SOIL GENESIS AND CLASSIFICATION

SIXTH EDITION

Introduction 1

This book discusses the composition of soils as natural bodies resulting from biogeochemical processes on the land surfaces of earth. It also examines human attempts to better understand the interaction of soils with biological components of the ecosystem, including humans, via the study and classification of soils. The main themes of soil genesis and classification follow:

1. Identification and description of soil profiles and pedons (soil morphology);
2. Characterization of chemical, mineralogical, and physical soil properties aided by laboratory and field investigations of soil properties;
3. Categorization and classification of soils according to similarity of properties and function;
4. Mapping the spatial distribution of soils as they exist on the earth's surface;
5. Analyses of the relationships between soil properties and the many potential uses of soils.

All of these activities comprise a recognized area of specialization within the discipline of soil science. The Soil Science Society of America changed the name of its Soil Genesis, Morphology, and Classification division to Pedology about a decade ago (Simonson 1999). "Pedology" (from Gr. *Pedos*, "ground," and *logos*, "science"; original formed as Russian, *pedologiya*) is a collective term used to refer to the combination of the two phases of soil science: (1) soil genesis and classification and (2) more inclusively, also soil morphology, survey or mapping, and interpretations. Pedology is practiced in many other countries, especially European and Asian countries and Australia (Editorial Staff 1940; Gibbs 1955; Leeper 1953, 1955; Northcote 1954). The International Union of Soil Sciences includes these aspects of soil science primarily in their commission of Soil in Space and Time.

Subdivisions of Pedology

Following are descriptions of each of the distinctive phases of activity encompassed by pedology.

Soil genesis is a century-old science that has dealt with soil in three conceptual phases: (1) as a geologic entity, (2) as a product of factors and processes of soil formation, and (3) as an open system capable of supporting the functions of soil in all

Soil Genesis and Classification, Sixth Edition. S. W. Buol, R. J. Southard, R. C. Graham and P. A. McDaniel.

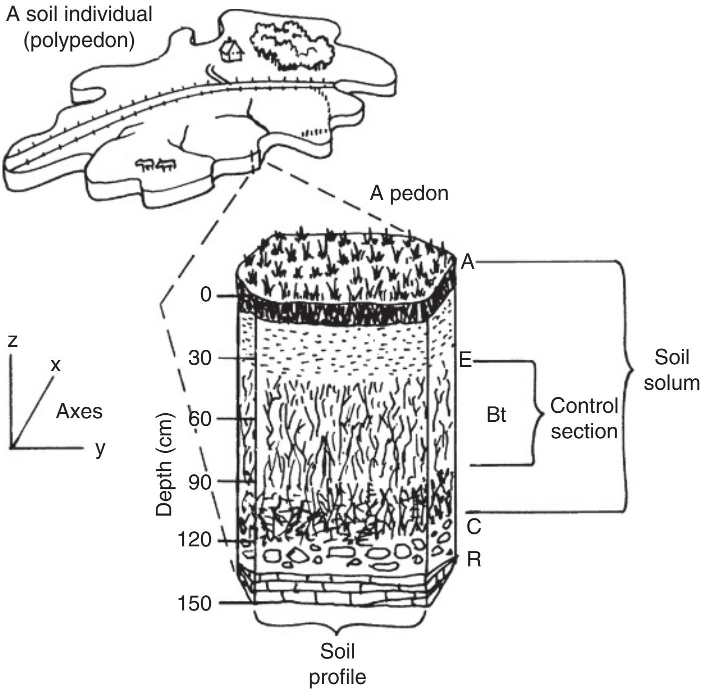

Figure 1.1. A soil individual is a natural unit in the landscape, characterized by position, size, slope, profile, and other features.

ecosystems. Soil genesis includes concepts of biogeochemistry. It conceptualizes the factors and processes responsible for the chemical, physical, and mineralogical properties of all soils and the spatial distribution of various kinds of soil on the landscape.

Soil classification is the categorization of soils into groups at varying levels of generalization according to their physical, mineralogical, and chemical properties. The objectives of soil classification include organization of knowledge, ease in remembering properties, clearer understanding of relationships, and ease of technology transfer and communication.

Many classification systems are used to classify soils and soil materials. Some are designed to relate soil properties to specific uses and are referred to as "technical classification systems." Others, termed "natural classification systems," are structured to categorize all soil properties. The primary classification system used in this book is *Soil Taxonomy*, a natural classification system. When the term *Soil Taxonomy* is capitalized and italicized in this book, it refers to the system of classification developed by the U.S. Department of Agriculture (USDA) Soil Survey Staff with the support of and contributions from land-grant universities, other federal and state resource agencies participating in the National Cooperative Soil Survey, and colleagues from other countries. It was formally released and published by the USDA in 1975, and a second edition was published in 1999 (Soil Survey Staff 1975, 1999). The system is also updated periodically through the release of revised *Keys to Soil Taxonomy*. The most recent edition of the *Keys* was published as the 11th edition (Soil Survey Staff 2010). *Soil Taxonomy* is now widely used throughout the world. *Soil Taxonomy* uses quantitative morphological criteria to define kinds of soil and concepts of soil genesis to guide the selection and orderly application of these criteria.

All classification systems are a mirror or state-of-the-art indicator of the available knowledge about the objects classified, assembled in a systematic fashion to facilitate communication with other scientists and, most importantly, with the students who will become the future scientists. The fact that classifications systems change over time is an inevitable result of research in soil science and in other sciences that relate to uses of the soil.

Soil morphology encompasses the color, physical structure, chemical and mineralogical properties of soil material; the spatial association of materials in soil horizons (Figure 1.1); and the temperature and moisture dynamics of soil in situ. The thickness, vertical relationship, number, and three-dimensional ranges and variations of horizons found in the smallest recognizable volume of soil that is classified (called the "pedon," the word rhymes with "head-on") are described and recorded by a standard nomenclature outlined in Chapter 2.

Perspective on the Role of Soil Genesis and Classification

It is useful, important, and interesting to consider how the study of soil genesis and classification interacts with other fields of soil science and other scientific disciplines. This is especially true for technical soil classifications derived from scientifically based natural classifications systems like *Soil Taxonomy* (Buol and Denton 1984). Soil properties are primary reagents in field experimentation. Documentation of soil properties at research sites is essential for the successful transfer of research results to other locations.

Soil genesis and classification studies have made contributions to research design and data acquisition in other fields of soil science, including biogeochemical redistribution of nutrients in ecological systems, ecology of soil microbes and mycorrhizae, and the availability and distribution of plant essential nutrients such as phosphorus and nitrogen in different types of soils (Runge and McCracken 1984). Soil maps furnish basic inputs to soil conservation planning in the United States and provide information used in equations for predicting soil loss and water pollution potential under various management practices on different soils.

Characterization of soil properties is fundamental to all soil studies. Complete soil characterization for classification purposes requires that all horizons of the soil be analyzed. Many laboratory and greenhouse studies require only characterization of soil material from a few horizons, but practical application of the results obtained from such studies requires verification with field studies. Soil characterization methods draws heavily on methods of soil chemistry, physics, mineralogy, microbiology, and biochemistry. Conversely, methods and results initially obtained in soil characterization and soil genesis studies have been useful in perfecting methods of soil analysis by providing materials representative of all kinds of soil for analysis.

Soil genesis embraces the concept of soil as “a natural entity to be studied as a thing complete in itself” (Cline 1961). This concept has survived the fragmentation of soil science into the subdisciplines of soil chemistry, soil physics, soil microbiology, soil fertility, and soil management by drawing upon and integrating the concepts, theories, and facts of these subfields of soil science into a holistic, integrated, multidisciplinary view of soil as a natural entity. Soil genesis and classification, or pedology, may also be likened to a system of bridges connecting the disciplinary islands of geology, biology, chemistry, physics, geography, climatology, agricultural sciences, economics, anthropology, and archeology. The interdisciplinary nature of this field of soil science gives it added importance in the training of scientists (Abelson 1964). Soil genesis and classification and its allied activities therefore have many interactions with and contributions to fields of science other than the science of soils.

Soil genesis and soil classification have some roots in geology, for they grew out of the study and mapping of rocks. The close ties between geology and soil science stem from the fact that most soils are derived from geologic materials such as granite, limestone, glacial drift, loess, and alluvium. Several of the early pioneer soil scientists were geologists by training. Because differences among soils are due in part to the different landforms they occupy, and because age of the soil is related to the stability of the surface on which they have formed, close ties between soil specialists in genesis and classification and geologists specializing in geomorphology continue to be strong and mutually beneficial.

Soil genesis and classification is seldom concerned with entire geological deposits, but rather deal with the upper portion of the deposit that has been influenced by plant and animal activity and by the intrusion of water and energy from the land surface. Therefore, soil genesis and classification, which deals with the dynamic, biologically active soil system, must also be concerned with biology, especially the subsciences of ecology, microbiology, plant physiology, and botany. Hans Jenny (1980) regarded soil and vegetation as coupled systems and thus an ecosystem. A knowledge and awareness of plant-soil interactions, meteorology, and hydrology are essential for soil scientists interested in soil genesis and classification.

