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Part I

The Building Blocks of Soil

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Chapter 1

Introduction

Soil landscapes and their spatial variation are exciting and complex. But to understand soils fully, they must be studied in space *and* time. Indeed, we embrace Daniels and Hammer's (1992) statement that soils are four-dimensional systems, not simply the one-dimensional profile. In this book we incorporate these ideas by synthesizing complex, overlapping topics and use this knowledge to help answer the questions: How do soil landscapes form? How and why do they change through time?

Soil genesis and geomorphology, the essence of this book, cannot be studied without a firm grasp on the processes that shape the *distributions* of soils – their complex patterns. Unfortunately, we will never fully understand the complex patterns of the Earth's soils. And even if we do aim to understand them, we must be mindful that the pattern is ever-changing. Again we quote Daniels and Hammer (1992: xvi): "One cannot hope to interpret soil systems accurately without an understanding of how *the landscape and soils have coevolved* over time" (emphasis ours). Every percolation event translocates some material (however minute) within a soil, while every runoff event moves material across its surface, changing the soil landscape ever so slightly. The worms, termites, and badgers that continually burrow, mix, and churn soils make them different than they were yesterday. Chemical and biochemical reactions within soils weather minerals and enable microbes to decompose organic matter, perpetuating the cycle from living matter to humus to chemical elements and back again. Like landscapes, soils evolve; changing patterns of soils over time are a reflection of a multitude of interactions, processes, and factors, replete with feedbacks, inertia, and flows of energy and mass. Yes, soils are a challenge! For that reason, we provide information, tools, resources, and background data to draw the reader closer to deciphering this most complicated – and important – of natural systems.

Whitehead (1925) wrote, "It takes a genius to undertake the analysis of the obvious." All people who walk the Earth's surface depend on the soil, yet the soil is not obvious to all. It is seemingly everywhere, and yet comparatively few study it. Additionally, soils are usually hidden from view and require excavation to be revealed. Neither are soils discrete entities like trees, insects, or lakes, which have clearly defined outer boundaries. Instead, soils grade continuously, one into another, until they end at the ocean, a sheer rock face, or a lake. When broken into discrete entities, in the way a geologist might break apart a rock, soils appear to lose their identity. This soil science – it's not easy. But therein lies the challenge!

We believe that a geographic approach is one of the most fruitful avenues to study soils (Boulaine 1975). Like most of the components of Earth science, soils are spatial things, varying systematically across space. To study soils completely, we must grasp not only *what* they are, but also how they relate to their adjoining counterparts. Soil geography focuses upon the geographic distributions of soils. It emphasizes their character and genesis, their interrelationships with the environment and humans, and their history and likely future changes. It is operationalized at many scales, from global to local. Soil geography *encompasses* soil genesis. Soil patterns cannot be explained without knowing the genesis of the soils that compose that pattern. Likewise, soil patterns cannot be fully explained or understood without knowledge of the *geomorphic evolution* of the landforms and rocks of which they form the skin. An understanding of how the Earth's surface may change over time, as a result of erosion, deposition, or weathering, is also necessary if we are to predict future changes in the soil landscape.

As the title says, this book is about soil genesis and soil geomorphology, and all that these disciplines encompass (Table 1.1). Tandarich *et al.* (1988) used the term "geopedology" to refer to the intersection of the disciplines of geology, geography, and soil science. We embrace that term and view it as the central motif of this book.

