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Soils as a Key Component of the Critical Zone

1.1. What are soils?

The year 2015 was the International Year of Soils, swiftly followed by the International Decade of Soils 2015–2024. Through this initiative, the UN General Assembly [UNI 13] wished to raise awareness with both civil society and policy-makers as to the crucial importance of soils in humans' lives. Scientific, political and media interest in soils has appeared to be revived for a number of years [HAR 08a, HAR 08b]. They are now genuinely acknowledged as support for plant production and human activities, but also as an essential land-based system in the biosphere, as regulators of the major equilibria (the water cycle, and the carbon, nitrogen, phosphorous, potassium, sulfur cycles and others, which have a remarkable multi-functionality [JEF 10, GIR 11a, GIR 11b, BIS 16]). This multi-functionality of soils positions them as a key component of the Critical Zone for humanity [NRC 01, LIN 10] where life flourishes. However, do we actually know what soils are and what they do?

The word "soil" comes from the French *sol*, itself derived from the Latin *solum*, meaning ground but also base, bottom, foundation, earth, land, floor and pavement. It also means dirt, originating this time from Old French *soillier* meaning to make dirty. Another meaning of soil is also where one is born.

These terms are linked: in western culture, that which can be cursed – "cursed is the ground because of you" (Genesis 3:17) – is that which is dirtied by its sediment, or even upon death and burial. It is also considered as a source of all life, sphere of the

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gods, provider of wealth, stories and legends, patriotic pride, and other factors. Hence, the various interests, indeed contradictory, or lack of interest for this entity which feeds plants, regulates water flow and shows a fantastic biodiversity containing no doubt 25% of the Earth's living species [DEC 10], other organisms and other biodiversity upon which we live and work. We should know that clay soils are used in pharmacopoeia (beidellite, attapulgite and smectite) for digestive disorders or in cosmetics (clay masks, hair degreasers, shampoos and other products) [LEF 11]. Do not forget that clay soils are used as construction materials (for example, adobe, tiles and bricks) and for thermal insulation. Did you know that these "soils" contain microorganisms (for example, bacteria and fungi), which produce antibiotics and vitamins and that studies of microbial population and of their antagonisms led Waksman to discover antibiotics (streptomycin) and to his Nobel Prize for Medicine in 1952 [BER 06]?

Do we know what soils are? How are they perceived? How do we define them? What is their position on the earth's surface? How are they formed? How do their processes work? What do they do? What purpose do they serve? It is such questions to which this series of six works under the heading *Soils* strives to respond. This first volume, entitled *Soils as a Key Component of the Critical Zone 1: Functions and Services,* contains 12 chapters, including this introductory one, focused around definitions, presentations and discussions around soil properties, around the processes and services that they ensure, around the pressures by which they are influenced and the perspectives that open up. The five following works are more specialized and more detailed (*Societal Issues, Soils and Water Circulation, Soils and Water Quality, Degradation and Rehabilitation* and *Ecology*) and will approach various major aspects of soil processes and the issues that they incorporate.

1.2. The Earth, land, soils, soil cover and the Critical Zone

The semantics of the term "Earth" are vast, even without mentioning the term "ground", which simultaneously takes account of geographical, economic and property aspects, which is hence situated at the level of the farm, the watershed or the ecosystem. The expression "field work" is analogous to "*in vivo*" versus "*in vitro*" and "laboratory study". Man's level of understanding is such that he rarely appreciates the layers underneath arable land. It is true that, to do this, you must plough the ground: "The harvest past, Time's forelock take, And search with plough and spade and rake… To show by such a measure, That toil itself is treasure." wrote Jean de La Fontaine in *Le laboureur et ses enfants* (The Ploughman and His Sons).

We can group the various meanings that the word "earth" takes into four different spheres:

– those attached to the Earth (with a capital letter), which comprises all of the continents and the oceans and the planet;

– those attached to the use of soils (and therefore a link with everything which is within agriculture). This may be:

- a surface area corresponding to a given land ownership – you often come across references such as "this is my land", or "the price of land" (which depends upon its use: a forest, crop production, vineyard, second home and similar terms), and "selling his or her land";

- a loose layer of the soil cover where plants grow: arable land, "wheat-producing land" and "unfertile land";

- the behavior, the properties or the qualities of the surface layer used by humans: "black loam", "soft soil", "organic soil", "sandy soil", "light soil", "soft soil", "clayey soil, "heavy soil", "limestone soil, "fallow soil", "cold ground", "poor soil", "heathland soil", "stony soil" and "fine soil". Thus, according to the Scandinavian proverb, "black soil produces white bread" and the Albanian proverb "the gardeners hands are blackened with earth but his loaves of bread are white" (see Chapters 6 and 7: "Soils, a Factor in Plant Production: Agroecosystems" and "Forest Soils: Characteristics and Sustainability");

– those attached to:

- clay – often confused with the term earth – as with, for example, clay used for pottery;

- construction material: "brick-earth", "fuller's earth" and "clay soil";

- surface characteristics: "red earth", "black earth", "white earth" and other such characteristics (see Chapter 9: "Soils, Materials and Infrastructure Supports");

– those linked with humanity, for example, using various expressions:

- "being known throughout the Earth", with the term "earth" meaning the entire humanity;

- "this is my land" indicates the area characterized by the property that a given individual owns;

- "native land", an expression which comes closer to myths, by qualifying a given space through its link with a population;

- "my ancestors' soils" may be linked in the sense of the previous expression, but it goes further in both the mythical and generational sense (see Chapter 10, "Cultural Dimensions of Soils"). Soils have an archaeological memory, but also an environmental memory, which associates or distinguishes the influence and history of human and climatic activities (see Chapter 11: “Environmental and Societal Memories of Soils”).

Soils can be considered as entities with their own constituent characteristics or as complex natural objects, defined by their structural and functional properties and their uses.

Their definition depends upon the perception of them, their uses, their functional processes and the benefits that they provide, the given study routes and the mode of study adopted. The Larousse dictionary of the French language defines soils as the “outermost layer for the crust of a telluric planet” (Earth, Mars, the Moon, Mercury, Venus). However, there are major differences between the soils on Earth and those on Mars or the Moon, as the latter do not appear to reveal organizational structures linked to the action of living organisms. They might be able to be described as regoliths, which are formations of loose particles [DER 64], which are not fundamentally altered by the effects of living organisms.

Within this work devoted to the Earth’s soils, soils comprise this layer of the Earth where life is highly active and which we describe as the “soil cover” [GIR 11a]. This quasi-continuous, three-dimensional soil cover, which evolves from the Earth’s surface, is a key component of what was recently defined as the “Critical Zone of humanity”. This Critical Zone (CZ) has been defined by early authors [NRC 01, LIN 10] as extending from the base of aquifers to the top of plant formations. In our view, it should have, as its sub-stratum limits, unaltered mineral substrates and as its top layer the lower atmosphere, sites where life and the biogeochemical and water cycles are still significant.

The term “soil cover” insists on the fact that soils form a given part, known as the pedosphere, located on the one hand upon another part which most often has a mineral content, the lithosphere, which marries the landscape, the toposphere, and on the other hand, beneath another part which is essentially gaseous, the atmosphere, or more rarely appearing below stretches of water.

This pedosphere also interacts in time and space with two other parts: the biosphere and the hydrosphere (Figures 1.1 and 1.4) by having highly significant matter and energy exchanges (see Chapters 3–5: “Soils and the Regulation of the Hydrological Cycle”; “Soils as Bio-physicochemical Reactors” and “Soils are Biosystems, Habitats and Reserves of Biodiversity”).