Soil underpins human food production and is a very significant component in our total stock of natural resources. Production economists call on soil scientists for data and estimates of the productivity of various soils under defined systems of management. Natural resource economists are concerned about the amount and distribution of useful productive land. Planners at local, state, regional, and national levels use soil surveys and soil interpretations for land-use planning, environmental protection, selection of building and highway sites, tax assessment, and land evaluation (Simonson 1974; Bauer 1973; Jarvis and Mackney 1979). This places additional responsibility on soil classifiers and interpretation specialists to provide sound, scientifically based evaluations of flooding, structural instability, and other economic potentials of individual kinds of soil. Soil scientists must consider economic and resource conservation factors in the preparation of technical and natural classification systems. Archeologists and anthropologists utilize soil information and data to date construction and destruction of human settlements and explain changes in agricultural practices (Olson 1981; Harrison and Turner 1978).

It is clear from the preceding examples that soil genesis and classification interact with a large number of disciplines and interests. Not only does this signify the important and varied uses for soil information, but it also challenges those working in this area to be aware of all potential uses as they seek to better understand the dynamic role of soils in the environment.

Developmental Stages of a Discipline

Three stages in the development of a discipline enumerated by Whitehead (1925) may be applied to soil genesis and classification and their related components:

Stage 1: Location in space and time. The basic operation of mapping soils to record their positions in space is a prerequisite to genesis and classification and their related components.

Stage 2: Classification. Whitehead (1925) calls this a "halfway house between the immediate concreteness of the individual things and the complete abstraction of mathematical notions." A great variety of genetic and descriptive soil classifications have been developed. Terminology used ranges from symbols, to synthetic terms based on classical languages, to a hodgepodge of folk terms. All classification systems rely on the knowledge and understanding available and are subject to change as that knowledge and understanding evolve.

Stage 3: Mathematical abstractions. More highly developed abstractions are possible by mathematical means. Mathematical models also help us to predict. Relationships between soils and other natural phenomena are conceived from observations. Statistical expressions are possible when sufficient quantitative data become available (Bidwell and Hole 1964; Hole and Hironaka 1960; Arkley 1976; Jenny 1941, 1961b, 1980). Computer-based models that project the effects soil properties have on numerous entities utilize both soil characterization data and spatial data recorded on soil maps (Bouma 1994). Attempts to utilize existing data to model soil genesis and classification, and to aid soil mapping have become an increasingly important part of pedologic research (Bouma and van Lanen 1987; Vereecken et al. 1992; Tietje and Tapkenhinrichs 1993; Rasmussen et al. 2005; Hartemink et al. 2008).

Developmental stages in soil classification are not chronological. Although soil mapping has identified many of the soils in the world, many areas remain poorly explored. Also, the methods for identifying soil properties are improved as new analytical technologies are developed. Classification of an object such as soil cannot be considered complete until everything is known about that object. Classification can only reflect what is known, and in soil science this knowledge base increases as new lands are explored and new analytical techniques are employed to describe and analyze soils. Mathematical abstractions are built on a foundation of what is known. Improvements can be made as more extensive and intensive databases become available.

The components of soil science to which we have been referring are subjects in this book. We think it desirable to have a brief summary of the historical development and a synopsis of the principles, concepts, and theories plus notes on the methods of each before proceeding to the specifics.

Historical Developments in Soil Genesis

By reviewing history we gain perspective about modern soil genesis concepts, become aware that this field of science is dynamic, come to appreciate the resistance new ideas have encountered, and become aware of the newness of soil science as we know it today.

Aristotle (384–322 B.C.) and his successor Theophrastes (372–287 B.C.), considered the properties of soil in relation to plant nutrition. Roman writers who discussed differences among soils in relation to plant growth included Cato the Elder (234–149 B.C.), Varro (116–27 B.C.), Virgil (70–19 B.C.), Columella (about A.D. 45), and Pliny the Elder (A.D. 23–79). In 1840 Justus von Liebig published *Chemistry Applied to Agriculture and Physiology* in which he states that plants assimilate mineral nutrients from the soil and proposed the use of mineral fertilizers to fortify deficient soils (Liebig 1840).

In the middle of the nineteenth century several German scientists, including Ramann and Fallou, developed agrogeology, which viewed soil as weathered, somewhat leached surface mantle over rock. Fallou (1862) suggested that "pedology"—which to him signified theoretical geological soil science—be distinguished from "agrology," the practical agronomic soil science.

In Russia, Lomonosov (1711–1765) wrote and taught about soil as an evolutionary rather than a static body. In 1883, V. V. Dokuchaev (1846–1903) (Figure 1.2) published a report of a field study of Chernozem soils present under grasslands in which he applied the principles of morphology to soils, described major soil groups and their genesis, produced the first scientific classification of soils, developed methods of mapping soils, and laid the foundation for soil genesis and soil geography. In 1886, Dokuchaev proposed that "soil" be used as a scientific term to refer to "those horizons of rock that daily or nearly daily change their relationship under the joint influence of water, air, and various forms of organisms living and dead" (Vilenskii 1957). He later defined soil as an independent natural evolutionary body formed under the influence of five factors, of which he considered vegetation the most important. Russian soil scientists K. D. Glinka

Figure 1.2. V. V. Dokuchaev.

Figure 1.3. E. W. Hilgard.

(1867–1927) and S. S. Neustruyev (1874–1928) reemphasized the concept of soil as a superficial geological entity, a weathered crust that exhibits specific properties correlated with climatic zones. V. R. Williams (1863–1939), another Russian soil scientist, developed the concept of soil genesis as essentially a biologic process rather than a geologic one. He stated that soil formation takes place best in grasslands. P. E. Müller (1878) wrote a monograph on soil humus, describing the biological character of soil genesis in forests.

In the USA, E. W. Hilgard (1833–1916) (Figure 1.3), working as a geologist and soil scientist in Mississippi and California, wrote about the relationships between soils and climate (Hilgard 1892). He "saw the farmer's dirt as a richly embroidered mantle of earth, whose design and fabric were deserving of scientific zeal and quest" (Jenny 1961a). G. W. Coffey, a soil scientist with the U.S. Division of Soil Survey, published a soil classification system for the United States based on the principles of soil genesis expressed by Dokuchaev and Glinka (Coffey 1912). However, this was an idea whose time had not yet come in the United States, because the idea of soil as a superficial geologic material still dominated.

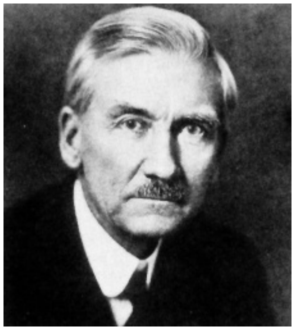

Figure 1.4. C. F. Marbut.

Figure 1.5. C. E. Kellogg.

C. F. Marbut (1863–1935) (Figure 1.4), while director of the U.S. Soil Survey Division, read Glinka's publications on soil genesis and classification and introduced their concepts into soil survey programs in the United States, as well as introduced his own emphases on the soil profile and the 'normal' soil (Krusekopf 1942).

Charles E. Kellogg (1902–1977) (Figure 1.5), Marbut's successor as director of the USDA Division of Soil Survey, continued the enhancement of the themes and principles of soil genesis as a necessary basis for soil classification and soil survey while introducing uniform techniques and nomenclature among soil scientists (Kellogg 1937; Soil Survey Staff 1951, 1960; Kellogg 1974).

Hans Jenny (1899–1992) (Figure 1.6) wrote a masterful treatise on the five factors governing the development of soils (Jenny 1941). He noted that quantitative elucidation of the processes of soil formation could not proceed without a larger body of data than was available. In a later work, Jenny (1980) put the five soil-forming factors

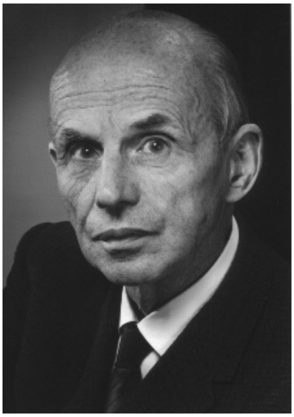

Figure 1.6. H. Jenny.

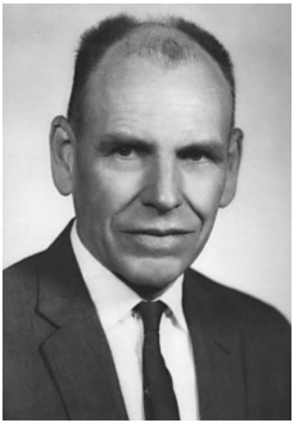

Figure 1.7. G. D. Smith.

"into a conceptual framework that permits solving the equation when landscape configurations are favorable."

In 1959, R. W. Simonson brought out the significant point, not well recognized previously, that many genetic processes may be simultaneously and/or sequentially active in any one soil (Simonson 1959). He pointed out that the horizons of a soil profile reflect the relative strength of these processes and the degree to which they offset each other.

In the 1960s and early 1970s, G. D. Smith (1907–1981) (Figure 1.7), as director of Soil Survey Investigations for the USDA Soil Conservation Service and chief architect of *Soil Taxonomy* (Soil Survey Staff 1975), with his colleagues, further advanced and refined soil genesis studies in support of soil classification and soil survey. Smith made the important point that concepts of soil genesis are very important for soil classification, but factors and processes of soil genesis cannot be used as the sole basis for soil classification because they can rarely be quantified or actually observed (Smith 1983). He stressed that soil classification was best based on properties that could be observed and measured within the present soil.