Pioneers of Soil Science, Soil Survey, and Soil Geography

Pedology (Russian *pedologiya*, soil speech) is the science of soil genesis, classification, and distribution. Many

Table 1.1 Some of the academic domains of pedology
Distribution of soils and soil taxa across the landscape
Soil survey and mapping
Soil genesis, both within and among pedons
Human impacts on soils: Anthropedology
Paleopedology and the study of landscapes of the past
Soil geomorphology
Soil-slope and soil catena studies
Soil landscape analysis and explanation of soil patterns
Pedometrics
Spatial representation of soils and the use of spatial soil data
Evolution of soils and landscapes

Note: Not an exhaustive list; in no particular order.
Source: Modified from Hole and Campbell (1985).

discourses have been written that focus on the nature and future of the field of pedology (Arnold 1992, Dudal 1987, Daniels 1988, Churchward 1989, Jacob and Nordt 1991, Clayden 1992, Brasher 1997, Bockheim *et al.* 2005, Richter 2007), although to many, it is roughly synonymous with *soil science*, and to most, it has a clear and strong *field* component. The application of pedology is often best manifested in soil mapping and survey. In recent years the field has evolved (and is evolving) into one that has more direct societal consequences and practical applications (Baveye 2006, Baveye *et al.* 2006), particularly as it relates to anthropogenic impacts on soils (White 1997, Tugel *et al.* 2005, Richter and Markewitz 2001).

Because soils have sustained human life since its inception, you may think that pedology has a long history. Not so. In fact, soil science was a late arrival among the natural sciences (Hole and Campbell 1985). Many attribute its founding to Vasili Dokuchaev (1846–1903), a Russian scholar and teacher. Others acknowledge the work of Charles Darwin (1809–1882), perhaps the world's most underappreciated soil scientist (Johnson 2002, Johnson *et al.* 2005, Johnson and Schaetzl 2014). Regardless of who gets the credit for jump-starting this discipline, pedology is unquestionably little more than a century and a half old! Our brief overview of the founders of soil science (later) should underscore that they were multifaceted thinkers who understood that the soil landscape was a complex system, requiring that it be studied using a geographic approach. More detailed accounts of the personalities involved in the development of the field are presented elsewhere (Kellogg 1974, Cline 1977, Tandarich and Sprecher 1994).

Dokuchaev is often called the father of soil science, although he acknowledged the influence of several others (particularly in the field of agricultural chemistry) in the development of his ideas (Tandarich and Sprecher 1994; Fig. 1.1A). Trained in Russia, he wrote his most reputed works on the soils of the Russian steppes, primarily Chernozems. In his work, he developed and used concepts on the nature and genesis of soil profiles, as well as soil landscapes. Dokuchaev and his students produced the first scientific classification of soils and developed soil mapping methods, laying the foundation for the modern fields of pedology and soil geography (Buol *et al.* 1997). He is known

