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Concepts of soils

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In this chapter we will explore some changes of people's perceptions of soils and their classification as background for the dominant concepts of today.

Close your eyes for a moment and imagine that when you open them you are at the beginning of human time, a hunter and gatherer somewhere in the world, isolated, with barest of necessities, and you are hungry. By trial and error and stories passed on to you, you now know which plants and berries are okay to eat and how to stalk and kill animals and how to fish for your survival. As a keen observer you detect the location of specific plants and the common habitats and behaviour of the animals that become your food. You can't go far from where you are because your source of protein is here – not somewhere else. One or two million years pass by almost unnoticed.

Close your eyes again and when you open them imagine that you look beyond the bank of a river to small plots of irrigated land where grain is growing. Fish are still an important protein source but now with harvestable and storable grains you can easily carry protein with you. The world around you opens up to exploration and conquest. Ideas and technology are transferable to faraway places. It is known locally that some lands are better than others for producing grains and are easier to prepare and manage. Your observations reveal many new relationships – for instance, that the effort expended and the yields returned are geographic for the most part.

Throughout the Holocene, starting 11–12 000 years BP, there has been evidence of increasing use of land for cultivated grains and fruits. From the early habitats at the edge of sloping uplands to the later migrations into the lower lying river and lake plains, there arose complex systems of irrigation enabling the blossoming of early civilizations. Egypt, the Middle East, India, China, and

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subtropical America – each with a remarkable history of use of land for agriculture and other needs of society (Stremski, 1975; Krupenikov, 1992). The concept of land (and soil) during the global expansion of people seems to have been twofold: one was the suitability for growing specific plants, and the other was the energy required to prepare and use the land. In general, sandy soils were much easier to prepare but the yields were more difficult to maintain, whereas clayier soils were hard to prepare but the yields were much better. Thus properties of soils, functions of soils, and classification of soils have been around a long, long time.

Soil, as we understand it today, is a concept of the human mind. From the earliest perceptions of soils as the organic enriched surficial layer to today's pedologic horizonation of profiles there is a rich history of beliefs and understanding of the vital life-sustaining resource. The earthy material is real, it exists, you can touch it, feel it, stand on it, and dig in it, but defining it is far more complex because it can be what you want it to be. The Mother of life, a healer of sickness, a home of spirits, a geomembrane that sustains ecosystems of which we are a part – yes, soil surely is all of these and likely much more depending on your cultural background and heritage, education and training, and your personal experiences.

An interesting aspect of thinking about soils is the uncertainty expressed as dichotomies, which have been present throughout humankind's involvement with this surficial layer of 'dirt' that somehow is vital to our existence and survival. From sacred to profane, from beautiful to filthy, from productive to unresponsive – all are human perceptions of soils – brave and bold and highly subjective.

Several references (Boulaine, 1989; Yaalon and Berkowicz, 1997) may help you get started in your search of vignettes of what the 'ancients' did. There is a natural tendency to look for the initiator – the first – the beginning – and then follow the paths of evolution, the birth and death of ideas. Why? Perhaps because we are also cyclic.

1.1 Some Greek and Roman concepts

By the time of Greek civilization there had already been several millennia of records of humankind's achievements and failures to control soils scattered among the languages of the Earth's inhabitants. Let us pick up the story with Aristotle. He said that there were four elements formed and shaped from the same amorphous matter by a spirit endowed with reason. Fire, air, water and earth were in opposition to ether, the fifth element, which could not be perceived by the senses. These four elements were carriers of both active and passive qualifiers. Earth was characterized by opposing qualities, such as warm and cold, dry and wet, heavy and light, and hard and soft.

One of Aristotle's students, Theophrastos (371–286 BC) gave soil the name of 'edaphos' to contrast it with earth (terrae) as a cosmic body. Edaphos was a layered system; a surface stratum of variable humus content, a fatty subsoil layer that supplied nutrients to grass and herb roots, a substratum that provided juices to the tree roots, and below was the dark realm of Tartarus. He described numerous relationships of soils and plants, and indicated six groups of lands suitable for different crops. The Greeks paid special attention to grapevines and Theophrastos even noted that an important way to increase productivity on stony soils was by transplantation of soil.

Herodotus (*c*. 485–425 BC), an experienced traveller, considered soil as an important element in characterizing a place, noting for example that Egyptian soil was black and friable, and consisted of silt brought by the Nile from Ethiopia.