Concepts of Soil Genesis

Concept 1. Soil-forming processes, also referred to as pedogenic processes and biogeochemical processes, that are active in soils today have been operating over time and have varying degrees of expression over space (that is, at various locations). The geologic uniformitarian principle that states "the present is the key to the past" is also applicable in soils with respect to downward translocation, biocycling, and transformation of materials—back to the time of appearance of organisms on the land surface. We can improve our elucidation of soil formation of differing soil profiles by application of this principle.

Concept 2. Many soil-forming (and soil-destroying) processes proceed simultaneously in a soil, and the resulting soil properties reflect the balance of both present and past processes (Simonson 1959). Soil-forming processes are actually combinations of specific reactions that are characteristic of particular time spans and conditions.

Concept 3. Distinctive combinations of geologic materials and processes produce distinctive soils. Observable morphological features in a soil are produced by certain combinations of pedogenic processes over time. The degree to which a morphological feature is expressed is dependent on the intensity and duration of the process.

Concept 4. Five external factors provide the reactants and energy to drive the pedogenic processes within the soil. These factors are climate, organisms, relief, parent material, and time.

Concept 5. Present day soils may carry the imprint of a combination of pedogenic processes and geologic processes not presently active at that site. Therefore, knowledge of paleoecology, glacial geology, and paleoclimatology is important for the recognition and understanding of soil genesis.

Concept 6. A succession of different soils may have taken place at a particular spatial location as soil-forming factors changed. The soil surface is lowered by erosion and dissolution of soil material and elevated by depositions of soil materials and tectonics. In this respect, the volume of material examined as soil on the land surface actually changes in vertical space over time.

Concept 7. The time scale for soil formation is much shorter than the geologic time scale and much longer than the age span of most biological species. The vulnerable position of soil as the skin of our dynamic earth subjects it to destruction and burial by episodic geologic events. Few, if any, soils are older than Tertiary and most no older than the Pleistocene epoch. Succession of vegetative communities and human activities often alter soil properties over short spans of time.

Concept 8. Complexity of soil genesis is more common than simplicity. Some processes that influence soil composition are discontinuous or episodic and disrupt soil features formed by other processes that are rather continuous over time.

Concept 9. Soils are natural sites for clay mineral formation on land surfaces. Most primary minerals on earth crystallize from magma at high temperature and pressure, and in the absence of free oxygen. When exposed to lower temperatures and pressures, free oxygen, meteoric water, and organic compounds near the land surfaces, the primary minerals decompose by processes known as weathering. Some of the elements reassemble into new mineral structures of clay size. It is likely that the clay particles in the shale and other sedimentary rocks are products of mineral alteration in soil prior to erosion and deposition.

Concept 10. Understanding and knowledge of soil genesis is useful in soil classification and mapping, but scientific classification systems cannot be based entirely on inductive concepts of soil genesis. Processes operating within a soil can seldom be observed or measured and are subject to change over time, which renders quantification difficult if not impossible.

Concept 11. Knowledge of processes of soil formation is basic to understanding the impact of human use and management. Humans alter both the factors and processes of soil formation in their attempts to improve a soil's performance for specific purposes. Knowledge of pedogenic processes helps assure compatibility of human actions and ambient soil conditions.

A Soil as an Anatomical Specimen

Just as Louis Agassiz (1807–1873) taught his students to learn about fish by making accurate drawings of specimens of fish, so Dokuchaev, Hilgard, Marbut, Kellogg, and others have taught us to learn about soils by describing them carefully (Marbut 1935). The *Soil Survey Manual* (Kellogg 1937; Soil Survey Staff 1951, 1993) provides detailed guides to the scientific description of soil profiles (Cline 1961). Observations recorded in a soil description represent the state of the soil body and surrounding landscape at a particular hour on a particular day. An accurate description of the soil profile is documentation needed to relate data obtained from laboratory or greenhouse studies of soil samples to the soil in situ on the land.

A Soil as an Energy Transformer

Soils and the vegetative covers that live in the soil are "energy transformers," receiving radiant solar energy by day and reradiating to space during the night. When radiant energy is absorbed at the soil surface, it is converted to sensible heat and warms the soil. Each night heat is lost through radiation to the atmosphere. If there is a dense

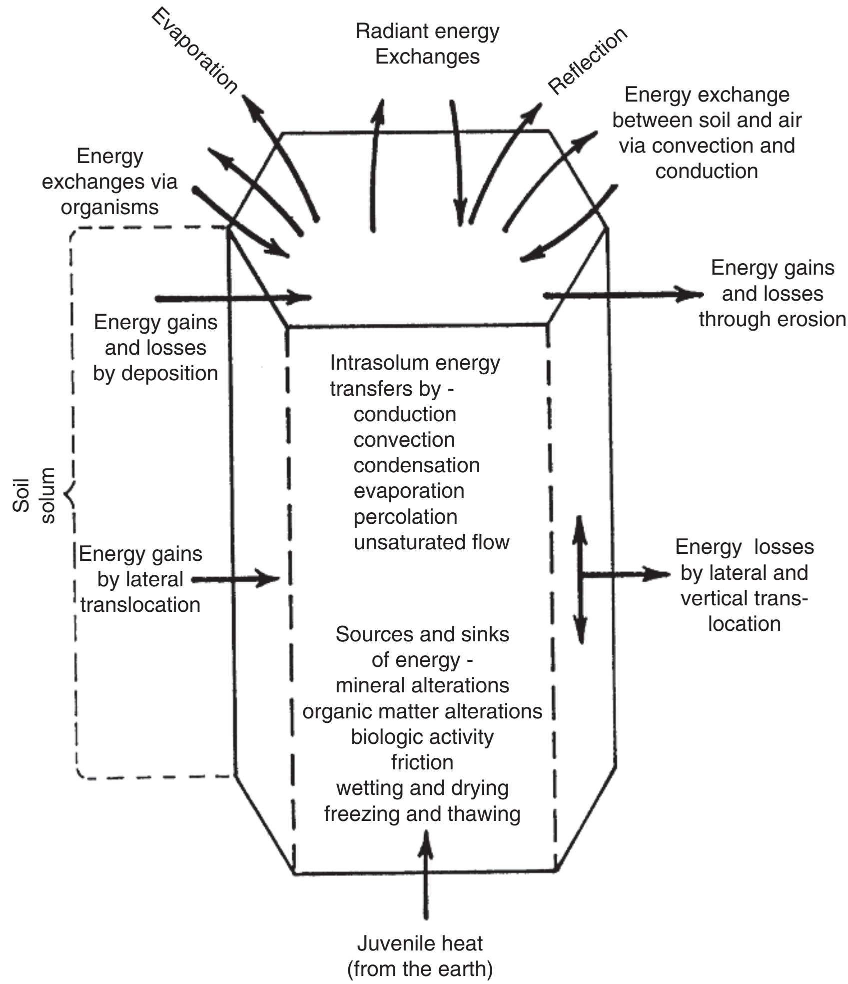

Figure 1.8. Schematic representation of energy sources and transformations in the solum.

cover of vegetation, the soil is shaded and experiences less heating and cooling. Small amounts of energy emanating from inside the earth (mostly as radioactive decay) escape as radiation from the soil. The energy transformations in the soil are accomplished through a variety of processes (Figure 1.8).

Each soil is fixed at a location and thus subject to the radiation dynamics at that location. Although the resulting soil temperature may be considered by some to be a climatic property, and not a soil property, soil temperature can be measured in the soil and is an important soil property that determines many of the interactions soils have with vegetation. Mean annual soil temperature and seasonal dynamics of soil temperature are used as criteria in *Soil Taxonomy*.

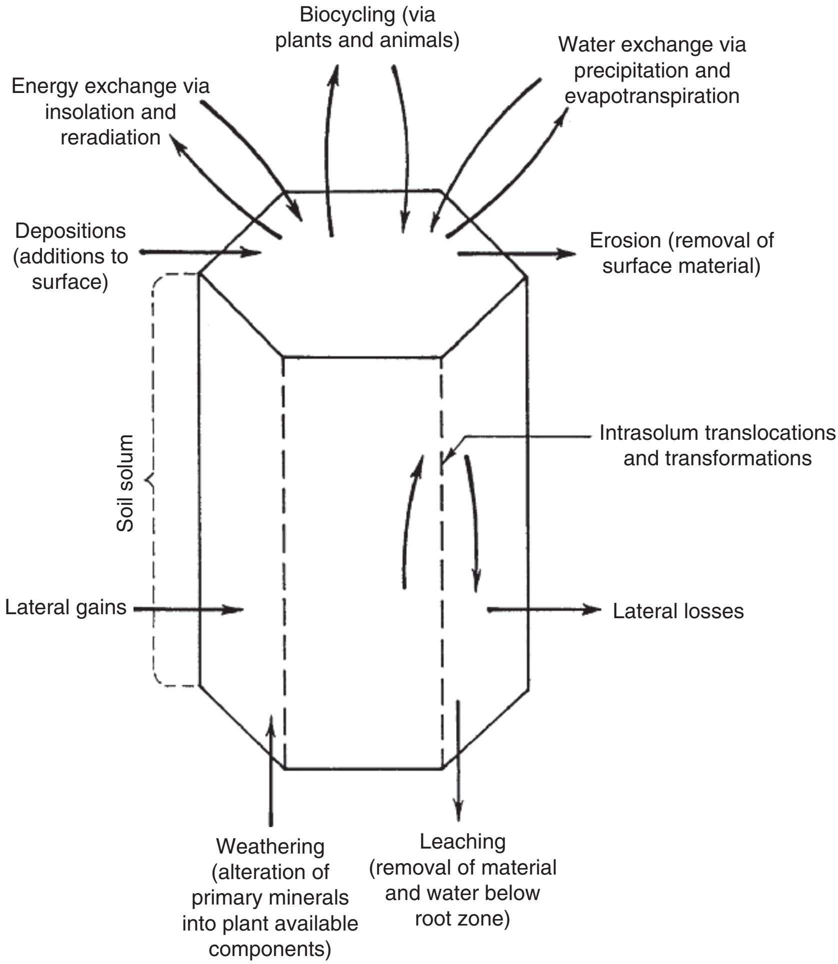

Figure 1.9. Schematic representation of the solum of a pedon as an open system.