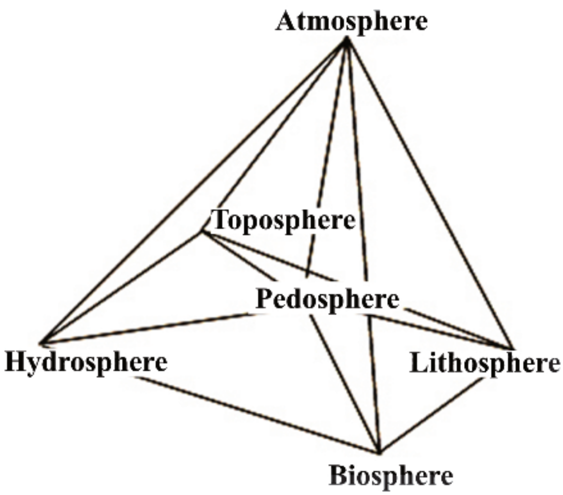

Figure 1.1. *The soil cover, pedosphere, at the heart of the Critical Zone of humanity, and integrating sections of other spheres (atmosphere, lithosphere, biosphere, hydrosphere and toposphere) [GIR 88]*

1.3. The term "soil" has various meanings according to use and function processes

The *Larousse Agricole* (a comprehensive French synthesis of modern agriculture) [LAR 02] defines soil as a "natural upper loose formation of the Earth's crust, resulting from the conversion, upon the contact of the atmosphere and human beings, with the underlying bedrock, under the influence of physical, chemical and biological processes".

A further definition is provided by Girard *et al*. [GIR 11a]: "Soil is an organized structure (within various layers), which evolves, in the presence of life, and the material of which is dirt. It is the location for flow transfers, whether water, air, energy or life".

These first two definitions must not hide the numerous other meanings of the word "soil" in current or common language [GIR 11a]. Some amusing examples can be presented here. There is, far removed from the subject of these works, the musical note (*Sol* in French – "So" in English). The French word *sol* was also a former unit of currency in France, during the early Middle Ages. In another, rarely used sense (except in physical chemistry), the term "sol" is a liquid containing dispersed matter within its given part, taking colloidal forms.

Other meanings have a closer relationship with the subject of these works, revolving around surface area, section of landscape, given territory (native soil), habitats for roots and animals and so on and will be presented and discussed hereafter.

1.4. The concept of soil varies according to the user

According to the given concerns of human societies, which have evolved over the course of their history, soils are perceived in very different ways (Figure 1.2). For over a century, the perception of soils has evolved to become almost exclusively agronomic (for example, [BER 15a, HAR 16]).

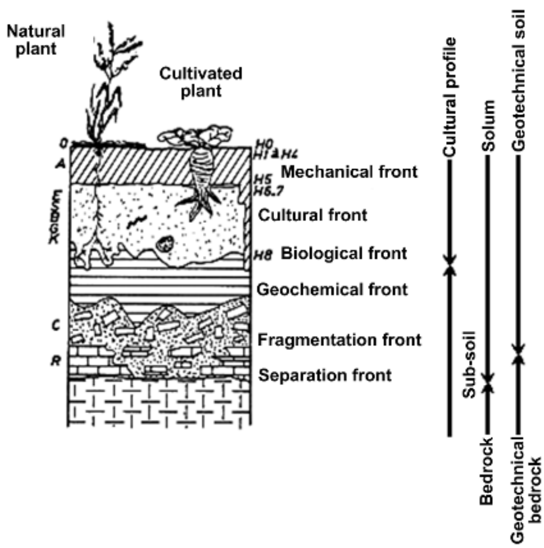

Figure 1.2. *Various concepts and perceptions of the “soil” [GIR 88]*

With the help of archeology, it is possible to read at least part of this history, and particularly when humanity has gone from the gathering phase to regular cultivation and onto the phase of dwelling in urban areas (see Chapter 11: “Environmental and Societal Memories of Soils”). Soils thus enable the discovery of part of human heritage.

1.4.1. *Agricultural sector*

Within agricultural societies which are more or less self-sufficient, soil is the means of obtaining food. For the agronomist and the forest ranger, it is designed as a resource comprising a plant nutrient reserve (whether or not this is cultivated) and a place for root growth and activity (see Chapters 6 and 7: “Soils, a Factor in Plant Production: Agroecosystems” and “Forest Soils: Characteristics and Sustainability”). It must be protected against erosion and other forms of decomposition (acidification, salinization, pollution and other factors – see volume *Degradation and Rehabilitation*). It is enriched with plant nutrient substances: water and fertilizers. Soil can thus be viewed as a “pantry” of a greater or a lesser size, which can be full to varying degrees for the benefit of plant life and other organisms living there. Its quality declines in the quantities of usable nutrients: what size “pantry” is required to ensure a sufficient good quality plant production, while maintaining the essential soil environmental functional processes?

1.4.2. *Scientific communities*

The points of view of various disciplines vary in relation to soils and may be summarized as follows. For geologists and geochemists (Allègre and Dars [ALL 09]), soil formation is a stage in the formation of sedimentary rocks.

For the geomorphologist, it is the part of the layered formations of continents transformed by living organisms and organic matter [DEW 08]. The geochemist views it as the ground compartment containing organic matter and newly formed silicate minerals (clays and oxides), which develop and constitute a stage in the formation of sedimentary rocks [ALL 09]. The climatologist views the soil as a screen which uses some of the sun’s energy and rainfall, by reflecting part of them, and which emits a given energy linked to its own surface temperature. The hydrologist (and the hydrogeologist) sees the soil as the environment which transforms precipitation into surface runoff or by infiltration and drainage transports it toward the water table, thus highly influencing both flood response times and the makeup of ground water and water courses. The ecologist perceives it as a source of transfers, production and water storage and of mineral or organic elements, a center for the food chains and organism habitats. The biologist and the microbiologist view it as a reservoir of organisms and genes of great scientific and application value. The biochemist perceives it as a reactor in which the most complex multi-enzyme reactions take place. Lastly, for the pedologist, it is a three-dimensional object, which evolves over time and creates its own organizational form (comprising its structures, layers and systems) which enables the development of life and which is rich in a very large range of plant and animal biodiversity.

1.4.3. *Urban communities*

For civil engineering and construction, you first have the chief surveyor, then the financier and the lawyer, who consider soil as an area to which fees, rights and obligations are attached. The geotechnical engineer, who constructs the buildings, views the soil as composed of materials of a more or less loose nature, which is situated above the bedrock. The urban planner perceives the soil as a material able to receive the foundations and the construction elements necessary for the construction of buildings [ROS 11]. For the city dweller or the sportsperson, it supports their various activities and it is where they walk or use their soccer shoes. In the view of the industrialist and the businessman, soil, which was often considered as a material resource or as plant sites, or for discharging residues or waste, is now, as with agriculture, an asset to use and manage, by applying regulations which are developed to ensure its protection, the protection of water supplies, and where its natural processes take place.

1.4.4. *Current pressures and questions*

Within our current societies, soils are subject to pressures, with a greater or a lesser intensity, exerted by human societies. The same societies should ensure great care in using, indeed in managing soils so as to respond to the multitude of questions and aim for harmonious and "sustainable" development of rural areas, urbanization, landscapes, plant production, water quality and other aspects.

Does the soil cover, the "epidermis" of the Earth, have the capacity to provide a protective and functional layer between the climate and its changes, water circulation and the availability of plant nutrient materials, but also for the animals and microorganisms which guarantee satisfactory operation of processes? (see Chapters 2–7 of this volume and the *Ecology* volume in this series).

Can soils provide food security and contribute to climate stability by 2050, while maintaining the functions and services with which they provide us? See Chapters 4–8 of this volume.

Can they maintain a sufficient level of soil fertility and plant production while contributing to maintaining biodiversity? See Chapters 4–7 of this volume and the *Ecology* volume in this series.

Can they efficiently ensure water quality together with the operation of the water cycle? See Chapter 2 of this volume and the volume *Soils and Water Circulation* in this series.

How can we avoid landslides and earth flows? What can be done so that the sands do not flood the lands behind the dunes where houses are built? See the volume *Degradation and Rehabilitation* in this series.