In summary, the Greek intelligentsia concluded that soil was something special and important, had a profiled (layered) structure, fertility was its main quality, soil was spatially variable, plants were both wild and cultivated, and plant selection and cultivation were highly dependent on the properties of the soils.

In ancient Rome, the problems of agronomy including technology and organization of agriculture, and better land utilization were important. The nature of Italy is diverse and these features created a complicated mosaic of soil cover; thus it was necessary for Roman farmers to determine 'which land likes what'.

Cato, the senior (234–149 BC), was a government official, a big landlord, and traveled on assignment for the Senate. One of his major works, *De Agricultura*, appeared about 160 BC. In addition to knowing 'which land likes what', he also admonished that careful ploughing and application of dung and use of green manure crops was necessary to create those conditions that are best for plant development. Cato dealt at length with the problem of dung manure. He developed a classification of arable soils based on farming utility with nine major groups that were subdivided into 21 classes.

Varro (116–27 BC), an encyclopedia specialist, was assigned by Julius Caesar the task of organizing a public library in Rome and may have been the first to recognize the independent status of farming as a science. He also observed that it teaches us what should be sown on which field so that the earth will constantly produce the highest yields. Varro devised a classification recognizing as many as 300 types of soil using soil properties such as moisture, fattiness (texture), stoniness, colour and compaction. Maintaining productivity by rotating crops was important advice to farmers.

Twelve volumes about agriculture by Columella (first century AD) covered the gamut of agronomy of the Mediterranean region. With regard to declining soil fertility he said that the guilt lies with people who deal with agriculture like a hangman with a prisoner, the lowliest among slaves. He developed a classification based on combinations of properties yet conceded that no one can know '*in toto*' the whole diversity of soils. He conducted many field experiments, noting that science shows the learner the correct path.

Stremski (1975) summarized Roman heritage by noting that Cato emphasized the suitability of soils for farming and their quantitative productive potential, Varro was concerned mainly with physical composition of soils, Columella emphasized physical properties, and Pliny the Elder focused on rocks and minerals as soil-forming materials. It is obvious that ancient knowledge of soils was extensive; however, agricultural soil science stagnated with the downfall of Rome only to be revitalized in the eighteenth and nineteenth centuries.

1.2 The transition

Close your eyes again and when you open them imagine that the Renaissance and the Age of Enlightenment have just finished. Here in the nineteenth century there abound a myriad of discipline-oriented concepts of soil based on the background and interests of scientists in different disciplines. The geologists refer to the straight-line function of rocks to soils; thus there were granite soils, limestone soils, shale soils, and so forth. Geomorphologists recognized upland soils, river valley alluvial soils, colluvial soils, mountain soils, steppe soils, desert soils and so forth. Botanists associated plant communities with soils; thus there were oak soils, prairie soils, pine soils, desert shrub soils, taiga soils, etc. Chemists denoted alkali soils, carbonaceous soils, base saturated soils, acid soils, and so on. Agriculturists referred to maize soils, wheat soils, pasture soils, fertile and infertile soils and many others. People concerned with mechanical behaviour recognized sticky soils, clayey soils, push soils, silty soils, one, two and three water buffalo soils, stony soils and so forth.

Throughout this period there was no general agreement on how to recognize and refer to soils. One cultural attitude still prevailed – that of the lowly status of those who tended the fields. Serfs, peasants and slaves were associated with the menial, filthy aspects of preparing, tilling and harvesting produce from the earth. By association soil was not generally worthy of serious consideration.

1.3 The awakening

As you open your eyes once more you suddenly stand in a gently waving sea of prairie grass looking across a seemingly infinite expanse of open landscape – the home of the famous Russian Chernozem. Severe droughts in 1873 and 1875 in this region caused untold misery and economic loss. In 1877 the Free Economic Society instituted the 'Chernozem Commission' and funded V. V. Dokuchaev, a geologist at the University in St Petersburg, to conduct geologic-geographic investigations of the Chernozem. In the report of the second year of work he described soil generally as a mineral-organic formation of unique structure lying on the surface and continuously being formed as a result of the constant interaction of living and dead organisms, parent rock, climate and relief of the locality. He also stated that 'soil exists as an independent body with a specific physiognomy, has its own special origin, and properties unique to it alone' (Krupenikov, 1992, p. 161). Dokuchaev's classic monograph, '*Russian Chernozem*' published in 1883, was the final report to the Free Economic Society about the Chernozem problem and it was defended as his doctorate dissertation.