A Soil as an Open System

A soil is an evolving entity maintained in the midst of a stream of geologic, biologic, and hydrologic activity (Figure 1.9). Individual soil bodies on the landscape and individual horizons within soil are the result of unequal distribution of materials within and between soils. Some soils and horizons within soils become enriched in certain substances; others become depleted. Water and energy flow through the soil surface, penetrate into the soil, and create an environment wherein primary minerals decompose and/or alter into secondary, mainly clay minerals (*weathering*). Plants and animals contribute to processes within the soil. The surface mineral horizon of a soil becomes enriched as carbon extracted from the air and chemical elements extracted from the entire rooting depth are deposited on the surface during leaf fall or death of the vegetation, whereas the lower part of the solum becomes relatively depleted in chemical elements extracted by plants (*biocycling*). There is transfer of material between soil bodies both at the surface (*erosion and deposition*) and by the subsurface flow of water (*lateral losses and gains*). Such transfers are more active on sloping land, wherein soils on the lower portion of a hill (footslopes and toeslopes) receive water and materials dissolved or suspended in that water from adjacent soils higher on the hillside (summits, shoulders, and backslopes). Materials may be removed from a soil in percolating water (*leaching*), but water from many rainfall events only percolates to a shallow depth, thereby translocating material dissolved and suspended in surface horizons to a subsoil horizon where it is deposited as plants transpire the water (*intrasolum translocations*) and new mineral and organic compounds may form (*intrasolum transformations*). Activity of earthworms, insects, macrofauna, the uprooting of trees, shrinking and swelling, and freezing and thawing all may act to reverse these downward translocations and physically move material upward within the soil.

Each soil has a budget of inputs and outputs that tends to establish a steady state at a given site. A steady state exists where the output is matched by an input of equal quantity and quality from a source not receiving the output. A steady state is often incorrectly considered equilibrium where material of equal quality and quantity moves to and from adjacent objects. Perhaps soils never reach a perfect steady state or equilibrium (Smeck et al. 1983), but in most soils the rate of change resulting from any imbalance is so slow it cannot be observed or measured. Where great imbalances exist, rapid changes in soil properties are observed. Perhaps the most noticeable changes are erosion losses on hillsides and depositional gains on floodplains.

The same factors and processes that influence soil formation influence terrestrial ecosystems. Processes of soil formation are components of ecological studies of potential global climatic and other environmental disturbances (Vitousek 1994).

Methods of Soil Genesis Study

Although there are many approaches to soil genesis study, depending on various circumstances, four general methods may be distinguished.

Independent Variable Method. This is a simple method insofar as it handles one item at a time (Jenny 1958). The intellectual assumption is made that all conditions are constant except one variable. For example, after installation of drainage to lower the water table in a soil rich in iron sulfide, the soil pH decreases to such a low level that little or no vegetation is able to grow. The obvious conclusion is that drainage has caused the soil to acidify. The danger in the independent variable method is that the observer may fail to verify that all conditions are the same and may be led to suppose that a relationship obtained in one place will hold elsewhere. The presence of iron sulfide is intrinsic to the result observed in the above example. When the soil is drained, air enters and oxidation reactions form sulfuric acid

(Fanning and Fanning 1989). It is obvious that drainage does not cause all soils to become strongly acidic or else we would have little agriculture as we know it today on the millions of hectares that have been drained.

Dependent-Variable Method. The soil complex is considered as a function of *n* variables, each of which can be written as a function of all the others, yielding *n* equations. This has the advantage of generalizing and dealing with a whole system. The results, on the other hand, may be quite unsatisfactory. For example, if the result of an analysis of a large soil region states that soils are extremely variable because conditions affecting the soils are extremely variable, no specific knowledge or understanding of soil formation is forthcoming.

Macroanalysis Method. By this method, the whole soil complex is divided into macro groups. This is actually a compromise between the oversimplicity of the independent variable method and the overgeneralization of the dependent-variable method. Examples of "macrogroupings" of soils are taxonomically defined soil groups, complexes, or associations of taxonomic groups. The risk in this method is that we tend to forget that taxonomic units are really complexes of individual soils, and we may consider them to be definite and stable entities.

Numerical Analysis Method. Numerical soil classification has been considered less objective and more fallible than traditional soil classification (Arkley 1976). Selection and weighting of soil properties interjects considerable bias into the analysis. Interest in numerical classification of soils was originally aroused by the success of the methods in terrestrial plant ecology, where a classification can be more objective than in pedology (Coventry and Williams 1983). In any case, numerical classifications of soils provide valuable insights. A necessity for numerical studies is access to data containing properties of soils (pedon databases) and geographic information systems that include data on soil-forming factors and processes (Anderson and Dumanski 1994). Smeck et al. (1983) concluded that numerical classifications have conceptual value, but none are totally acceptable. Nonetheless, numerical classification methods now play an increasingly important role in soil classification and mapping research.

Some Definitions of Soil Classification

Classification is the process of sorting or arranging of objects into groups on the basis of one or more objectives and according to a system or set of principles. *Categorization*, according to usage by cognitive scientists (Rosch and Lloyd 1978), involves the prior establishment of classes or groups of objects possessing one or more commonalities of properties and the placing of objects into preconceived and preformed groups according to quantitatively measurable criteria for category membership. This is done in a fashion that will provide maximum information with a minimum of classification effort while best representing the natural structure in the perceived world. Much of what we do in placing soils in groups is categorization rather than classification, but we bow to common usage and will use the term "classification" to cover both classification and categorization.

Class is a group of individuals or other units similar in selected properties and distinguished from all other classes by differences in these properties.

Taxon (pl. *taxa*) is a class of a formal classification system at any level of generalization or abstraction.

Category is a series or array of taxa produced by differentiation within the population being categorized at a given stated level of generalization. Note that we often use category and class as synonymous in our everyday conversation, but in the parlance of classification and categorization, a category is composed of an array or set of classes. Stated in another way, a category means a number of objects that are considered equivalent (Rosch 1978).

A *differentiating characteristic* is a property chosen as the basis for categorizing individuals (or classes of lower levels of generalization) into groups. There may be one or more characteristics used to represent or differentiate a class.

A *multiple-category* or *multicategorical system* is a hierarchical system of categories designed to classify a large and complex population that has a vertical structure of categories usually proceeding from more general, broadly defined categories to more specific, or narrowly defined, categories.

Taxonomy is a particular formalized system of classification or categorization developed for a specific purpose and categorized according to a set of prescribed differentiating characteristics. The term may also refer to the science of classification and categorization. In cognitive science, "taxonomy" is defined (Rosch et al. 1976) as a system by which categories are related to one another by means of class inclusion, with each category within the taxonomy entirely included within another, more generalized (higher) category, unless it is the highest category.

General Perspective of Soil Classification

People have a natural tendency, urge, and need to sort and classify the natural objects of their environment. Folk, or local, classifications (for example, those made by indigenous peoples) are based on recognition of natural breaks in readily perceivable characteristics. These classification systems tend to classify all natural objects in a local geographic area and make class distinctions according to technology locally available at a basic level of generalization roughly comparable to the level of the genus (Berlin 1978; Rosch 1978). Soils are no exception. Folk classification and names of soils have carried over into present-day classifications (Simonson 1985). Soils are present throughout the world, and many classification systems exist. Many soil classification systems that include only portions of the world are well constructed, but are limited in the worldwide transfer of information among soil scientists and others that seek information regarding soil properties.

The classification system used in a scientific discipline reflects the state of the art and knowledge in the field. Kubiena (1948) claims, “Show me your [classification] system and I will tell you how far you have come in the perceptions of your research problems.” The renowned physicist Ampére is reported to have said, “Perfect scientific classification is first possible when one knows everything concerning the classified natural objects” (Kubiena 1948).