Will soils harness climate change as one research program (the so-called "Four for One Thousand") proposes studying? The program which aims to favor the storage of excess atmospheric carbon within the soils? See Chapters 4–6 of this volume.

There are many questions (or issues) and answers that are presented in this series of volumes on soils. Soils are recognized here as a key component of the Critical Zone of continental surfaces, going from the atmosphere down to the bedrock – ensuring the "good functioning" of the Earth's ecosystems (or that provide and support the fundamental services and functions of the Earth's ecosystem).

1.5. The approaches and procedures of soil scientists and pedologists

The responsibility of such scientists is to understand the organization, the processes and development of soils, of their structure and everything from the smallest elements (that is to say, micro-habitats and micro-sites) to the largest elements (land parcels, watersheds and soil landscapes). The traditional method is to sort objects according to different criteria and then to group them together and to associate them so as to move from a state of disorder to general laws of organization. This is what botanists and zoologists do, within their respective disciplines, albeit dealing with individual subjects.

This is not the case for soils. It is difficult to find an individual soil. So as to do this, American authors have proposed the concept of "pedon". However, the latter does not genuinely correspond to organizational reality and modes of operation for soil systems. This was evidently a stage or a possible approach to characterizing and studying soils. We can also define "soil profiles", which are a picture of a vertical sample of the soil cover, and "solums", images of vertical zones of the soil cover which correspond to soil sections (Figure 1.2).

Currently, we may well perceive what we currently call "soils" as not constituted of given individual aspects, but as a *continuum* that Russian authors [FRI 75] have called "soil cover". This responds to a new paradigm which calls into question all forms of sorting, all typologies and all forms of classification. We have thus gone from the notion of the taxonomic boundary to that of the datum boundary [FAO 06, BAI 09]. If it is not possible to define the limits of a given *continuum*, we can define, either conceptually or statically, modal entities (in the statistical sense).

As far as the pedologist is concerned, although for a long time we have talked of soils [BOU 88], only for a little over a century have soils been defined as objects of study [AFE 17], which has led to the definition and teaching of pedology [DUC 61]. The term "pedology" originates from the Greek πέδον (*pedon*): what is under our feet (as opposed to παιδός (*paidós*): child), and from λόγος (*logos*): science or discourse on. Pedology is acknowledged as an Earth science and/or a life science. This interface has not helped its development, which should be resolutely interdisciplinary, relying steadfastly upon the disciplines involved in Earth sciences, physics, chemistry and biology. Its Latin equivalent, which has given rise to soil science, has led physicists, chemists, mineralogists and biologists to apply their given approaches to soil samples. This has favored more disciplinary research, rather than interdisciplinary or multidisciplinary research, integrating the processes and parameters which control the given processes.

It is appropriate to develop studies on soil cover by considering its three-dimensional, evolutionary character and the interactions that play out at various scales of space and time. The mechanisms for soil formation are from its development and its resulting processes, from the transformation of materials (minerals and organic matter) through various fluids (water and gas) and through living organisms (animals and plant life whether aerobic or anaerobic microorganisms or heterotrophic or autotrophic), under the influence of biological, physical and chemical processes. It is a location for matter flows (both organic and mineral) due to various energy sources. These include gravity, pressure gradients, heat, life and solar energy.

1.6. Two principles to take into account: geographical continuity and multi-temporality

1.6.1. *Principle of continuity*

Transfers of matter and energy occur within all directions throughout the soil cover. Obviously, the force of gravity intervenes as a priority and leads to vertical displacements, but also lateral displacements of materials and solutions. This is far less true at the microscopic level: other forces are intervening and exchanges are moving in all directions, but in an "anisotropic way". Fauna moves in directions specific to each species. Roots explore the soil according to the given plant species, by interacting with soil density, its compaction, but also depending upon the nature of sites where both water and the necessary elements to provide food for them are found.

Transfers take place, upon various scales, in far more vast areas. In this section, they prove particularly active in the Critical Zone and condition its development. The links of existing soils and the landscape should therefore be taken into account, so as to understand soil structure and development.

We can thus define pedoclimates and pedolandscapes as follows:

– "pedoclimates", which exist under the soil cover, are dependent upon the properties of the soils concerned, their topographical position and the given climate conditions;

– "pedolandscape" indicates all of the soil horizons and the elements of the landscape (vegetation, the effects of human activities, geomorphology, hydrology and the substratum), including the spatial organization enabling the definition in its entirety of a given soil cover (or a part of the soil cover).

The geographical continuity, at the various levels of understanding, poses the issue of the limits of the given study. What about the materials constituting the soils which are moved: are they products of erosion, transported by the wind or rivers, or do they arrive by other means? Do alluvial and colluvial deposits or eolian silts resort from the work of the geologist, the geomorphologist or the soil scientist? In the interests of making greater progress, they should depend upon the work of all three, not separately but interacting together.

What are the limits between the roots of vegetation and the soil, and within whose competence is the study of the rhizosphere? In that regard, it is as much biologists, agronomists, physicochemists, microbiologists and others who are concerned about developing integrated approaches to such a study. A question of the same type occurs for the leaf litter: the layer including the vegetation deposited on the soil (leaves and twigs and other such material) and soil layer activity in the broad sense, and the biological layers at the surface of the soils made up of blue-green algae, mosses, lichens and other similar materials. Does it apply to materials that are out of the water or flooded, owing to short cycles (tides) or longer cycles (mangroves), around the shores? Does the depth of soil correspond to root depth or biological activity, or even indeed that of physically or chemically altered zones, and where autotrophic bacterial areas can develop? What are the limitations of study between the spheres of the agronomist, research forest ranger, of the botanist, of the zoologist, chemist, the microbiologist and so on and the soil scientist?

A location for matter flows (organic and mineral flows) due to various sources of energy and soil cover is still present at the surface of the continental area. It exists within deserts where microbial communities develop, which may weigh several hundreds of kilograms per hectare [DOM 70], and is also found underneath ice sheets [TED 66]. It can thicken, be covered, submerged or on the contrary be eroded. Some layers are thus buried, flooded, thinned or moved, and a new evolution develops. It is the same if the environmental conditions change. These might include climate, land use and geomorphology. The sections of the soil cover, which are periodically recovered with water (such as given humid marine shore areas), and those permanently covered with water, encourage the consideration that the soil cover is also present in marine and continental waters. Life forms that develop there are very different from those of continental areas, and even more within the deep sea areas, where very high pressures reign. We find products there that have been released, and then carried along during the evolution of the soils of the continental surface, these being principally calcium (Figure 1.3) and clays [WIN 76].

Upon looking at the map of underwater soil materials, we note that those from continental shelves come from transfers of soils that have emerged (Figure 1.3). The distribution of the relative abundance of clay minerals within oceanic sediments [LIS 96] shows that maximum accumulations have chorological links[1] with soils in which these types of minerals are found or formed (Figure 1.3). We must also take account of material transported by air which is deposited in the oceans, estimated by Windom [WIN 76] to be 10–30% of marine materials. The key components of these materials originating from soils have undergone an evolution, a conversion and a displacement. We find traces of soil structures such as, for example, dessication cracks (but also traces of animal footprints). There are also gases, as although the oxygen content becomes almost nil below 200 meters deep, on the other hand, the content of H_2S becomes significant below 600 meters. The limestone dissolves completely beyond a depth of 5,000 meters and at shallower depths within cold oceans, since the cold increases the solubility of CO_2 and carbonates. Therefore, chemical evolutions are altered. These elements indicate that it is legitimate to consider that if they are not soils, strictly speaking but mud flats, or mangroves (nomenclature of the soil system of reference 2009), they are at least sediments of soil origin, which are sorted and some transformed by their reaction with seawater, or even more so by the process of diagenesis. Other sea sediments are clearly not soils, such as coral reefs or chalk.