In 1882 the Nizhi Novgorod province requested Dokuchaev to conduct geological and soil investigations for a rational assessment of land. The project continued from 1882 to 1886, was published in 14 volumes, and laid the foundation for the new school of genetic soil science. According to Dokuchaev the main aim of pedology was to study soils 'as they are' and to understand the regularities of their genesis, interrelations with the factors of soil formation, and geographical distribution. This was the principal difference from the prevailing notions of soil as just an object of agricultural activities. What did this really mean? It brought together many of the ideas about soil, restructured them into a set of integrated causal relationships, and provided a framework for research and understanding of soil as an independent science.

1.4 Genetic supremacy

After blinking your eyes again, you realize that another hundred years has passed and that pedology has been constantly evolving (Bockheim *et al*., 2005). Genetic soil science has been accepted around the world and soil surveys have been underway in many countries for a number of years, associated mainly with agriculture and forestry. Pedologic and geologic concepts and terminology of soil horizons, solum, profile and weathering layers have come into existence and been adapted to meet both scientific and societal needs (Tandarich *et al*., 2002).

The conservation of soils has usually been stimulated by catastrophic events related to their degradation. For example, the Dust Bowl in the USA in the 1930s spurred government action to create a Soil Conservation Service in the Department of Agriculture. Along with practices to mediate water and wind erosion, there were attendant actions to better manage water resources and maintain fertility. Advice about protecting soils was based on knowledge of the soil resources; consequently an expanded programme of soil survey was undertaken. The need for basic units of classification and for mapping was evident and pedological concepts prevailed.

Based on the 'neo-Dokuchaev paradigm of pedology' that relates factors → processes → properties (Gerasimov as referenced by Sokolov, 1996, p. 253) there arose two major pedological concepts of soils. One is represented by the pedon, or arbitrary volume; the other by the polypedon, or small landscape unit (Fig. 1.1). The literature contains many terms for both small arbitrary volumes of soils and the spatial entities identified by named and defined kinds of soils (Arnold, 1983).

A major Russian textbook based on Dokuchaev's concepts stated that 'the moisture and thermal regimes determine the dynamics of all phenomena in soils, i.e. they are fundamental in soil formation as a whole' (Gerasimov and Glazovskaya, 1965, p. 147); however, neither soil temperature nor soil moisture state were considered or defined as 'soil properties'. Climatic regimes,

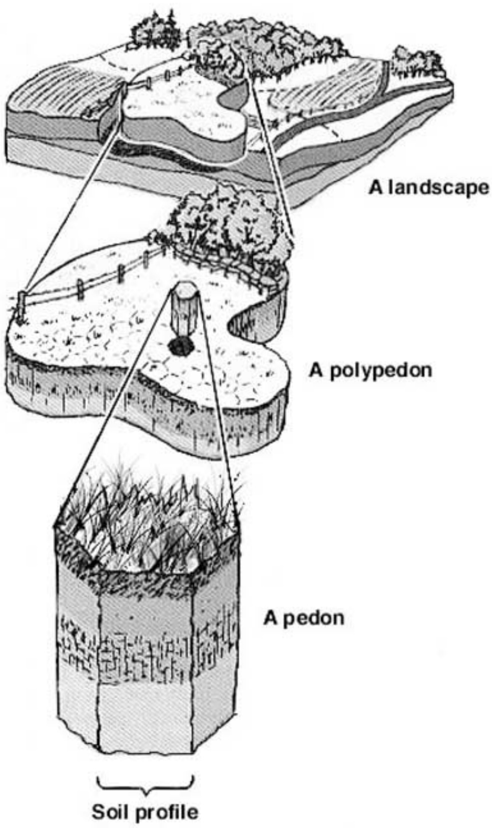

Fig. 1.1. A hierarchy of spatial relations of soil bodies commonly used in pedology. The profile, a thin rectangular section is the basis for soil description; the pedon represents a small sampling volume for property characterization; the polypedon represents a body having a set of similar properties in a landscape; and the landscape represents a portion of the pedosphere containing bodies of several kinds of soils. Adapted from Fig. 3.1 in Brady and Weil (1996).

by contrast, were commonly identified as important environmental conditions for specific kinds of soils in Russia. The United States Department of Agriculture's (USDA) '7th Approximation' and subsequent editions of *Soil Taxonomy* (Soil Survey Staff, 1999) have described and defined soil temperature and soil moisture state as soil properties. Proper placement of soils in Soil Taxonomy has been achieved by defining patterns of soil temperature and soil moisture as regimes and using them to define specific taxonomic classes. This revolutionary deviation from other taxonomies recognized soils as dynamic entities in addition to being historical records of soil evolution by quantifying these properties.