Classification and categorization of natural phenomena (like soils) are generally done for one or more of the following purposes:

1. Organize knowledge of the subject.
2. Provide maximum knowledge about the subject with the least cognitive effort (perception, recall, and memory of properties).
3. Provide a map or organization chart of structure of the world we perceive and live in, to satisfy our natural curiosity, and for ease in communication.
4. Reveal and understand relationships among individuals and classes of the population of interest.
5. Identify and learn new relationships and principles not previously perceived in the population of interest.
6. Provide objects or classes as subjects for research and experimentation and/or research design.
7. Establish groups or subdivisions of the object classified and under study in a useful manner, such as:
   a) predicting behavior,
   b) identifying best uses,
   c) estimating their productivity,
   d) identifying potential problems and as basis for taking action to meet potential problems,
   e) facilitating easier transfer of information and technology.

Kinds of Soil Classification. We differentiate between natural or scientific classification and technical classification as follows.

Technical classifications of soils organize and classify objects into groups for specific applied purposes Cline (1949b). Technical classifications are often created to facilitate implementation of land use regulations or laws. Technical classifications utilize criteria specific to purposes of concern for a specific technology and ignore other soil properties. Technical classifications therefore rely on the state of the art and understanding of the intended use of the soil or the present land-use regulation. Technical classifications are subject to change as regulations change or the knowledge of the technology or land use practice changes. These systems are seldom useful in presenting the state of the art in soil science, but serve a vital purpose in communicating information regarding specific soil properties to a variety of disciplines.

Natural or scientific classifications bring out relationships among the most important properties of the population being classified, without reference to any single specified applied or utilitarian purpose (Cline 1949b). In the field of logic, a natural classification is one that considers all the attributes of all the individuals in a population (Mill 1925). Those attributes having the greatest number of covariant or associated characteristics are selected as criteria in defining and separating various classes. From the standpoint of cognitive science, a natural classification is one in which a basic level of categorization is established within which as many attributes as can be identified and measured are common to all members of the category. In *Soil Taxonomy* this basic level unit would be roughly equivalent to the soil series. A superordinate level is also established. This level is organized around a few prototype members that display a limited number of attributes that have been selected as having the greatest number of covariant or associate characteristics. In *Soil Taxonomy,* this level is the soil order. Intermediate levels between basic and superordinate levels are established in which an increasing number of attributes are shared by all or most members (Rosch et al. 1976).

Principles of Soil Classification

Now we need to consider some principles as background for our discussion of soil classification systems. Some aspects are unique to pedology, but most are general principles germane to the natural classification of all natural objects.

Genetic-Thread Principle. The theories and concepts of soil genesis provide a framework for determining the significance and relevance of soil properties for use as differentiating characteristics. This principle parallels the use of theories of evolution as a framework for taxonomy in the plant and animal kingdoms.

Principle of Accumulating Differentia. In a multiple-category classification system, differentiating characteristics accumulate or pyramid from the higher levels of generalization to the lower levels of the system. As a result, classes at the lower levels are defined and differentiated not only by the differentiating characteristic(s) used at a given categorical level but also by those used as differentia at the higher levels. In the lowest category, a large number of differentiating characteristics have been accumulated so that the classes are quite narrowly defined.

Principle of Wholeness of Taxonomic Categories. All individuals of the population must be classified in each category, according to the characteristics selected as differentiating at that level. Another way of stating this is that any differentiating characteristic should classify all the individuals of a given population. Some soil classification systems have violated this principle by omission of certain kinds of soils from classification at one or more of the categorical levels.

Ceiling of Independence Principle. A property or characteristic used as a differentiating characteristic in a higher category must not separate individuals grouped together in a lower category. Every characteristic used to define individuals in a category is limited in its use by a “ceiling” categorical level above which it cannot be applied without injecting confusing and inappropriate cleavages in lower categories.

Succession of Classifications

Classification undergoes revision as the body of knowledge on which it is based expands. In this sense, classification succession is a phenomenon common to all disciplines. We should always keep in mind that classification systems are developed by human beings to organize ideas and properties in the most useful manner (Cline 1963). Classification systems are abstracts of “knowledge” and of concepts derived from knowledge, based on the past experiences, available data, and present biases of people (Cline 1961). The data we consider to be “facts” are facts only within the context and perspective of the operations by which these data were obtained (Bridgman 1927). An example in the field of soil science is the previously held concept, and hence “fact,” that exchangeable hydrogen was the main source of soil acidity in acidic mineral soils, whereas it is now generally accepted that exchangeable aluminum is the main contributor to soil acidity in such soils (Coleman et al. 1959; Jenny 1961c). A comparison of the general basis and class definitions for a soil classification system published in the 1938 USDA *Yearbook of Agriculture* (Baldwin et al. 1938) with those in *Soil Taxonomy* (Soil Survey Staff 1975, 1999) is a more complete and complex example of chronological secession.

In the development of the total field of science, we can see many examples of the uncovering of new facts requiring rather complete reorganization of the theories and laws making up the body of understanding in a particular field and thereby requiring extensive changes in the classifications based on this understanding (Bridgman 1927; Cline 1961). The point is that we must accept the provisional, ephemeral, changing state of current knowledge and consequently of classifications based on that knowledge, particularly in soil science, where not only methods of analysis are evolving, but intensity of observations are not uniform throughout the world. We must be prepared to accept additional changes in soil classification as soil science research continues; indeed, we should help make them.

Avoiding Rigor Mortis in Classification

It is easy for a classification system to prejudice the future and for us to become prisoners of our own taxonomy (Cline 1961). At times and in some places this has been a particular problem with soil classification systems. The nomenclature of classification systems is preserved in the written text and fixed conventional wisdom; incomplete data and tentative hypotheses harden into dogma, thereby restricting acceptance of new ideas, concepts, and research patterns needed for acquisition of new facts. Therefore, a classification system, particularly in a field such as soil science, must have a self-destruct mechanism—a procedure for continuing reevaluation of the body of theories making up the genetic thread in our taxonomy. Also, we must avoid selection of soil genesis theories and hypotheses as basic differentiating characteristics, although we may use them, with caution, as guides to relevant soil properties that may be used as differentia.

Historic Perspective of Soil Classification

The evolution of soil classification can be subdivided into five general periods: (1) an early technical era; (2) the founding period of pedology by the Russian group of soil scientists; (3) the early American period; (4) the middle period of general development of soil classification and soil surveys in the world, and especially in the United States, which we refer to as the Marbut period; and (5) the present modern period of quantitative taxonomy.

Early Technical Period. Soil classification had its inception and flowering in Western Europe in the middle and latter parts of the nineteenth century. For example, Thaer (1853) published a classification that combined textural (particle-size distribution) properties as a primary higher category, with agricultural suitability and productivity as classes of a lower category. He identified six kinds of soil: clay, loam, sandy loam, loamy sand, sand, and humus. As an example of classes within these six kinds of soil, he recognized four classes within the group of clay soils: black klei-heavy wheat soil, strong wheat soil, weak wheat soil, and thin wheat soil.

Fallou (1862) devised the following soil classification largely based on geologic origin and lithologic composition of what we now call parent material:

Class 1: Residual Soils	Class 2: Alluvial Soils
Soils of limestone rocks	Gravel soils
Soils of feldspathic rocks	Marl soils
Soils of clay rocks	Loam soils
Soils of quartz-bearing rocks	Moor soils

Von Richthofen (1886) worked out a system of soil classification with a strong geologic basis and nomenclature similar to Fallou's system:

A. Residual soil types
   1. Disintegrated rock
   2. Deeply weathered rock
   3. Eluvial soils of plateaus
   4. Colluvial loam
   5. Laterite
   6. Organic soils: humus, moor, peat
   7. Undissolved residues

B. Accumulated soil types
   1. Coarse sediments of continental waters
   2. Fine-grained sediments of continental waters
   3. Chemical deposits in fresh waters
   4. Marine soils
   5. Glacial deposits
   6. Volcanic ash
   7. Eolian accumulations

These systems of classification used differentiating characteristics of geologic deposits, not properties of the soils. We have presented them for comparison with more recent and comprehensive classification systems and a historical record of the first stirrings of a new field: soil science.

The Founding of Pedology. The founding of pedology, or soil science as an independent science, can be traced to soil studies on the Moscow Plains in Russia. On the great Central Russian upland, uniform loess-like parent materials extend for hundreds of miles. An increasing temperature gradient is imposed on this area from north to south, and decreasing annual rainfall and moisture gradient extends from west to east. Associated with these climatic parameters are important vegetation pattern differences, especially the major shift from forest to grassland steppes. These factors of climate and vegetation left their imprint on the relatively uniform parent material, producing distinct soil differences. These differences were noted by the founder of modern pedology, V. V. Dokuchaev, who first understood the significance of soil differences not related to geologic material and thereby established the concept of soil as an independent natural body.

V. V. Dokuchaev was born in a middle-class family in Smolensk, where he graduated from a seminary. Upon entering Petersburg University, he received training as a geologist. He did his first fieldwork in the Smolensk area and prepared his first published work, "Origin of River Valleys." About this time he met the Russian statistician and natural scientist, Chevlovsky, who had prepared the first soil map of Russia, using folk definitions and names (e.g., "poor" and "rich" soils). As a result Dokuchaev became particularly interested in the "Chernozem," the "richest" of soils in Russia. He received a grant from the Free Economic Society in St. Petersburg for studies of these soils (apparently the first grant for scientific research on soils). In 1883 he published his classic monograph, *Russian Chernozems* (Dokuchaev 1883). This was the first published work on soil as a natural body formed by action of a set of soil-forming factors producing genetic layers in the parent material. He followed this monumental monograph with a series of publications on soil genesis and classification, including the first publication with a classification of soils based on the properties and soil-forming factors of the soils themselves (Dokuchaev 1886). Dokuchaev was concerned about and interested in not only the technical and scientific aspects of soil classification but also in practical applications of soil classification. For example, he interpreted his classification of soils of the Nizhnii-Novgorod (now Gorki) region in terms of tax value assessment (Dokuchaev 1886). Also, he became concerned about very serious droughts in parts of the Russian steppes and established a series of experimental plots on different soils. From the results obtained, he recommended forest belts and other procedures for wind protection and water conservation.