There are therefore underground soils, which mean that the soil cover is not limited to the continental surface (Figure 1.3). On the other hand, geographically, the soil horizons are discontinuous: they begin and end, but their components also develop and migrate in geographical terms.

1 Chorology: the study of links that exist between an identified characteristic (intrinsic factors) and its distribution throughout the three-dimensional landscape (extrinsic factors).

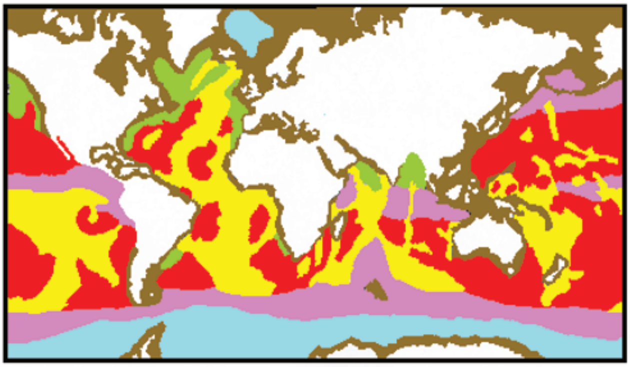

Figure 1.3. *Distribution of soil materials in marine environments – from [DAV 76] within [SCH 06], where we also find kaolinite, illite, smectite clays and chlorite distributed. White: continents; brown: soil materials of continental shelves coming from the transfers of emerged soils; green: terrigenous sediments, including delta plains; red: red clays of deep sea areas; yellow: carbonated materials; purple: siliceous materials; blue: glacial materials. The distribution of clays (kaolinite, smectites or chlorite), not shown here, also reveal these continental origins (source: http://www.geolsed.ulg.ac.be/sedim/sedimentologie.htm and F. Bouvain (University of Liège: http://www2.ulg.ac.be/geolsed/FB.htm); redrawn by M.-C. Girard). For a color version of this figure, see www.iste.co.uk/berthelin/soils1.zip*

1.6.2. *Principle of multi-temporality*

1.6.2.1. *Time*

What is the significance of time in relation to soil cover? This is difficult to understand, since, as for the spatial aspect, soil cover is in a state of "perpetual" activity and movement with variable time steps: this varies from the microsecond to millions of years. There are rapid and permanent exchanges that leave the impression of a given stability when changes in geographical timescale are made or we notice longer time steps. For example, the speed of cation exchanges on dispersed clays is considered as instantaneous. On the other hand, on aggregated clays or aggregated and flocculated clays, they can be very slow, limited by the speed of diffusion through these compacted structures. There are extremely slow movements which are neither perceptible nor easily measurable across a given century or centuries, thus giving the impression that nothing actually changes.

1.6.2.2. *The duration*

It should be considered that soils are always under the influence or effects of transforming processes. However, they don't "die" as such, since the soil materials currently exposed will be submerged during the increase in sea level or during tectonic events. The materials that line the current depths of the seas and oceans prove to be the parent materials of soils, when they are exposed, or new rocks if they are subject to the processes of diagenesis and metamorphism.

They only “arise” rarely, when, for example, a volcano crossing the Earth’s crust comes out of the sea, and a given soil is directly formed both from exposed material and from pedological particles which, transported by the wind, are deposited upon the rock that itself is new.

1.6.2.3. *The age of the soil*

The soils thus occupy the area included between the mechanical erosion front on their surface and the modification front, also called the in-depth chemical erosion front.

The time necessary for soil formation depends on the type of soil and therefore the climate and soil formations rich in humus, as well as the nature of the substratum and the topography, upon which pedogenesis and geodynamic stability occur. In stable geodynamic conditions (quasi-stability of a soil landscape or biostasy in the sense of Erhart [ERH 67]) the pedogenesis develops, within unstable conditions (rhexistasy). Pedogenesis changes, as materials comprising soils are eroded, transported and deposited as sediment. The study of sedimentary archives enables the regeneration of the history of soil landscapes (see Chapter 11).

The approach of the age of soil would only arise if one considers that in a given location, a particular soil started to form and then evolved until a given date. At this point, its destruction process occurs – its end; but what becomes of it afterwards? Would the end of its evolution mean that it reaches a degree of stability and evolves no further?

There is no place for this question to be asked, as (1) the soil constitutes neither an object nor a living organism as such and therefore it is neither born nor dies – it simply transforms; and (2) it is not specifically demarcated since it is part of the soil cover (the principle of geographical continuity).

We can then ask how quickly soil forms. This question does not have a simple response. Indeed, soil is made up of a group of sections and volumes, defined as the horizons, which, if they were superimposed in a certain order within a given place, would not form at the same speed. The top section of the litter (the leaves falling each year) is transformed within anything from a few months to a few years, according to its nature (coniferous trees versus deciduous trees) or the climate (humid tropical versus boreal), and ultimately disappears. The superficial horizons can form over a few decades, indeed less, as we observe with the reconstitution of mountain soils with rehabilitation works of ski areas [GRA 10]. Structural horizons

(S horizons of 20-cm thickness) can form in a few centuries (eight centuries for the existing Calcosol around the mound of oyster shells at Saint-Michel-en-L'Herm, Vendée, France) or in several millennia, or many more for deeper soil horizons. We speak of millions of years in respect of sections of the soil cover in tropical regions. The concept of plate tectonics, within the most active areas, is also a major parameter for weathering and erosion, and therefore the age and evolution of soils [STA 88]. Some methods of isotopic geochemistry assist in the determination of age, but rarely actual process dynamics. Predictive models are being developed, but they are only two-dimensional, and although they take account of lateral transfers, they assume that the soil itself is an inactive material. Consideration is currently under way to integrate an erosion model. It would also be necessary to take into account irreversible differentiations that exist within the soils [COR 16], but also possible means of resilience and/or reconstruction that are yet to be defined. The use of cosmogenic isotopes ^{10}Be and ^{27}Al enables the measurement of speeds of mechanical erosion and lateral movement over timescales of several thousand years of geomorphological scenarios, such as the speed of retreat of glaciers and the thinning of the soil cover [BOU 08a]. The analysis of dissolved elements released by the weathering enables the measurement of sink rate of the weathering horizons in given landscapes. In stable conditions, the speed of weathering of a surface of granitic rock is of the order of 10–20 m/Ma [BOU 08b]. The speed of mechanical erosion varies according to the climate and especially the gradient of 1–40 m/Ma [BOU 08a, BOU 08b], so soils can either become deeper or be totally eroded.

A large number of soils are formed from materials with a preexisting pedological character. There are, for example, soils found on alluvium, on exposed mangrove swamps or other areas. They thicken more quickly.

We should also talk of the speed of evolution and the speed of pedogenesis, which necessitates taking into account various pedogenetic factors by organizing them into a hierarchy, as they each have different weights and speeds which, moreover, are not constant during the various phases of development.

1.7. Nature, organization and major modes of soil processes

1.7.1. *Soils before the arrival of humans*

Humanity has only been here for a very short time, on the scale of development of continental earth life which was firstly in a microbial form and then rich in plant and animal life. Human activity, which models the landscapes, is relatively recent, only going back some 10,000 years. It intensified with demographic growth and is at the origin of major environmental changes which has led particular authors to speak of an era that they describe as the Anthropocene.

1.7.1.1. *Colonization of the continental area by life*

Around 3.8 billion years ago, well before humans appeared, life colonized the oceans and then the continents, when the atmosphere became oxidizing in the Proterozoic era (2.3 billion years), in microbial prokaryotic form (bacteria and cyanobacteria). The initial soils were formed of "layers" without doubt resembling those of the current cold or warm deserts (a desert varnish made up, for example, of associations of cyanobacteria and/or bacteria). These prokaryotic organisms had been on the ground for 1,200,000,000 years when eukaryotic organisms (for example, algae and fungi) appeared. The lichens (symbiotic algae associations – fungi) are without doubt, as we currently observe in glacial retreat zones, pioneer organisms for soil colonization, mineral weathering and producers of organic matter. Life that was swarming in the oceans came out of the water with the first plants which diversified at the end of the Silurian era and at the beginning of the Devonian era, around 400 million years ago. The first vascular plants (*aglaophyton*), bryophytes and pteridophytes, contributed to form the first pedoclimatic environments of the Primary Era, with the plants-microorganisms groupings.