1.5 Sampling volumes

Arbitrary small volumes of soils are the basic source of information about the genesis and properties of soils (Holmgren, 1988). This information abstracts the central concept of a soil and the properties characterize a soil mainly for purposes of classification and correlation.

Because soil-forming factors occupy space and their influence is over time, there is a concept of soil as a geographic entity whose recognition and distribution depend on limits associated with defined kinds of soils and external features associated with the processes and properties of the dominant soil.

The USDA Soil Survey Manuals of 1951, 1962 and 1993 highlighted a number of concepts guiding soil surveys in many parts of the world. Soil was thought of as the collection of natural bodies on the Earth's surface, in places modified or even made by humans of earthy materials, containing living matter and supporting or capable of supporting plants out of doors. The upper and lower limits with non-soil were discussed but not quantified.

Natural soil bodies were still considered to be the result of climate and living organisms acting on parent material, with topography or local relief exerting a modifying influence and with time required for soil-forming processes to act. Some confusion still existed about whether soil referred to the broader concept of a resource, or to its component members; that is, the soil, or kinds of soils.

In the first version of a new Russian soil classification scheme (Shishov *et al*., 2001) soil was considered to be a system of interrelated horizons composing a genetic profile, which derived from the transformation of the uppermost layer of the lithosphere by the integration of soil-forming agents.

A pedon was regarded as the smallest body of one kind of soil large enough to represent the nature and arrangement of horizons and variability in other properties that are preserved in samples (Soil Survey Staff, 1999). It had a minimal horizontal area of 1 square metre but ranged to 10 square metres depending on the variability in the soil. In the USA, the pedon was originally considered to be a sampling unit within a polypedon that was a unit of classification, a soil body homogeneous at the series level, and big enough to exhibit all the soil characteristics considered in the description and classification of soils (Fig. 1.1). Because of the difficulty in fitting boundaries on the ground and the circular nature of the concept, the polypedon seldom served as the real thing to be classified.

In the 1998 *Keys to Soil Taxonomy* (Soil Survey Staff, 1998) soil was referred to as a natural body that comprises solids (mineral and organic), liquid and gases that occur on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers and transformations of energy and matter; or the ability to support rooted plants in a natural environment. This expanded definition of soil was meant to include soils of Antarctica where pedogenesis occurred but where the climate was too harsh to support the higher plant forms. For purposes of classification the lower limit of soil was set at 200 cm. The deposition, alteration, and layering of sediments helped explain discontinuities of parent materials. Recognition of *in situ* alteration such as weathering, hydrothermal influence or contamination expanded the concept of factor interactions.

For the most part profile features were combined into models of soil formation involving the processes and events of geomorphology that had influenced and helped to shape the hypothesized features.

As portrayed by the National Cooperative Soil Survey in the United States, a soil series was a group of soils or polypedons that had horizons similar in arrangement and in differentiating characteristics. The soil series had a relatively narrow range in sets of properties. Map unit delineations had commonly been identified as phases of the taxonomic soil series. This process attempted to bridge the gap between classification and geography as classification became more quantitative; however, the resolution by refining soil series definitions to fit the limits imposed by the hierarchical Soil Taxonomy resulted in the loss of much landscape information.

After several decades of study the Food and Agriculture Organization's (FAO) legend for the map of World Soil Resources was accepted at the 1998 World Congress of Soil Science as the basis for developing a World Reference Base to correlate soil classification systems with the intent to provide an updated legend, map and database for global soil resources. Although no real definition of soil was reiterated (FAO/ISRIC/ISSS, 1998), Reference Soil Groups were defined by a vertical combination of horizons within a defined depth and by the lateral organization of the soil horizons, or by the lack of them, at a scale reflecting the relief of a land unit. Soil horizons and properties were intended to reflect the expression of genetic processes that are widely recognized as occurring in soils (Bockheim and Gennadiyev, 2000).