Dokuchaev has been erroneously regarded and described by certain latter-day soil scientists as a theoretical scientist who related soil formation and classification solely to climates, for example, a “climatic soil scientist.” Although much of Dokuchaev’s writing emphasized the importance of climate, this misconception apparently stems in part from a statement made by Glinka (1931) in a widely translated book in which he listed five main soil types as proposed by Dokuchaev, linked to climate as the sole or main soil former. However, we should point out that a sentence translated from Dokuchaev’s classic work, *Russian Chernozem*s, states that “soils must be classified and studied according to their profiles.”

Dokuchaev is reported as being a very sociable man who liked people. His writings and dynamic personality attracted many capable students. Those of his students most closely involved in soil classification were N. M. Sibirtsev and K. D. Glinka. Their contributions also stand as significant monuments in the Russian pedological founding period.

Sibirtsev (1860–1899) developed the concept of soil zones, a powerful idea that certain kinds of soils are associated with certain “climate-vegetational” or ecological regions. This concept is a basic part of many soil classification systems. Sibirtsev completed his classic text, *Soil Science* (*Pochvovedenie*) in 1901, apparently the first text on soils and soil classification, but unfortunately he met an untimely death from tuberculosis.

Glinka (1867–1927) was the most influential and prolific writer among Dokuchaev’s pupils and the best known in the Western world because of widespread translations of his works: *The Types of Soil Formation, Their Classification and Geographical Distribution* (1914), *The Great Soil Groups of the World* (1927), and his classic *Treatise on Soil Science* (1931). His first book introduced the new Russian concepts of soils, soil classification, and the major soil type names of Chernozem, Podzol, and Solonetz to the Western world. Glinka emphasized soil geography, soil formation, and weathering processes. He was a brilliant lecturer and organizer, being responsible for the organization of soil science in Russia. A number of other outstanding Russian soil scientists were active and prominent in the latter part of the Russian pedologic founding period, but we discuss only the pioneers of this particular period.

The Early American Period. Ruffin (1832) pointed out the need for a soil classification program in the United States. E. W. Hilgard pioneered early soil classifications and mapping in the United States. He was a geologist for the state of Mississippi and published a classic pioneer work on soils of Mississippi and later was responsible for establishment of work on soil science in California, especially with respect to sodic and saline soils. He apparently was first in America to conceive of soil as a natural body and pointed out correlations between soil properties on the one hand and vegetation and climate as causal factors. It has been suggested that Dokuchaev was a follower of

Hilgard. Although Dokuchaev's work came a little later, there is no clear indication that the two were in contact or knew of each other's work. Hilgard's concepts and ideas about soil and soil genesis were not applied in operational soil surveys in America, and introduction of similar ideas was not to come until more than 50 years later.

In 1894 a division was created within the Weather Bureau for "the study of climatology in its relation to soils," and in 1901 a Bureau of Soils was created in the USDA (Whitney 1905). Emphasis was placed on technical or single-factor classifications of soil in operational programs of soil surveys in the United States. In these programs, there was bias toward geologic techniques and nomenclature, though there were some notable exceptions. Milton Whitney developed the first American soil classification system related to soil survey and used as a basis for soil-mapping operations. This system was published in 1909 (Whitney 1909), although actual soil surveys started in the United States about 1899 (U.S. Department of Agriculture 1899). Whitney's system was a broad classification, mainly according to physiographic regions or provinces and the texture (particle-size distribution) of the soil. Whitney and associates established as the highest taxonomic category the soil province, composed of soils within the same physiographic regions, such as coastal plains or piedmont. Soils within a province formed from similar geologic materials (such as marine sediments or glacial till) were defined as a "series," a term still in use today in the United States for the taxa of the lowest taxonomic category. Soils were subdivided within the series according to texture to form the lowest taxonomic category and the mapping unit: the soil type. Whitney and his associates defined "texture" more broadly than is now the case in the United States. "Texture" included particle-size distribution, soil consistence, organic matter content, aggregation, and related properties. This system was widely used as a basis for soil surveys in many parts of the United States.

Coffey (1912) was apparently the first in the United States to propose soils as independent natural bodies that should be classified on the basis of their own properties and that differences in these properties were due to climatic and associated "vegetational" differences from place to place. He proposed five great soil groups (apparently the first use of this term, which became widely used): arid, dark-colored prairie, light-colored timbered, black swamp, and organic. However, his concepts and proposals apparently were not generally accepted and were not made the basis for any operational soil survey program, but his ideas did serve as a forerunner and signaled changes to come in soil classification in the United States.

The Middle American Period. C. F. Marbut was the central figure in the evolution of soil classification and survey during this period in the United States. Born in 1863 and raised on a Missouri farm, he was trained in geology, especially geomorphology. He undertook graduate study in that field at Harvard University under the well-known American geomorphologist William Morris Davis. He became interested in soils and joined the USDA Bureau of Soils in 1910. He introduced the concepts of Dokuchaev, Glinka, and Sibirtsev to the United States after translating a German edition of Glinka's work on types of soil formation and soil groups of the world (Glinka 1914) into English. This introduced the soil-forming factors of climate and vegetation and

Table 1.1. Soil classification by Marbut (1935)

Category 6	Pedalfers	Pedocals
Category 5	Soils from mechanically comminuted materials	Soils from mechanically comminuted materials
	Soils from siallitic decomposition products	
	Soils from allitic decomposition products	
Category 4	Tundra	Chernozems
	Podzols	Dark brown soils
	Gray-brown Podzolic	Brown soils
	Red soils	Gray soils
	Yellow soils	Pedocalic soils of Arctic and tropical regions
	Lateritic soils	
	Laterite soils	
Category 3	Groups of mature but related soil series	Groups of mature but related soil series
	Swamp soils	Swamp soils
	Glei soils	Glei soils
	Rendzina	Rendzina
	Alluvial soils	Alluvial soils
	Immature soils on slopes	Immature soils on slopes
	Salty soils	Salty soils
	Alkali soils	Alkali soils
	Peat soils	Peat soils
Category 2	Soil series	Soil series
Category 1	Soil units or types	Soil units or types

reduced the emphasis on the geologic nature and origin of soil materials as developed by Whitney. His ideas on classification evolved in successive steps (Marbut 1922, 1928a, 1928b) and culminated in his masterwork on soil classification published in the *Atlas of American Agriculture* (Marbut 1935). A summary outline of this 1935 classification is presented in Table 1.1.

This dedicated man, who died in 1935 while in China, must be considered to be the founder of pedology in the United States, based on his many contributions in addition to his worldwide influence (Krusekopf 1942). Some of his many contributions were:

1. Establishment of the soil profile as the fundamental unit of study. He focused attention on properties of soils themselves rather than their geologic relationships or broad soil-forming factors.
2. Preparation of the first truly multiple-category system of soil classification.
3. Establishment of criteria for identifying and naming soil series.

Although Marbut's classification system advanced soil science, additional information and further developments and improvements identified some difficulties and problems. Some of these are as follows:

1. His multiple category system was not truly comprehensive. The emphasis on "normal" soils on "normal landscapes" (meaning the well-drained soils on hillslopes)

Table 1.2. Soil classification in the 1938 USDA *Yearbook of Agriculture* (highest two categories only)

Category 6 Order		Category 5 Suborder
		Soils of the cold zone
	Pedocals	1. Light-colored soils of arid regions
		2. Dark-colored soils of the semiarid, arid, subhumid, and humid grasslands
Zonal soils		3. Soils of forest-grassland transition
	Pedalfers	4. Light-colored podzolized soils of the timbered regions
		5. Lateritic soils of forested warm-temperate and tropical regions
Intrazonal soils		1. Halomorphic (saline and alkali) soils of imperfectly drained arid regions and littoral deposits
		2. Hydromorphic soils of marshes, swamps, seep areas, and flats
		3. Calomorphic
Azonal soils		No suborders

omitted the classification of "immature and abnormal" soils in one or more categories, thus violating the principle of wholeness of taxonomic categories.

2. Certain criteria for differentiation (differentiating characteristics) based on assumed genesis or genetic interferences were incomplete or incorrect. For example, the assumption that Zonal ("normal") soils could be divided into two broad classes—one in which calcium carbonate accumulates (Pedocals) and another in which aluminum and iron accumulate (Pedalfers)—has been shown to be inadequate and not satisfactory. A soil that is a "normal" Pedocal in one region was considered an Intrazonal (not normal) Pedocal in another region due to slight differences in parent material or landscape position. Some soils accumulate both $CaCO_3$ and Al-Fe compounds. For these and related reasons, this differentiating characteristic and these particular classes had to be abandoned.
3. His "normal soil on a normal landscape" concept as a basic frame of reference for soil classification was not appropriate because it ignored more poorly drained soils in complex landforms. Further, differences in soil age, as well as differences in climate over time, made it difficult, if not impossible, to establish which soil is the "normal" soil of reference in many landscapes.
4. Extreme emphasis was given the two-dimensional soil profile, largely ignoring the three-dimensional aspects of soils on the landscape.