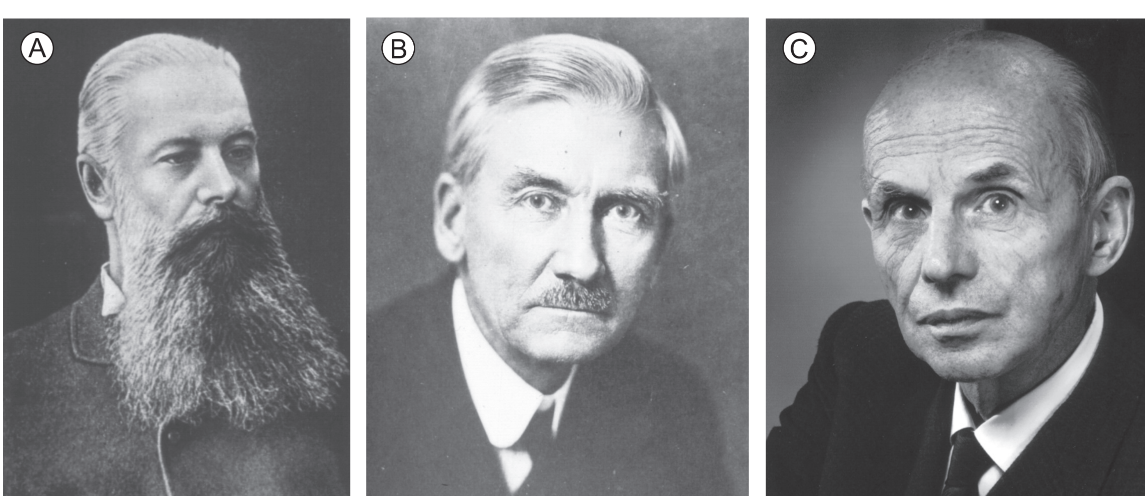

Fig. 1.1 Three influential scholars in the field of soil science: (A) Vasili V. Dokuchaev (1846–1903), Russian agriculturalist, geographer, and pedologist. Image courtesy of J. Tandarich. (B) Curtis F. Marbut (1863–1935), American agriculturalist, soil scientist, and early developer of the U.S. soil classification system. Image courtesy of J. Tandarich. (C) Hans Jenny (1899–1992), Swiss pedologist and agricultural chemist; professor at the University of California. Image by R. Amundson.

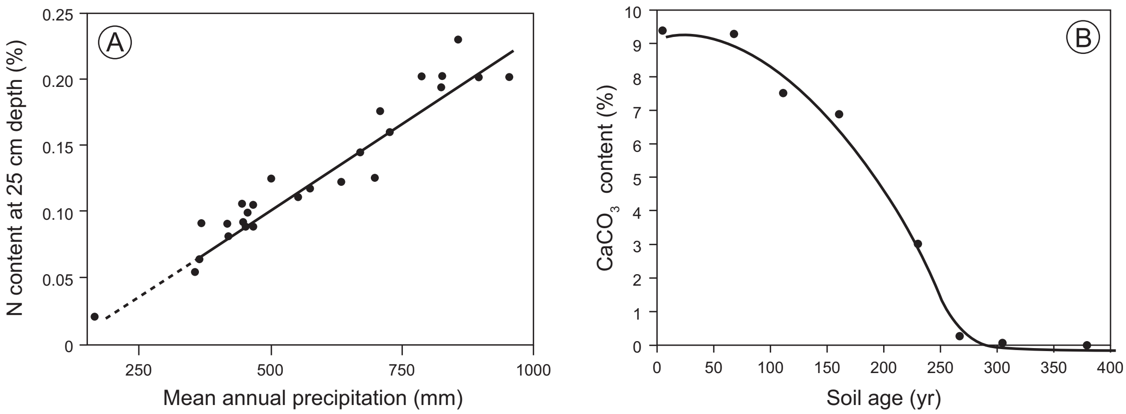

Fig. 1.2 Examples of two functional relationships that Hans Jenny produced for his 1941 book, *Factors of Soil Formation.*

for developing the basic A–B–C horizon nomenclature, and a factorial model of soil development, in which soils and soil patterns were seen as a function of independently varying state factors of the environment. Although not universal, this model remains, in various revised forms, the primary explanatory model for soils worldwide (see Chapter 12). Dokuchaev's model led to the development of the concept of the *zonal soil*, which characterized vast tracts of land and was thought to represent the end point of soil development for that region. Zonal soil concepts, although obsolete today, essentially jump-started soil survey and mapping worldwide and made the complex world of soils more understandable to the masses. Dokuchaev's teachings, carried across the Atlantic by E. W. Hilgard (1833–1903), were highly influential on many prominent soil scientists.

Darwin was a contemporary of Dokuchaev. Unfortunately, by omitting Darwin's ideas from his writings, Dokuchaev would inadvertently bury them. Darwin focused on local-scale biological origins of many soil properties and on biomechanical processes in soils, such as mixing by worms (Darwin 1881, Johnson 1999). The lack of soil terminology in his works, his general lack of students to spread his approach, coupled with the growing acceptance of Dokuchaev's factorial model for soil development doomed Darwin's *biomechanical soil processes* to the theoretical back seat, until resurrected decades later (see Chapter 11).