1.6 Landscape systems

Several other approaches to describe and define geographic bodies of soils were summarized by Fridland (1976). Most of these concepts arose where detailed soil mapping was not the major soil survey activity, but where exploratory and other small-scale studies were being undertaken. The French school of pedology has refined and implemented many concepts related to soil landscape mapping (Jamagne and King, 2003). Soils were believed to result from transformations that affect the material of the Earth's crust, and that successive climates and biological and human activities had been the agencies directly responsible. Their effect depended not only on the nature of the rock and their derived formations that have resulted from them, but also on landscape relief and the migration of matter in solution or in suspension in water. The overall result was that the original arrangement of geological material disappeared, leaving an entirely new arrangement of pedological origin.

They maintained that the genetic conditions of soils resulted in a double differentiation: in their vertical arrangement and in their spatial distribution. The former corresponded to the common notion of soil profiles that are vertical sections through the nearly horizontal layers of altered parent materials (horizons) (Fig. 1.1), and the latter corresponded with the lateral arrangement of different types of horizons within the landscape, thus allowing for the definition of soil systems in space.

The concept of soilscape or 'pedolandscape' was defined as the soil cover, or part of the cover, whose spatial arrangement resulted from the integration of a group of arranged soil horizons and other landscape elements. A soil system was a type of soilscape, a toposequence, where the differentiation was linked with a functioning process. A reference relief unit was a catchment or watershed area and the analysis of lateral transfers on, in and through the soils (vertically and laterally) had to be considered to understand the functioning of the landscape units. The systems could be open or closed relative to the flow of water and energy. Soil systems provided a framework to describe the process dynamics of the evolution of a landscape and its associated soils.

1.7 The new millennium

Now as you open your eyes once more, a new millennium has begun. It is one full of uncertainty, especially concerning the extent to which humans have irreversibly altered their global habitat. It has been postulated that the achievements of the Industrial Revolution and the rapid changes of the Information Age are characteristic of the Anthropocene, the current geological period.

In the 1997 edition of the Russian classification (Shishov *et al.*, 2001) special attention was given to agrogenically and technogenically transformed soils. These soils were considered to be the result of soil evolution under the impact of human activities. When considering natural soil, the anthropogenically transformed soils formed an evolutionary sequence grading finally to non-soil surface formations. Recognition was based on morphology and did not include direct impacts on soil fertility. The initial proposal recognized Agrozems as soils whose profiles had been agrogenically modified providing a homogeneous topsoil more than 25 cm deep over diagnostic subsoils or parent material. Agrobrazems lacked a surface diagnostic horizon due to erosion, deflation or mechanical cutting but had a specific surface horizon formed from subsoil or parent material. Abrazems, although similar to Agrobrazems, were recognized by the presence of a subsoil horizon or transition to parent material and were not suitable for cropping. In addition degraded soils due to chemical impacts, Chemdegrazems, could be recognized in any other class of soil. A special group of artificially constructed materials (non-soils) called Fabricats were suggested for trial use. They included Quasizems that had a humus-enriched surface layer placed over chaotic mixtures, Naturfabricats that lacked an organic matter enriched surface layer but consisted of human transported or mixed materials, Artifabricats that had substrates whose materials are absent in nature, and Toxifabricats that consisted of toxic, chemically active materials unsuitable for agriculture or forestry.

Man as an important soil-forming factor is also reflected in the concepts of soils as functional entities now within the realm of the noosphere where man and nature are considered to be co-evolutionary factors of the biogeosphere. Ecological and environmental soil functions as described are human values associated with actual and potential behaviour of soil landscapes and their relevance to society. Although not far removed from the concepts attributed to use of the soil by ancients, the details are more focused and even global in scope.

One perspective describes the function of soils in the pedosphere as they interact with associated spheres, namely the atmosphere, biosphere, hydrosphere and the lithosphere (Arnold *et al.*, 1990). These concepts portray the pedosphere as the active geomembrane interface that mediates energy fluxes and enables terrestrial life to exist (Ugolini and Spaltenstein, 1992).

Another perspective describes major soil functions as: biomass producer and transformer; filter, buffer and reactor; habitat for macrobiota and microbiota; direct utilization as raw material and infrastructure support; and cultural and heritage aspects (GACGC, 1995). Both perspectives are significant to our understanding of soil quality, soil health, ecosystem sustainability, and the world of human-influenced soils. The chapters that follow describe major aspects of pedology and lead us to consider the challenges and changes of the concepts that will guide the future.