As new information was obtained and evolution of concepts took place, a comprehensive effort was made to improve Marbut's classification of all known soils in the United States. This revision was published in the 1938 USDA *Yearbook of Agriculture, Soils and Men* (Baldwin et al. 1938). An outline of the orders and suborders proposed by Baldwin and coworkers is presented in Table 1.2.

The Modern Quantitative Period. After World War II, efforts were undertaken to revise the 1938 USDA *Yearbook* classification (Thorp and Smith 1949; Riecken and Smith 1949). In these revisions, new Great Soil Groups were added, and definitions were revised and sharpened, but the authors determined a need for a new more quantitative approach to soil classification. In 1951, a decision was made to develop a new soil classification system in the United States (Smith 1968).

Reasons for undertaking development of a new system of classification in the United States are summarized in the following points, drawn in part from Kellogg (1963a), Simonson (1952a, 1952b, 1986a, 1986b, 1986c), and Smith (1968, 1983, 1986):

1. The highest category of the 1938 system, based on zonality, did not provide mutually exclusive taxa; it was not possible to define clearly the differences between Zonal and Intrazonal soils.
2. Classification at higher levels of the 1938 system, as well as those of other existing systems, was based on external environmental factors and assumed genesis as differentiating characteristics, not properties of soils themselves. Thus, there was risk of "prejudicing the future" by incorporating assumed soil genesis concepts, and it was difficult to classify certain soils because of uncertainties or disagreement among soil scientists concerning their genesis.
3. Some definitions of taxa were based on virgin soil profiles under their native vegetation, without allowing for modifications due to tillage and/or erosion.
4. Too much emphasis had been placed on soil color as a differentiating characteristic without consideration of relevance or number of accessory characteristics associated with color.
5. Many of the lower categorical taxa levels were defined in terms of comparative and subjective definitions. Quantitative, objective differentiating characteristics of taxa were needed to assure interpersonal agreement on classification and to make taxa suitable objects for research and interpretations.
6. Some soils were not identified in all categorical levels. Provisions were needed for all known soils to be classed at all categorical levels, and flexibility was needed to accommodate classification of newly discovered soils in sparsely surveyed areas of the United States and developing areas of the world.
7. Soil families had not been clearly defined as a category, and taxa within this category were poorly identified.
8. The nomenclature used in existing systems was a collection from several sources, both folk names in several languages and coined names. Often the same term held different meaning for different people, translation was difficult, and the naming of soil intergrades was difficult if not impossible.

As a consequence, development of a completely new system, above the levels of the soil series, was started within the USDA under the leadership of G. D. Smith. Smith was a tireless worker whose excellent scientific skills, practical judgments, and friendly personality enlisted the cooperation of soil scientists in the United States universities and many overseas scientists in the task of developing *Soil Taxonomy*.

The development of this new comprehensive system was by a series of *Approximations*, each widely circulated for criticism and comment. *Soil Classification, A Comprehensive System–7th Approximation* was published and distributed at the International Soil Science Society meeting in 1960 (Soil Survey Staff 1960) to ensure worldwide circulation and, hence, a broader spectrum of comment and criticism. Both comments received and further studies were used as a basis for supplements published in 1964 and 1967 (Soil Survey Staff 1964, 1967). After 15 years of intense efforts to test and document criteria, *Soil Taxonomy* was published (Soil Survey Staff 1975). From 1975 to 1998 the *Keys to Soil Taxonomy* underwent seven published revisions. In 1999 the second edition of *Soil Taxonomy* was published (Soil Survey Staff 1999). We use this edition, plus the most recent edition of the *Keys to Soil Taxonomy* (Soil Survey Staff 2010), as a basis for presentation in this book. (See Chapter 7.)

Soil Morphology

This aspect of soil science deals with the description of a soil at a specific site. Methods of documenting soil morphology have advanced greatly since the conception and initiation of field soil surveys in the late nineteenth century. Early soil descriptions were highly personalized descriptions that lacked quantification and standardization needed for effective communication. For example, early descriptions of soil color included such picturesque terms as *lemon yellow*, *coffee brown,* and *mouse gray*. The use of the Munsell color system now quantifies the color measurement and provides standard terminology.

In this section we introduce some basic definitions and concepts of soil morphology. A more detailed and expanded discussion of morphology is presented in Chapter 2. Details of the methods of field descriptions and recording field observations are given in the *Soil Survey Manual* (Soil Survey Staff 1951, 1962, 1993) and in the *Field Book for Describing and Sampling Soils* (Schoeneberger et al. 2002).

Soil is that portion of the earth's surface located in the vertical space between air above and geologic substratum below, with horizontal limits bounded by materials such as deep water, ice, and rock outcrop that are not considered soil (Figure 1.1). At any location a vertical exposure of the soil is known as a soil profile.

A complete *soil profile* is a vertical exposure that includes all material that has been altered by chemical, physical, and biological reactions that are caused entirely or in part because of proximity to the land surface (Figure 1.1). A soil profile may be observed in a freshly dug pit, along a road bank, or in many other places. In practice it is not always possible to expose a complete soil profile. It is often difficult to determine at what depth the material ceases to exhibit properties resulting from reactions related to its position near the land surface. That is to say, "Where does the soil stop and the 'nonsoil' begin?" Examination and description to a depth of 2 m or more may be necessary to adequately examine a soil to interpret soil-forming processes. By convention, *Soil Taxonomy* restricts soil classification to soil features that occur within 2 m of the soil surface. If a hard root-restricting layer is encountered at a shallower depth, every effort available should be made to identify the restricting layer. The soil profile is the basic unit for observing soil, but several other units of soil related to a soil profile need to be introduced.

The *soil solum* is an incomplete soil profile (Figure 1.1) that may be simply defined as "the genetic soil developed by soil-building forces" (Soil Survey Staff 1975). In this context, the solum includes O, A, E, and B horizons, defined in Chapter 2. Although this definition seems simple enough, much confusion can arise when application is made in the field. Determination of the lower boundary of a B horizon, hence, the solum may be difficult (Chizhikov 1968). The maximum rooting depth of adapted vegetation is another criterion for identifying the lower limit of the solum. The primary difference between soil and geologic material is the presence of living plant roots, deposits of organic materials originating from vegetation, morphologic evidence of root penetration, or evidence of bioturbation by soil fauna. It can be argued that any portion of the earth's crust that is reached by plant roots has been changed from geologic material into soil. In this context, it can be reasoned that the *solum* includes horizons significantly affected by soil-forming processes (that is, O, A, E, and B horizons), but that the *soil* extends to a greater depth, the depth affected by plant roots. Thus, a complete soil description does not stop at the bottom of the solum, but includes one or more underlying layers, ideally to a depth of 2 m.

The *control section* (Figure 1.1) is a portion of the soil profile delimited in terms of specified depths in family category of *Soil Taxonomy* (Chapter 7), primarily for identifying particle-size and mineralogy classes. The location of the control section differs depending on a number of soil properties and classification criteria. The control section of the soil profile has utility in soil classification because it is little influenced by common management practices such as plowing and fertilization, and thus provides a volume of soil where soil chemical and physical properties remain relatively constant over time. This arbitrary working rule, considered necessary to aid uniform soil classification, is not a conceptual aid in a study of soil genesis.

Soil Individuals on the Landscape

Although the soil profile is the basic unit for observing the vertical arrangement of soil components, a soil profile provides only one observational point of a given kind of soil. Like other natural bodies, an individual soil body is bounded laterally by other soil bodies or by nonsoil material. For example, in a forest, an individual tree of one species may be surrounded by other species of trees. While the lateral margins of individual trees can be easily seen, individual soils merge with adjacent soil bodies, and it becomes necessary to establish conventions by which individual kinds of soil can be differentiated. Practical considerations limit the spatial detail useful in delineating the minimum volume of observation required in establishing soil individuals.

A *pedon* is the smallest volume of soil that should be recognized as a soil individual (Figure 1.1). The pedon has been defined as follows (Soil Survey Staff 1999, p. 11):

> A pedon has the smallest volume for which one should describe and sample the soil to represent the nature and arrangement of its horizons and variability in the properties that are preserved in samples. A pedon is comparable in some ways to the unit cell of a crystal. It has three dimensions. Its lower limit is the somewhat vague limit between the soil and "nonsoil" below. Its lateral dimensions are large enough to represent the nature of any horizons and variability that may be present. A horizon may vary in thickness or in composition, or may be discontinuous. The minimal horizontal area of a pedon is arbitrarily set as $1\,m^2$, but ranges to $10\,m^2$, depending upon the variability in the soil.