In 1899, the United States started its soil survey program, under the direction of Milton Whitney (1860–1927), primarily using geological concepts of soils, e.g., granite soils and alluvial soils (Shaler 1890). This approach continued for a little more than a decade (e.g., Marbut *et al.* 1913). A major sea change later occurred when Curtis F. Marbut (1863–1935), who earned his Ph.D. in geology at Harvard under the eminent geographer William Morris Davis (1850–1932), was appointed soil scientist in charge of the U.S. Bureau of Soils (Tandarich *et al.* 1988; Fig. 1.1B). While at Harvard, Marbut had been influenced by the writings of Konstantin Glinka (1897–1927), a student of Dokuchaev's, and the soils-related work of Nathaniel Shaler (1841–1906). Marbut had translated Glinka's book *Die Typen der Bodenbildung* from German into English and applied many of the ideas within to the budding soil survey program (Cline 1977, Tandarich and Sprecher 1994). Marbut's impact on soil science in the United States proved to be strong and long-lasting. Indirectly but strongly influenced by the ideas of Dokuchaev, he changed the way soils were viewed, emphasizing that they should be classified and mapped on the basis of horizon and profile characteristics, thereby reducing the influence of geology. Marbut eventually developed a multicategorical soil classification system that stood as the U.S. standard for decades (Marbut 1927a, b, 1935; see Chapter 8).

In 1941, Hans Jenny (1899–1992), professor of soil science at the University of California-Berkeley (Fig. 1.1C), published a landmark treatise entitled *Factors of Soil Formation*. Much of this book is devoted to his functional–factorial model of soil formation, following on the work of Dokuchaev. In this model, soils are seen as being influenced by five interacting factors: climate, organisms, relief, parent material, and time (see Chapter 12). Jenny developed many numerical soil functions, each an equation showing how soils change as four of the factors are held constant and one is allowed to vary (Fig. 1.2). Jenny was both a soil geographer and a soil scientist. He noted (1941a: 262) that "the goal of the soil geographer is the assemblage of soil knowledge in the form of a map. In contrast, the goal of the functionalist is the assemblage of soil knowledge in the form of a curve or an equation." He commented that soil maps display areal arrangement but give no insight into causal relationships, and that mathematical curves reveal dependency of soil properties on state factors, but the conversion of such knowledge to the field is impossible without a soil map (Arnold 1994). Thus, Jenny proposed that the union of geographic

Table 1.2 | Some of the major advances in the field of soil science, from its inception to the present day

Date(s)	Conceptual/theoretical/methodological advances
Pre-1800	Soils classified on the basis of relative productivity
1800–1880	Concepts of soil as (1) a medium for plant growth and (2) a weathered rock layer; soil classifications based on geologic/physical soil properties of surface horizon; A-B-C horizon designations introduced
1880–1920	Appearance of fundamental soil geography concepts: (1) environmental correlations and (2) soil as a natural body; introduction of zonal classification based on climate-vegetation relationships; links between soil horizons, profiles, and factors introduced; U.S. Soil Survey established; development of soil series concept
1920–1940	Widespread appearance and adoption of fundamental pedology concepts: (1) soil as a natural body and (2) soil-forming factors; development of first regional soil classification systems, often based on zonal soil concepts; A-B-C horizon designations and solum concept become widely accepted; focus on collection of physical and chemical soils data; organization of soil series into regional soil classification systems; development of catena and soil cover pattern concepts
1940–1960	Factors of soil formation refined and clarified; development of global soil taxonomic systems; intensified soil mapping facilitated by development of functional relationships for quantitative study; aerial photography enhances soil mapping
1960–1990	Introduction of pedon and polypedon concepts; development of quantifiable, properties-based taxonomic systems; development of new models of soil formation, including first "process" models; recognition of coevolution of soils and landforms; recognition of regressive-progressive nature of pedogenic processes, and of polygenesis; importance of pedoturbation as a soil-forming process increasingly recognized; expansion of paleopedology; introduction of M-S-W horizon designations for tropical soils; methodological advances in soil micromorphology
1990–2005	Increased understanding and modeling of pedogenic and soil-geomorphic processes; refinement of global soil models and global soil taxonomic systems; development of statistical and computer-based soil information systems, and the rise of the discipline of pedometrics; beginnings of digital soil mapping; enhanced recognition of biomantles in soils; concepts of soils as a key component (1) in interrelated Earth physical systems and (2) as complex, nonlinear systems; expansion of absolute dating techniques applicable to soils; soil science and ecosystem sustainability concerns surface; increased attention to soil C cycles and stores
2005–present	Expansion and increased availability of soil geographic data in digital form, and GIS utilization/applications thereof; increased recognition of the importance of humans as a soil-forming factor; recognition of soils as a key component of Earth's critical zone; efforts to create first worldwide digital soil map