The biogeochemical cycles already constituted within the oceans have extended across continents by diversifying and developing those created by microorganisms. The increase in the partial pressure of CO_2 within soils favors rock weathering and the formation of clays, iron, manganese, aluminum hydroxides and oxides, assisted in this by autotrophic and heterotrophic activities of microorganisms and plants.

1.7.1.2. *The emergence of properties and soil structure*

The minerals formed within soils are of a small size (nanomaterials). They take spherical forms, platelets or fibers and have variable surface charges. Organic matter (humic components) is mainly macromolecular, belonging to large chemical families, but with significant subgroups of aromatic compounds which are more or less condensed. They also have variable charges and, like clays, have colloidal properties, just like bacteria. These organic and mineral constituents, specific to soils, may remain juxtaposed. However, they can frequently be associated with each other and with soil organisms to form groups with new physical properties: macromolecules, fibers and filaments resistant to traction; piling up of spheres resistant to pressure; platelets that can provide rigid or plastic structures. These structures have physical properties, and rheological properties in particular, which themselves are properties of the "soft matter". This is what is observed within biologically constructed aggregates, which are typical of the lumpy texture of soils.

These structural properties of soils favor the retention and circulation of water and air, the fixation and exchange of nutrients, the establishing of roots and living organisms which, moreover, are protected. Indeed, living things participate in the development of structures which are favorable to them [BRU 17, CHE 17]. Please see Chapter 5 of this volume for further information.

1.7.2. *Specifics and origins of the Earth's soils*

The origin of the Earth's soils, in which there is a large biodiversity, rests upon a specific organizational structure comprised of

– fluids (water, diverse solutions and air);

– inorganic and organic constituents: clays, oxides, oxyhydroxides coming from the conversion of materials carried by the winds, or laterally by gravity or even by the underlying substratum;

– organic matter coming from mainly plant matter; living organisms (microorganisms, animals and roots) responsible for a dense and highly diversified life [BER 11a, BER 11b].

These are therefore "the product of weathering, reworking, and the organization of the upper layers of the Earth's crust through the action of living things, the atmosphere and the structure of energy exchanges which are evident there" [AUB 67].

Through their functional diversity, their physicochemical, chemical and biochemical reactivity and the interactions taking place at that point, soils can be viewed as complex biogeochemical reactors, interactive, reservoirs of microorganisms and major Earth ecosystem compartments, which are anthropized to a greater or a lesser extent (see Chapters 4–6 of this volume). These are dynamic, interactive open systems which are four dimensional (Figure 1.4).

These interactions and matter and energy exchanges take place within the pedosphere, from the molecular and cellular level to that of the aggregate, the soil profile (or solum), a given parcel, the ecosystem, the watershed or the pedolandscape and with other "compartments" of the Critical Zone: the atmosphere, the biosphere, the toposphere, the hydrosphere and the lithosphere. Within this Critical Zone of humanity which assures the major functions and services without which life in all its forms would not be possible, soils constitute the essential motor. Figure 1.4 represents the pedosphere, the key component of the Critical Zone, with its activities, its interactions and the exchanges between its constituent parts and the other compartments of the continental systems.

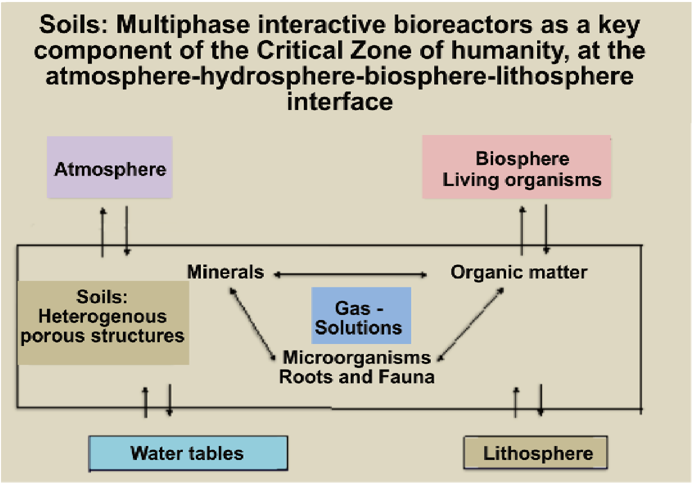

Figure 1.4. *The pedosphere as a key component of the Critical Zone of humanity: interactive bioreactor soils, with a multiphase at the atmosphere-hydrosphere-biosphere-lithosphere-toposphere interface (source: J. Berthelin, F. Andreux, C. Munier-Lamy [BER 11a])*

The highly "reactive" constituents of soils (oxides, oxyhydroxides, clays, microorganisms), their interactions [BER 11a, BER 11b] and their organization between them and with other constituents within variable aggregated porous systems are conferring upon soils the fundamental and essential properties for the proper functioning within the Earth's ecosystems and for supporting human activities. Soils, generally of decimeter to metric thicknesses until they reach rock materials, whether bedrock or partially altered underlying rocks (regoliths), can even reach, as in tropical environments, decametric depths.

The observation of soils and underlying formations shows that the structures of soils, in particular those which are biologically constructed, are fundamentally different from lithological structures, hence the difference between the "pedological structure" and the "lithological structure". Naturally, it is at the surface that living beings are the most numerous and active, which makes lithological structures dominant deeper down and pedological structures dominant at the surface.

1.7.3. *The parameters controlling differentiation and diversity of soils*

The major factors of pedogenesis, which determine both the differentiation and soil evolution, are linked as a priority for bioclimatic factors which integrate climate and vegetation. These are the parameters which reveal the zonation of soils throughout the world from humid tropical regions to boreal regions. The other large series of parameters involves rigid factors, which integrate the nature of the substratum (material support or bedrock) and the topographical conditions. Parameters linked to altitude (mountain soils and Alpine soils) present characteristics of a bioclimatic and topographical order. Human activities with the development of agriculture and then more recently with industrialization and urbanization appear as determiners. Around 10,000 years ago, after the glacial retreat and the increase in sea level, a new stage appears to have commenced with sedentarization and the discovery and development of agrosystems. Human activities, and in particular agricultural practices, and urbanization in the broad sense become determiners in the evolution of soil cover (see other chapters of this volume).

Figure 1.5 shows a diagram summarizing the relationships between climatic conditions from the boreal zone to the equatorial zone and the type of soils, in particular their depth, associated with pedoclimatic conditions, and therefore with the form and the speed of weathering of parent rock. There is scope to stress the remarkable thickness of the soils (several tens of meters) within tropical environments.

