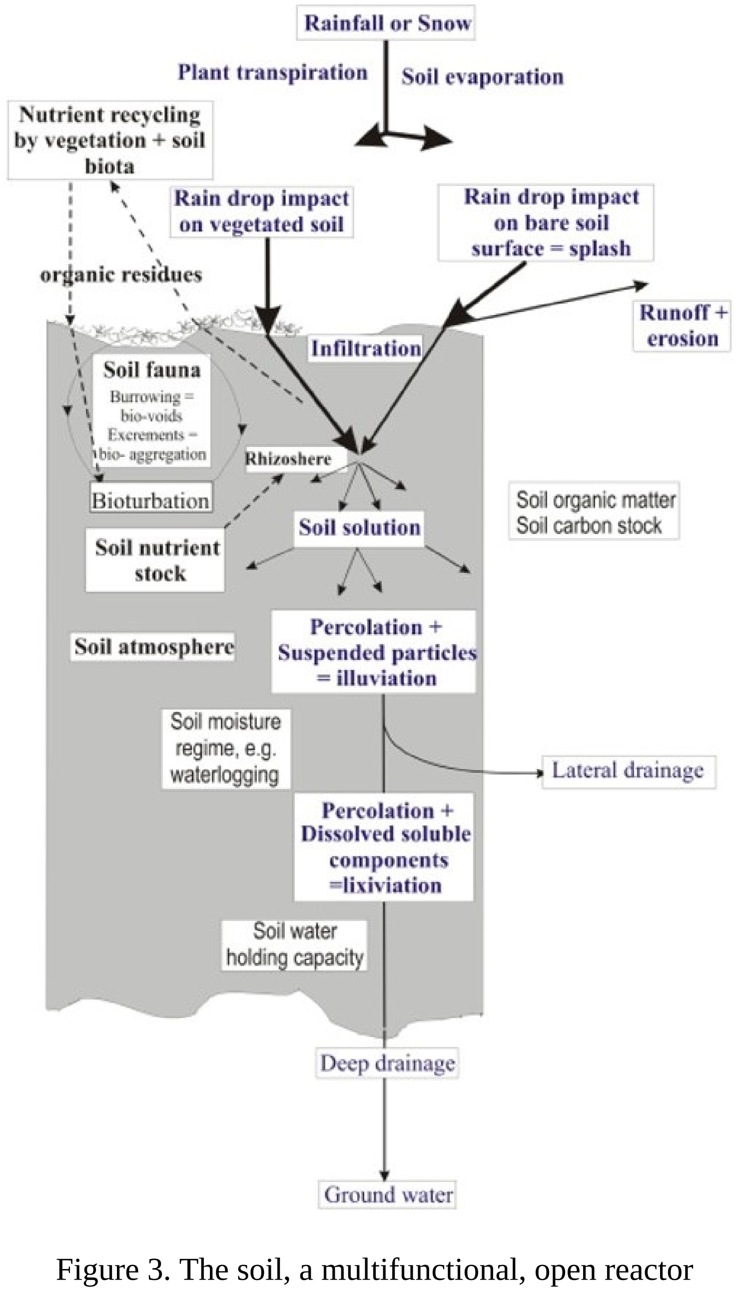

Figure 3. The soil, a multifunctional, open reactor

Water acts physically, through the energy of raindrops, and also by freezing and thawing; physicochemically, by penetrating inside some clay minerals (swelling clays); chemically, by dissolving soil constituents or encouraging their accretion; and by making life possible in the soil. Water carries soil components vertically and also laterally as solutes, as pseudosolutes, and as suspensions. Water is also responsible for mass movements vertically and laterally, while soil macrofauna moves the soil material up and down.

Pedologists use the term "soil-forming process" for any action taking place in the soil that modifies physically and/or chemically the parental materials. Most soil-forming processes consist of a combination of elementary mechanisms: for example, the impact of a raindrop on a bare soil is an elementary mechanism, while clay illuviation (see below) is a result of many elementary mechanisms which together constitute a soil forming process.

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Biographical Sketch

Nicolas Fedoroff, an associate professor at the Agricultural University of Paris (France), teaches soil genesis and soil classification in the department of Agronomy and Environment. He is also delivering there a course on tropical soils, genesis, and management; coordinating Earth Sciences; and delivering a course on soils and paleosols at *Diplôme d'Etudes Approfondies* (equivalent to a PhD course) on Environmental Archaeology of University Paris I. He has been an invited professor at various universities and research institutes, such as Université Laval (Sainte Foy, Québec) and Université du Québec à Montréal (Canada), Instituto Geographico Agustin Codazzi (Bogota, Colombia), Post-grade University of Agriculture of Montecillos (Mexico), Moscou State University (Russia), and the Agricultural University of Tunisia. He was made Doctor Honoris Causa of the Polytechnic University of Barcelona.

In the late 1960s, he introduced Soil Micromorphology in France and has since developed it. In 1985, he organized the Seventh International Working Meeting on Soil Micromorphology in Paris and later he was elected president of the Soil Micromorphology subcommission of the International Soil Science Society. He is one of the authors of the basic textbook, *Handbook for Soil Thin Section Description* and he has co-edited the Proceedings of the Paris meeting. Almost all of his papers on soil genesis and paleosols have a micromorphological support.

Nicolas Fedoroff has trained and supervised more than 30 PhD students from all over the world. They all came to his lab in order to be trained in Soil Micromorphology and for applying microscopic techniques to a wide variety of themes.

The relationships existing between aeolian dust deposition, sand dune accretion, soil forming processes, and erosional phases is one these themes. Investigations were conducted on loess in the Paris basin, on the Loess Plateau of China, on the Colombia Plateau (Washington, USA) and on stabilized dunes in the Sahel (Niger). Presently, he is continuing these investigations on the Dogon Plateau (Mali).

The genesis of Lateritic soils and Oxisols is another theme. On Youth Island, a small island south of the Cuba mainland, a toposequence only a few kilometers in length was thoroughly investigated. It consists of incipient soils lying on an almost unweathered bedrock to well developed Laterites. Later, these Youth Island soils were compared with the Oxisols of the Havana plain. Intermediately developed Lateritic soils were also studied on the coastal plain of southern Mexico. Relict, highly developed, Lateritic soils were also tackled in Western Africa (Mai and Niger). Nicolas Fedoroff has also visited Lateritic soils and Oxisols in Australia (Queensland and South Western Australia) as well as in northeastern Argentina.

Pedologists usually do not take into account the various processes of soil reworking. Complex soil materials resulting of aeolian volcanic deposits and slope horizon slides have been investigated in intramountainous basins of Andes in Colombia and of Central Mexico (tepetates).

Two thesis on sustainable agriculture were also supervised by Nicolas Fedoroff, one in tropical Mexico (erosion and soil ecosystem conservation), the other on human-induced alkalinization in the inner delta of Niger (Mali).

He has also been involved in international research programs such as Archaeomedes, funded by the European Union. The soil sustainability of a small basin, the Vera basin (southeastern Spain) since the beginning of agriculture (Neolithic) was investigated by correlating data on civilization collapses and evolution of soils through time.

Presently, Nicolas Fedoroff is interested by identifying in soils and paleosols features and fabrics which could have been formed during abrupt climatic events such as the Younger Dryas or Henrich events.