Source: Modified from Bockheim *et al.* (2005), with contributions from Mermut and Eswaran (2001).

and functional methods provided an effective pedological research motif. Arnold (1994:105) restated this idea as follows – spatial soil patterns need to be understood through functional relationships of the soil-forming factors in *space and time*. Jenny's (1941a) model stands today as one of the most geographic of the several soil models, because it is used subliminally or overtly by almost every soil mapper. More recent models, which refine and elaborate on Jenny's, as well as those that propose very different ways of looking at the soil landscape (Johnson and Hole 1994), are discussed in Chapter 12. Table 1.2 provides a summary of the major conceptual advances that have occurred in pedology, from its beginnings to the present.

Things We Hold Self-Evident

Following the lead of Buol *et al.* (1997) and Hole and Campbell (1985), we provide in the following listing some concepts or truisms in soil science and soil geography, slightly modified from their original sources.

- Soil complexity is more common than simplicity.
- Because soils lie at the interface of the atmosphere, biosphere, hydrosphere, and lithosphere, a thorough grasp of the workings and nuances of soils requires some understanding of meteorology, climatology, ecology, biology, hydrology, geomorphology, geology, and many other Earth sciences.

- The state factor model of soil formation (climate, organisms, relief, parent material, and time) is a useful conceptual approach to understand the spatial variation in pedogenic processes and soils.
- The characteristics of soils and soil landscapes include the number, sizes, shapes, and arrangements of soil bodies, each of which can be characterized on the basis of horizons, degree of internal homogeneity, slope, landscape position, age, and other properties and relationships.
- Distinctive bioclimatic regimes or combinations of pedogenic processes produce distinctive soils. Thus, morphological features, e.g., illuvial clay accumulation in B horizons, are produced by combinations of pedogenic processes operating over time.
- Pedogenic processes act both to create and to destroy order (anisotropy) within soils, and these opposing sets of processes can and do proceed simultaneously. Soil profiles reflect the balance of these processes, present and past.
- Contemporary soils carry imprints of pedogenic processes that were active in the past, even if they are difficult to observe or quantify. A succession of different soils may have developed, eroded, and/or regressed at any particular site, and during that time, pedogenic and site factors, e.g., vegetation, sedimentation, geomorphology, have changed. Thus, an understanding of paleoecology, paleogeography, glacial geology, and paleoclimatology is important to studies of soil genesis. These studies constitute a basis for predicting future soil changes and for interpreting *paleosols* – soils of past environments.
- The geologic principle of *uniformitarianism* applies to soils, i.e., pedogenic processes active in soils in the past are similar to those that are active today. These processes, however, may vary in expression and intensity over space and time.
- There are relatively few old soils (in a geological sense). Little of the soil continuum dates back beyond the Tertiary Period, and most soils and land surfaces are no older than the Pleistocene Epoch. Why? Over time, soils are eroded or buried by geological events, or they are modified by shifts in pedogenic processes. In short, soils exist at a vulnerable location – the skin of the Earth.
- Knowledge of pedogenesis and geomorphology is critical to effective soil classification and mapping. Nonetheless, soil classification systems cannot be based entirely on *perceptions* of soil genesis, because genetic processes are seldom observed and are difficult to measure directly. Classification systems must be based on observable and measurable soil characteristics, as informed by an understanding of pedogenesis.
- Soils are natural clay factories. Shales worldwide are, often, simply soils that have been eroded and deposited in the ocean basins, to become lithified at a later date.
- Humans can and do alter soils, inadvertently and purposefully. It follows that an understanding of pedogenesis is basic to wise land use and management practices, and knowledge of how humans affect soils is essential to interpreting their current morphology and chemistry.