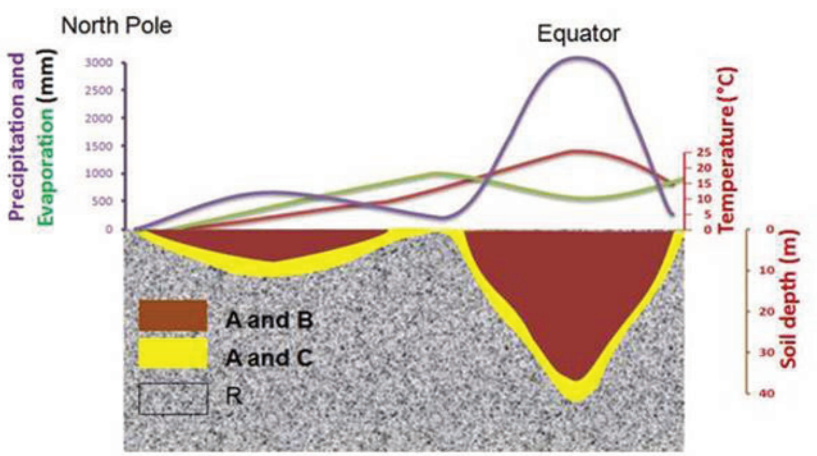

Figure 1.5. *Differentiation of soils on a global scale. Within mid-latitude zones and either side of the equator, soils are the most developed (horizons A, B, C) and deeper than in semi-arid zones, as a result of the variation of pedogenetic factors of rainfall (reduced by the evaporative demand) and the annual temperature. Soils close to the equator are moreover older than those of mid-latitude zones, for which pedogenesis was only revived after the last glaciation through to the Holocene era. (R = bedrock) (source: [STR 67] redrawn by C. Valentin). For a color version of this figure, see www.iste.co.uk/berthelin/soils1.zip*

The impact of major parameters, cited above, leads to a major diversity of Earth-based soils with various types of gradient:

– from tropical soils to boreal soils;

– from soils that are very well drained to soils of the processes which are dependent upon surface water tables (more or less hydromorphic soils);

– from forest soils to agricultural soils and urban soils and other soils.

To these gradients, we can superimpose fragility gradients (erosion and drought) and richness (low or high fertility, risk of salinization and other aspects) of soils, and therefore observe the richness or poverty of the countries with such soil problems.

Atlases and taxonomic systems stress this major diversity. For France and its overseas territories, the Référentiel Pédologique (Pedological Reference) [BAI 09] presents an easily accessible approach, close to the *World Reference Base*, [WRB 14]). This WRB replaces the legend of the map produced by the FAO/ UNESCO (Food and Agricultural Organization/United Nations Educational Scientific Cultural Organization) of world soils [FAO 06] as an international standard. There are national classifications or taxonomies of which some such as "Soil Taxonomy" of the USDA (United States Department of Agriculture) largely exceed the US framework. Classifications or taxonomies exist in Germany, Australia, Brazil, Canada, China, Norway, Poland, Russia and other countries.

Figure 1.6 shows various soil types that have developed in temperate climate conditions, mountainous or tropical conditions: (1) Dystric brunisol or Cambisol, or Acidic brunisol on granite rocks and under fir and beech growing together (Vosges, France); (2) Spodosol or Podzol on sandstone rocks and under pine wood (Vosges, France); (3) hydromorphic soils – (a) Redoxisol or Stanic gleysol or Amphigley with two water tables, one non-permanent at the surface (bleached horizon), the other permanently deep (bluish horizon), corresponding to two reduction zones (Yvelines, France) – (b) a bog with a permanent water table, up to the surface of the soil and the accumulating peat (Quebec, Canada); (4) Ferralitic soil or Ferralsol, from tropical humid environments and the aerial view of deep zones of erosion (Lavakas of Madagascar). The denominations of soils use the Référentiel Pédologique Français (French Pedological Reference), the nomenclature of the FAO – WRB and the French classification of soils, proposed by the French Commission for Pedology and of the Cartography of Soils (CPCS). The *solum* is also termed "profile".

Soils, within landscapes, are also organized into chains of soils or toposequences of soils or catenas, as seen, for example, in tropical humid regions, ranging from Ferralsol and Cambisol on the plateaux to hydromorphic soils, and gleysol on foot and toe slopes and valley bottoms. Moreover, consideration should be given to ferruginous deposits, and Plinthosol, which develop within *solum* (profiles) [DUC 01, GIR 11a]).

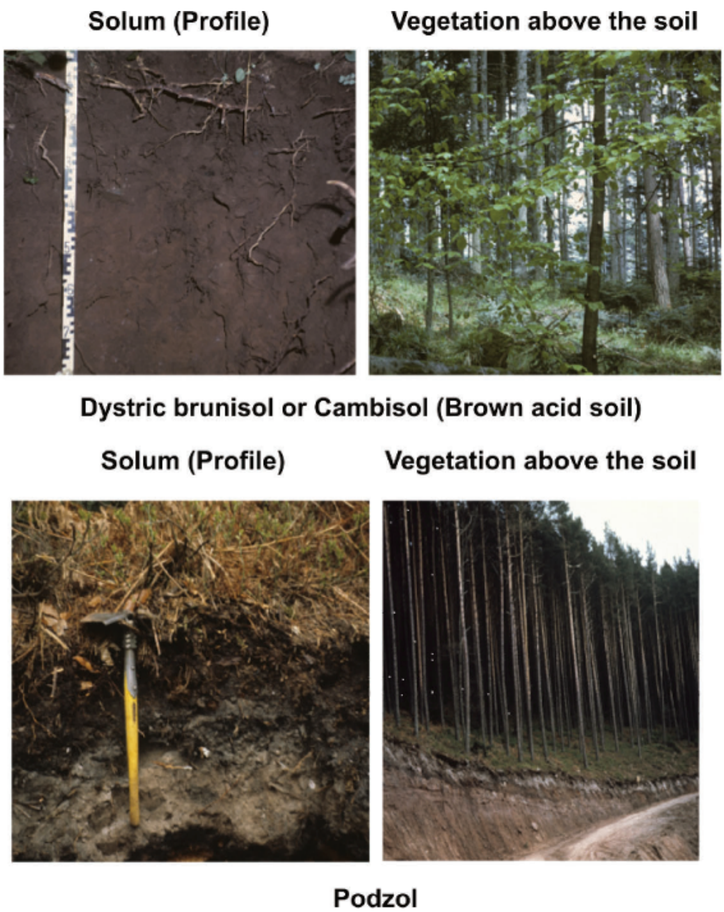

Figure 1.6(a). *Presentation of some soil types which have developed within different environmental conditions (climate, soil materials, vegetation and topography) (Photographs: J. Berthelin). For a color version of this figure, see www.iste.co.uk/berthelin/soils1.zip*

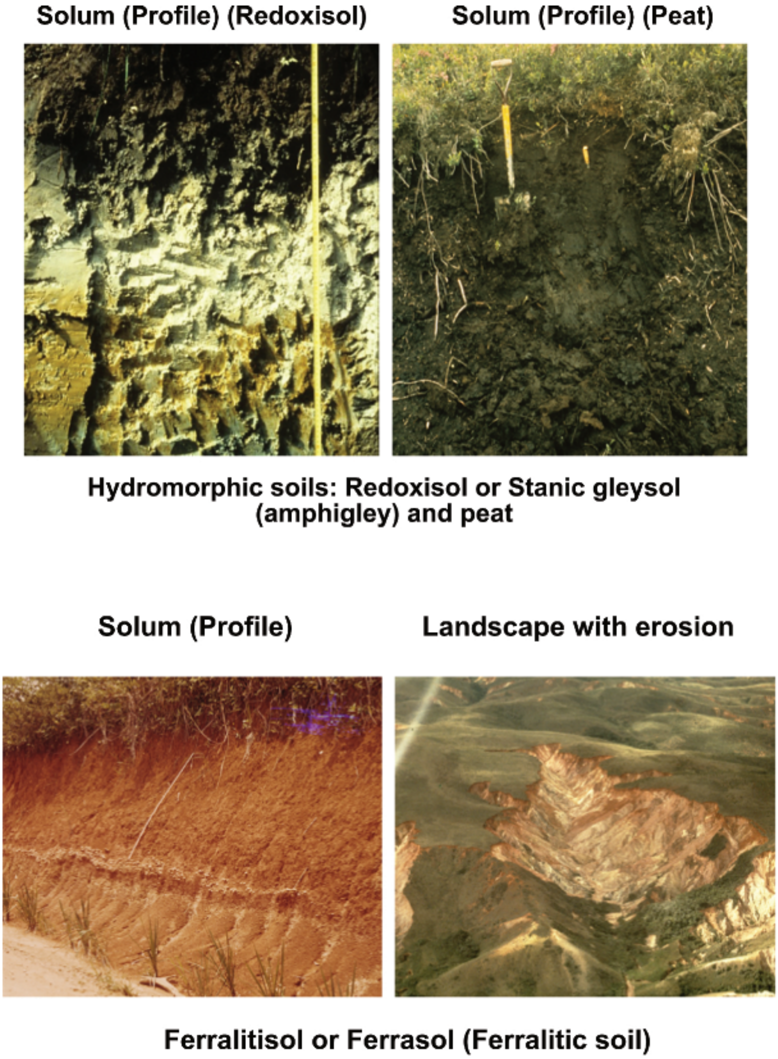

Figure 1.6(b). *Presentation of some soil types which have developed within different environmental conditions (climate, soil materials, vegetation and topography) (Photographs: J. Berthelin) (continued). For a color version of this figure, see www.iste.co.uk/berthelin/soils1.zip*