The pedon concept enlarges upon that of the soil profile to include both lateral and vertical dimensions of a soil and puts limits on the volume to be considered as an individual soil. In essence a pedon includes properties that repeat within a lateral distance of 10 meters or less. Judgment must be used in application of the pedon definition in field situations. It is not prudent to describe and sample the material in an animal burrow or the auger hole made by a previous soil scientist that may vertically traverse a soil, unless one is researching the composition of material in animal burrows or auger holes. Narrow cracks in bedrock underlying the solum may be penetrated by roots and should be described as a feature of that bedrock layer. Sampling may not be possible.

Although a pedon is the smallest volume that can be considered a soil individual, it is seldom the case that a soil individual can be adequately described and defined from one pedon. The range of properties observed in several similar pedons, a *polypedon* (Figure 1.1), are aggregated to define a soil individual.

A *soil individual* is a defined range of soil properties used to classify soils. Judgment is required in defining a soil individual. Soil individuals are defined by experienced soil scientists with due consideration to the present and potential uses. The defined range of pedon properties that identify an individual soil must mutually interface with other soil individuals so as to include all soils. An individual soil is the smallest aggregate of defined soil properties used to identify taxonomic units in constructing soil taxonomic systems. A soil individual is a defined concept, with a range of properties seldom, if ever, totally present in one pedon. The soil individuals used as taxa in *Soil Taxonomy* (Soil Survey Staff 1999) are known as series. (See Chapter 7.)

The task of establishing consistently recognizable limits for soil individuals is daunting. In the absence of a specific characteristic that is present and of significance in all soils, like DNA in humans, a variety of quantitative characteristics are necessary to identify soil individuals. This results in definitions that often seem complicated by the specific conditions they establish. However, vaguely defined criteria or criteria that can be recognized only under very special conditions add confusion and distrust of the system. Although soil property associations with vegetation, topography, and parent material can indicate where soil differences are likely to occur, such associations should not be used as criteria in defining soil individuals because such associations are not universal. Criteria that are dependent on management practices are usually too transient to be useful. A change in soil management practices can render meaningless soil classes based on conditions detectable under the old practices. Only properties that can be consistently identified and measured within the soil under a range of soil management practices should be used as criteria for establishing taxa.

Precisely defining individual soil taxa is only the first step in conveying soil information to most people who seek information about soils. A pedon or an individual soil has little practical value unless it is used to identify an area of land. Rarely do all the soils spatially clustered on the landscape belong to the same taxon. The spatial intermingling of taxonomically different individuals is common among all natural entities. For example, in a lawn that contains one predominant species of grass, we often see a different plant species growing and call it a weed. Taxonomically different soil individuals are frequently "weeds" in an area where the soils are mostly of one taxon, but the identity of that "soil weed" only becomes apparent when we examine several adjacent profiles or pedons.

Soil map units are not part of the classification system of *Soil Taxonomy*, but are constructed during the course of a soil survey to identify populations of taxonomically identified soil individuals within a spatial area on the land. Soil mapping is the action, or field, phase of the genesis-classification-morphology-survey-characterization-interpretation continuum. Butler (1980) describes the soil survey as "one of the basic technologies of soil science." Soil maps are cartographic representations depicting the location of a population of soil individuals (Fridland 1976a, 1976b). A taxon name is commonly used as part of the map unit name, but unavoidably soil map units contain soils not taxonomically defined by that name (inclusions, "soil weeds"), confusing the nonsoil scientist (Cline 1977b). Readers are cautioned to remember that when used to name a map unit, the name of a soil individual, usually a soil series name, almost always identifies a spatial association of several soils. This subject is discussed in greater detail in Chapter 20.

Other Soil Genesis and Classification Activities

Soil characterization is the measurement of soil properties by laboratory procedures, using soil samples from pedons, the morphology of which has been described by standard procedures and nomenclature. Soil characterization is conducted to classify soils, to determine chemical and physical properties not visible in field examination, and to gain a better understanding of soil genesis. Laboratory procedures for standard soil characterization conform to protocols to assure that direct comparisons can be made among the individual soils sampled. The Natural Resources Conservation Service of the USDA now has characterization data for more than 20,000 pedons from the United States and more than 1,100 pedons from other countries.

Soil interpretations are predictions of how a soil, or an area of soils within map unit delineations, responds to land use and management practices. It is through this process that the data, knowledge, estimates, hypotheses, and theories are put to the test of practical, applied uses. The purpose of soil classification and mapping activities in the United States has been to provide interpretations for technical assistance in soil conservation programs, for planning agricultural programs, and as a basis for financing credit (Kellogg 1960; Smith 1968). Since the first soil survey reports and maps were produced in the United States, technologies of soil use have changed, necessitating many changes and additions in the soil interpretations. Interpretive rating guides for more than 70 specific types of interpretations are presented in the *National Soil Survey Handbook* (Soil Survey Staff 2009), a constantly updated handbook used in the writing of soil survey publications.

Soil Survey

Soil survey encompasses mapping, classification, characterization, and interpretations of soils. The field mapping of soils by many individual soil scientists requires quality control activities, commonly called correlation, to assure compatibility and comparability among soil surveys per agreed-upon principles, nomenclature, and established classifications. Soil characterization is an important aspect of quality control. Interpretations of soil taxa need to be uniform, but interpretations of mapping units also must reflect local conditions and spatial associations unique to individual soil survey areas. The field observations are compiled and recorded on hard copy maps and in digital geographical information system (GIS) formats. While not directly undertaken for soil genesis research, soil survey provides the factual observations necessary to formulate and test pedogenic theories.

Systematic soil survey was formally organized and initiated in the United States in 1899 (Whitney 1900, 1905; Simonson 1986a). By 1905 the USDA Bureau of Soils had mapped 56.9 million acres (Whitney 1905). The earliest soil surveys adhered to a concept of soil as a geologic material with some admixture of organic matter (Simonson 1986a). The term “soil series” was derived from the concept of a series of soils found on a particular geologic formation. As such, a series was consistent with what is now known as a map unit, but now the term “series” is used to identify an individual soil or taxon. Most early soil mapping was at the scale of 1 inch per mile (1:63,360) and was accomplished with the aid of a plane table and alidade to prepare the base map as the field survey proceeded. In the 1930s the practice of using air photos as a base for the field mapping was introduced, soon followed by the practice of publishing the soil maps on an air photo base (Simonson 1986c). Present-day soil surveys use digital orthophoto imagery as the base. Most surveys are published digitally and are accessible at the Natural Resources Conservation Service Web Soil Survey site (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm).

Progress in concepts of soil and technology of soil mapping has proceeded in fits and starts. A number of states and other federal agencies undertook soil-mapping programs, leading to the formation of the National Cooperative Soil Survey in the 1950s. The Soil Conservation Service, renamed the Natural Resources Conservation Service in 1995, was responsible for correlating the surveys and publishing the reports and maps. The scale of mapping increased to show more soil pattern detail, especially in agricultural areas. Present soil map scales in agricultural areas range from 1:12,000 to 1:24,000 or higher. The number of soil series and erosion, slope, and other phases has increased algebraically in the past 70 years, and the use of soil maps for nonagricultural planning, inventory, engineering, and evaluation purposes has greatly increased in this period.

The *Soil Survey Manual* (Kellogg 1937; Soil Survey Staff 1951, 1962, 1993) has been periodically upgraded and extensively revised. Quality assurance and compatibility among surveys is provided through the use of the *Manual* and the constant updating of the *National Soils Handbook* (Soil Survey Staff 2009). The adoption of *Soil Taxonomy* has impacted the soil survey in the United States by providing precise and quantitative criteria for identifying and classifying soil characteristics. This has improved the quality of interpretive information in soil survey reports.

Although soil surveys have been conducted in the United States for more than 100 years and almost all of the country has been surveyed once and much of it two or more times, the demand for soil survey continues, and old surveys are periodically updated with new soils information. At least three rather universal observations can be advanced to explain the continued demand for information obtained in a soil survey.

First, the scientific understanding and technology used to measure soil properties continues to advance. Soil scientists are now able to obtain measurements of soil properties that could only be estimated or perhaps were unknown only a few years ago.

Second, technologies that use soil continually evolve. Agronomic and forestry interpretations need to consider new cultivars and cultivation practices. The function of different soils in waste disposal, heavy metal contamination, carbon sequestration, and wetland preservation are but a few of the more recent topics soil scientists are asked to evaluate.

Third, relates to the rather old cliché “they aren’t making any more land.” As more intense use is made of land, especially in urbanizing areas, there is a demand for more precise identification of small parcels of land. This requires that soil scientists map at scales much larger than in previous times and be able to provide interpretations of areas that were too small to be identified in older soil surveys.

Perspective

In this introductory chapter we have outlined the history, described and defined the main themes of this book: soil genesis and classification, sometimes referred to collectively as pedology. Soil genesis is sometimes referred to as soil formation and soil classification as soil taxonomy. We prefer the terms *soil genesis* and *classification* and reserve the term *Soil Taxonomy* (Soil Survey Staff 1999) for the comprehensive scientific classification system now used in many countries. Soil genesis deals with studies, concepts, theories, factors, and processes responsible for soil development and change. Classification deals with the categorization of soils into scientific or technical groupings, and the cognitive basis of this categorization. The identification and definitions of soil profile, pedon, soil individual and soil map units presented are fundamental to discussions that follow. Brief definitions, descriptions, and histories of the important allied and/or corollary activities of soil morphology, survey, interpretation, and characterization have also been presented.