The Framework for This Book

This book has three major parts. We introduce the building blocks of soil in Part I. We continue adding to the basic knowledge base in Part II (Chapters 9–13), but add a great deal more material on theory and soil genesis/processes. In Chapter 12, for example, we introduce a large dose of pedogenic and geomorphic *theory*, which in combination with the previous chapters allows us to discuss soil genesis and pedogenic *processes* at length in Chapter 13. An understanding of soil genesis provides important information to scientists who classify and map them. Finally, we pay considerable attention in Part III (Chapters 14–16) to examining soil landscapes over time and how soils can be used as dating tools and as keys to understanding past environments. Part III is the synthesis section, for within it we pull together concepts introduced previously and apply them to problems of dating landscapes and understanding their evolution. Lateral flows of materials and energy link soil bodies to adjoining ones on the landscape, helping to reinforce the all-important three-dimensional component – an emphasis of Part III. Woven into the book are studies and examples of soil landscapes in three dimensions, often through the use of traditional block diagrams. We hope that the reader will gain from these applications and discussions a *holistic* perspective on soils, and begin to appreciate that they are integrated across and within landscapes, and that they have a history and a future.

We introduce, throughout the book, many classic studies and examples of how the evolution of soils has been effectively worked out, in order to tie certain concepts together and expose the reader to some of the classic literature. To be sure, our book has a North American focus – we live there, and it is the focus of a large proportion of the soil literature. However, we have gone to great lengths to include the global soils community in this book.

In sum, we think this book will be of use to "land lookers" worldwide (Hole 1980). We hope it is enjoyable, intellectually stimulating, and, most importantly, useful to you, the reader. We thank you for choosing *Soils: Genesis and Geomorphology*.

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Chapter 2

Basic Concepts: Soil Morphology

What Is Soil?

Soil means different things to different people. To a farmer or horticulturalist, it is a medium for plant growth. To an engineer, it is something to build on, or remove, before construction can occur, or it may actually be a type of medium used for road building, house foundations, or septic drain fields. To a hydrologist, soil functions as a source of water purification and supply. To some geologists, it is the post-Pliocene overburden that is covering up the rocks!

We use a slightly modified statement from the one offered by Johnson (1998a) as the best and most widely applicable definition of soil: Soil is organic or lithic material, normally at the surface of planets and similar bodies, that has been altered by biological, chemical, and/or physical agents. This definition and the one proposed by Richter and Markewitz (1995) – "Soil is the biologically excited layer of the Earth's crust" – give equal rank to biological processes and agents, which were ignored by some previous definitions that focused on the physical and chemical processes of soil formation. Pedologists and soil geographers often use a similar definition: A soil is a natural, three-dimensional body that has formed at the Earth's surface through the interactions of at least five soil-forming factors (climate, biota, relief or topography, parent materials, and time). This definition emphasizes that soils are "naturally occurring" bodies and introduces the five soil-forming factors into the equation, front and center. All of these definitions have merit and fit with the ways in which soils are discussed in this book.

Soils are composed of clastic particles (mineral matter), organic materials in various stages of decay, living organisms, water (or ice), and gases within pores of various sizes (Fig. 2.1). The absolute amounts of each, and their arrangement into a particular fabric, are the sum of soil morphology. Every soil has a distinct morphology, defined as its structure or form. Soil morphology is all that can be seen and felt about a soil. It includes not only "what is there" but also how it is "put together" – its architecture. To many, the main components of soil morphology include *horizonation*, *texture, color, redoximorphic features, porosity, structure*, and *consistence*, i.e., the look and feel of the soil. In this chapter, we will discuss the main features associated with soil morphology, many of which are normally included in a standard soil profile description.