1.8. The functions and services of soils

The functions of soils, services provided [GIR 11a, GIR 11b], their cultural contributions (Chapter 10 of this volume) and historical contributions (Chapter 11 of this volume) make soils an essential and fundamental compartment of the current life, of our life and our history. Their role within biogeochemical cycles, the water cycle (see Chapters 3 and 4 of this volume), the development of biodiversity and of its resources in organisms and within genes (for example, [GOB 10]), see Chapter 5 of this volume), for plant production (see Chapters 6 and 7 of this volume), animals and food security, water quality and air quality (see Chapter 2 of this volume and the other volumes in this series) mark them as irreplaceable actors, for which the properties and functions will be set out within this series of works: *Soils.*

Soils undergo natural pressures such as erosion, acidification or salinization as well as those resulting from human activities (see the works in this series *Degradation and Rehabilitation* and *Soils and Water Circulation*). These functions, services and pressures should be considered within a broader societal context [BOU 15, LAL 15, BER 15a, NEV 15] (Chapter 12 of this volume and the volume *Societal Issues*).

1.8.1. *Major functions*

The soils, porous media, are the major players of the water cycle that they regulate. The water percolates in such places, accumulates and flows toward subterranean water tables. They play a purifying role. The plants use water from soils but by returning a significant share of such water toward the atmosphere through evapotranspiration. A better control and modeling of the water cycle within soil-plant systems is all the more necessary since climate change is already at sensitive levels (Chapter 3 of this volume and the volume *Soils and Water Circulation*).

The soils ensure the functions of accumulation, conversion, transfer and production of matter and energy, thanks to their constituents, their structure and organizations, and a fantastic diversity of living organisms. They are “mechanisms” or reactors for chemical, physicochemical and biochemical activities, which are both efficient and highly diversified. These “activities” are necessary for the “correct” operation of the cycles of the major elements (C, N, P, K, S, Fe and others) and numerous trace elements [BER 07, GOB 10]. See Chapters 4 and 5 of this volume. They have a purifying role regarding waste and residues (see the volume *Degradation and Rehabilitation*).

The processes involved, dependent upon local conditions, are relatively well established. However, the parameters and interactions that control them deserve to be better defined to establish quality indicators and propose relevant and robust management tools of soil-plant systems [BER 15b, BIS 16].

Soils are, together with the oceans, the Earth compartments where life is active with its fauna (microfauna, mesofauna and macrofauna), its microorganisms and plants (roots). They are reservoirs of living organisms, the majority of which have not yet been identified [DEC 10, GOB 10] (Chapter 5 of this volume). The biological resources of soils are actually well studied in terms of the purposes of their diversity, but require further understanding to establish and control the conditions of their activities [BER 15a, BER 15b, BAV 16]. See Chapter 5 of this volume and the volume *Ecology*. This diversity may be explained by the multiplicity and the heterogeneity of the resources and the habitats, but also the presence of complex and diversified trophic networks. All of the major groups of microorganisms (bacteria, archaea, fungi, algae and protozoa) are present in the soils but only 5–10% of them may be cultivated and identified. They are the key for biogeochemical cycles [BER 07] (see Chapters 4 and 5 of this volume). The parameters of activity checking and of cycle coupling are still to be stated. The control of rhizospheric symbiotic associations and rhizospheric non-symbiotic associations (roots-microorganisms) and the conditions of their activity are far from being established and further advances are necessary (see Chapter 5 and this volume and the volume *Ecology*).

These properties and soil functions are dependent upon climate, a major factor of the formation and evolution of soils. However, soils interact with the climate by controlling the temperatures, the water cycle, the biogeochemical cycles and the flow of gas toward the atmosphere (see Chapters 3–5 and the volume *Soils and Water Circulation*).

1.8.2. *Services provided by soils*

Soils, support for plant production, enable humans and animals to be fed, but also produce fibers, materials and fuels (Chapters 8 and 9 of this volume).

Progress in agronomy in the broad sense has enabled remarkable qualitative and quantitative improvements for the enrichment of soils, but the intensification of the agriculture can present risks of soil degradation (for example, loss of organic matter, erosion, acidification, salinization and pollution) and water contamination (by nitrates or phosphates). See Chapters 6 and 7 of this volume and the volume *Degradation and Rehabilitation*. A current concern revolves around maintaining environmental quality and soil productivity, among other objectives, to assure food security and fight against the effects of global warming. Cultural practices and soil land uses develop toward such objectives. Agroecology opens and/or rediscovers numerous avenues of which some are promising (see Chapter 6 of this volume). This is the case for better knowledge and use of the potential of living soil organisms or for the development of cultural practices, apt to preserve and restore soil quality and guarantee world food security (see Chapters 5 and 6 and the volume *Ecology*).

Soils support the production of renewable energies, not only to produce plants based upon energy productions but also for infrastructure supports (for example, wind and solar as well as other sources) which produce energy. See Chapter 8 of this volume.

The soils possess industrial and construction material resources, which have been exploited by Man since the beginning of his sedentarization (for example, laterites used for making bricks or ground layers for constructing roads in tropical regions and marly layers for forming adobe mud and others). Construction and industrial materials come from quarries (clays, bauxites, andalusite) (Chapter 9 of this volume) and soils are or can thus be destroyed. The measures of protection and rehabilitation (mining code, environment code and public policies) exist, but further progress can still be made (the volumes *Societal Issues* and *Degradation and Rehabilitation*).

Soils support the greatest share of human activities, and therefore urbanization in the broad sense with the development of dwellings, commercial and industrial plants, railway networks, road networks, sport infrastructures and leisure activities. These use both agricultural and forestry soils and can cause soil degradation, especially soil impermeability. This artificialization is a major pressure upon the soils, which must be controlled in the best way (Chapter 9 of this volume and the sixth volume, *Societal Issues*).

These human activities have also left in recent history, and even further back, particular polluted sites and soils. These can be orphan sites, for which it is necessary to reconstitute history so as to better monitor, treat and rehabilitate them (Chapter 9 of this volume and the fifth volume, *Degradation and Rehabilitation*).

Soils are therefore far more than a foundation from which we may cut ourselves off unless contemplating a life without soil, but the viability of this remains to be demonstrated. This discussion is set out at the end of Chapter 12.

1.8.3. *The role of soils within our culture and our history*

After a slow evolution, humanity has become attached to the ground (indeed to the soil) from his sedentarization, around 10,000 years ago, through appropriation expressed in words, sounds and visual representations.

Since Genesis (*Adam* means "red soil" in Hebrew אָדָם), throughout Antiquity and up to the present day, writings express the cosmic and parent soil (Gaia). Soil is also celebrated by music and song. Representation through drawing, painting and sculpture came later, beginning with the Renaissance. Beautiful images were created at that point (Figure 1.7).

a) b)

Figure 1.7. *Representations of soil viewed by Bénédicte and Louis-Marie Bresson (available at the address: www.art.bresson.pro/menu.html). The two pictures produced with soil samples from Rotalier, a village in the Jura and Le Crêt de Chalam. Both cases show the field in strips and highlight the color of geological materials and soils and the organization of the landscapes (source: B. Bresson and L.-M. Bresson). For a color version of this figure, see www.iste.co.uk/berthelin/soils1.zip*

For humanity, soils present a cultural ambivalence since they guarantee that we are fed, but also in many cultures represent the place where the dead are buried. They are associated with our imagination, with myths and given rites and may be both feared or revered (Chapter 10 of this volume).

Soils are also the receptacle of the past which help us to discover archeology, anthropology and paleontology. As they have covered continental surfaces for hundreds of millions of years, they retain in their "memory" traces of ancient processes, climates, flora and fauna, the contributions of wind, erosion and flooding, as well as traces of fire. We may find traces of the history of humanity but also pedological archives, of which knowledge is yet to be developed to understand the evolutionary parameters and indicators of continental ecosystems (Chapter 11 of this volume).

Despite the obvious significance of soils, we have to accept that they are in danger [GIR 11a, GIR 11b, NEV 15]. According to the FAO[2], nearly one-third of soils are already moderately or highly degraded by erosion, the exhaustion of nutrient substances, acidification, salinization, compaction and chemical pollution or artificialization. The work *Soils as a Key Component of the Critical Zone 5: Degradation and Rehabilitation* will come back to these issues. To this, numerous land use conflicts are increasingly added. There are currently some seven billion human beings on Earth and, according to the United Nations, the planet will be home to nearly 9.7 billion in 2050. To guarantee food security, according to the FAO, it will be necessary to increase global agricultural production by 60%. Even if we avoid the loss of food, this involves resorting to the use of new land for cultivation and, in any case, the preservation of the fertility of all of the current land. The cultivated soil resource is limited to around 22% of global land or 3,300 million hectares including only 51–52% without major limiting constraints or otherwise prohibiting farming [BER 15a]. However, due to soaring urbanization on a global scale, the available agricultural areas are significantly reducing. By 2050, it is estimated that the global urban population will reach nearly 70% of the total population compared to 30% in 1950 and this is often occurring within the already urban areas, which are themselves increasing at massive rates. Thus, across all global territories, there are clashes and there will be further clashes in the future between field land and land in the cities, often to the detriment of the former, so huge is the demographic pressure. The loss of agricultural land is estimated to have been between 2000 and 2012, in France, between 40,000 and 90,000 hectares per year.[3] The concept of urban sprawl, having gained ground, is often criticized but remains, despite legal constraints, a poorly controlled phenomenon. We may observe the development of land-grabbing initiatives by states and private companies, which manage their own shortages or anticipate them by taking over land in areas within countries other than their own. The phenomenon is not new, but it has accelerated since the food crises of 2007. According to the project *LandMatrix*,[4] 83.2 million hectares are or were subject to international transactions for agricultural purposes between 2000 and 2010. The impacts are often dramatic, depriving numerous peasants of access to land and degrading local ecosystems through the reconversion of forests or their over-exploitation [RIC 12]. See the volume *Societal Issues*.

2 Food and Agriculture Organization of the United Nations, available at the address: www.fao.org.

3 Report by the National Observatory for Consumption in Agricultural Areas, France, May 2014.

4 Chapters 2, 4, 6 and 9. Available at the address: www.landmatrix.org.

Within the entire world, soils are therefore increasingly sought by human activities and for the services that they generate. The resulting land use conflicts are thus extremely diverse, by their nature, their intensity or the given level concerned. Above all, disagreements concern the use and access to the given resource. They are linked to the fact that stakeholders use soils for different ends or intend to manage them according to their own methods. At the local level, this conflict often brings riparian owners into dispute and can simultaneously affect land control and land use planning, the cohabitation between agriculture and other activities, or the perception of environmental pollution associated with the given land uses [TOR 14]. Although tensions are fierce, they are seldom violent, but serve to check the development of areas trapped within states of compromise and the futile *status quo*. We find increasingly significant land use conflicts at a more global level, which are sometimes huge, and the appropriation of the richness of associated sub-soils. The tensions are more geostrategic or commercial, between states, international firms and local populations. It is thus not rare to see fierce tensions appear between countries, indeed local armed conflicts, linked to the destabilization of the social equilibria in place. A cycle of violence may then be implemented, which is difficult to get out of. Lastly, a final level of conflicts can appear between direct users and those who indirectly depend on the maintenance of services derived from ecosystems in these soils. This is notably the case with the storage of CO_2 and the fight against the greenhouse effect, which places the free choice of local communities with global demands into a state of tension.

As necessary for human life as economic development, the use of soils therefore creates conflicts of interest, able to go from verbal jousting to armed violence, from local conflicts to international power struggles, or from confrontations between riparian owners to more political struggles. Consequently, how are we able, with this limited and fragile capital, to articulate everyone's needs and act coherently at the various levels affected? How are we able to respond to short-term interests without compromising long-term interests?

It is no doubt appropriate to record that the services which they generate are not immutable, and that the confrontation of the interests of the various parties, without proper management, will not enable their maintenance. All of this eventually comes back to a governance problem, in other words, management procedures enabling positive strategy linkages of needs and ambitions, which are sometimes contradictory. This governance may rest in a first analysis around certain given conditions. At first, it may be orientated within given objectives, frameworks which are both quantitative and qualitative, thought of on extensive scales but adjustable. This is the domain of international or macro-regional agreements. These orientations would result from a dialog of various viewpoints and they may be, for the most part, informed by scientific, technical and socioeconomic experts. This global framework would then form the limits of what is possible for the finest adjustments. It then rests upon the activation of local management programs widely involving populations. It is a question of accepting a given flexibility to enable players to find the most adapted solutions in the context of such a change. No doubt, it is necessary to come to terms with unique solutions and to accept the rationales of subsidiarity to deal with problems at the correct level. It is therefore the given territory, the collaborative project area, which is here the essential matrix for action. The methods for this land co-action should be, so as to be efficient and sustainable, animated by a mechanism for strategic mediation between the various stakeholders. It is essential to result in a viable solution. This whole "unit" may ultimately form a process of a virtuous "societal co-production" [NEV 15]. Such governance may tend toward activating collective intelligence which should be able to embody locations – through forums, from a global scale to individual areas where methods for taking charge of this resource are negotiated and decided. It is a question of entering into the era of collaborative democracy where individuals become coauthors of solutions.

Whatever it is, it appears necessary to return humanity's relationship to the soil and, as a result, to return our management of this fundamental natural capital to multiple services. The acknowledgment of soils as shared assets, to be looked after as such, would open new perspectives, which will be discussed within the volume *Soils as a Key Component of the Critical Zone: Societal Issues.*

1.9. The need and significance of soil information systems

So as to best understand and manage soils and their condition using an integrated approach to their properties and by stating and better defining their uses through agreement, soil information systems have been implemented and developed at various levels. These include local, regional, national and international. The second chapter of this volume will discuss the domain of soil information systems. The complexity of "soil-plant" systems, but also approaches and patterns of use, should not discourage the implementation of such systems and their development.

1.10. Conclusion and recommendation

Since 2015, 5th December has been declared by the UN as World Soil Day. The UN Secretary General, Ban Ki-moon, when this annual day began in that year said: "During this World Soil Day, I consider that we must focus greater attention to urgent questions concerning soils, including climate change, resistance to antimicrobial agents, diseases transmitted by the soil, contamination, nutrition and health human".

New issues appear relevant to soils. These include environmental, food, health, economic and political issues. To respond to these, it is important to better understand, recognize, defend and protect the functions and services that soils provide for all of the Earth's ecosystems, and for them to assist humanity. They are genuinely a key component of the Critical Zone which assures the continuity of life on Earth. This volume and indeed this series of works aims to provide multiple "insights" upon what soils are and what function they serve for humanity and around the richness of the assets which they possess.

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