Soil Profile Descriptions

Soil scientists often start their study of soils by excavating a pit, using an exposure, such as a road cut, or by extracting an undisturbed soil core using a hydraulic sampling probe, and then *describing* the soil they see. Soil descriptions are a standard way of communicating information about soils, as they occur in the field. They represent the most fundamental data of soil genesis. The current best guide for making soil profile descriptions is a *Field Book* published by the USDA-Natural Resources Conservation Service (Schoeneberger *et al*. 2012). It contains instructions, definitions, and concepts for making or reading soil descriptions and for sampling soils, as presently practiced in the United States. It draws heavily from the *Soil Survey Manual* (Soil Survey Division Staff 1993).

There is no one best way to describe a soil, just as there is no one best list of features to describe. Soil profile descriptions are tailored to the investigation. Nonetheless, most descriptions include at least the following components: (1) date, (2) location, (3) slope gradient and aspect, (4) landscape position and likely geomorphic origin, and (5) soil horizonation. Then, for each horizon, the scientist describes the following morphological characteristics: (1) depths of the top and bottom of the horizon; (2) color(s); (3) texture, including an estimate of coarse fragment content and characteristics; (4) structure; (5) consistence; (6) degree of effervescence (if calcareous); and (7) redoximorphic features that are indicators of wetness. Presence of a water table or other notable features, e.g., ped or rock coatings, roots, pores, animal burrows, concretions or nodules, forms of disturbance, or discontinuities, are also noted. The shape (topography) and distinctness of the soil

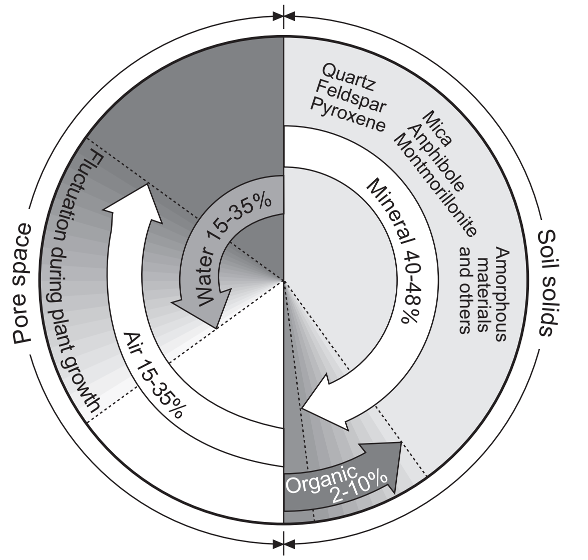

Fig. 2.1 Volumetric composition of soil pores and solids. The broken line between water and air indicates that these proportions fluctuate as the soil wets and dries. Similarly, organic matter contents of soils vary from zero to nearly 100%, although 2–8% is a common range for most soils.

horizon boundaries are also included in the description. Taken together, the data of a soil profile description constitute a powerful tool for the interpretation of soil and landscape genesis (see Landscapes box).

Texture

Mineral (clastic) soil particles are usually first divided into the fine earth fraction (<2 mm diameter) and coarser fractions. Geologists commonly use the *phi* scale when referring to the sizes of individual particles, whereas pedologists usually refer to particle diameters in millimeters or micrometers, following the USDA system (Fig. 2.2). *Texture* is a term that refers to the relative proportions of differently sized particles in a soil. Textural class names usually include descriptors for the fine earth fraction only, e.g., silt loam, sandy clay, unless the amount of coarse fraction is large enough to warrant inclusion, e.g., gravelly loamy sand. First, let us discuss the coarse fraction – the "gravelly" in the previous texture class example.

The names given to coarse fragments vary among naming systems, depending on size, shape, and lithology (Alexander 1986, Poesen and Lavee 1994; Table 2.1, Fig. 2.2). Except for the larger ones, e.g., cobbles, stones, and

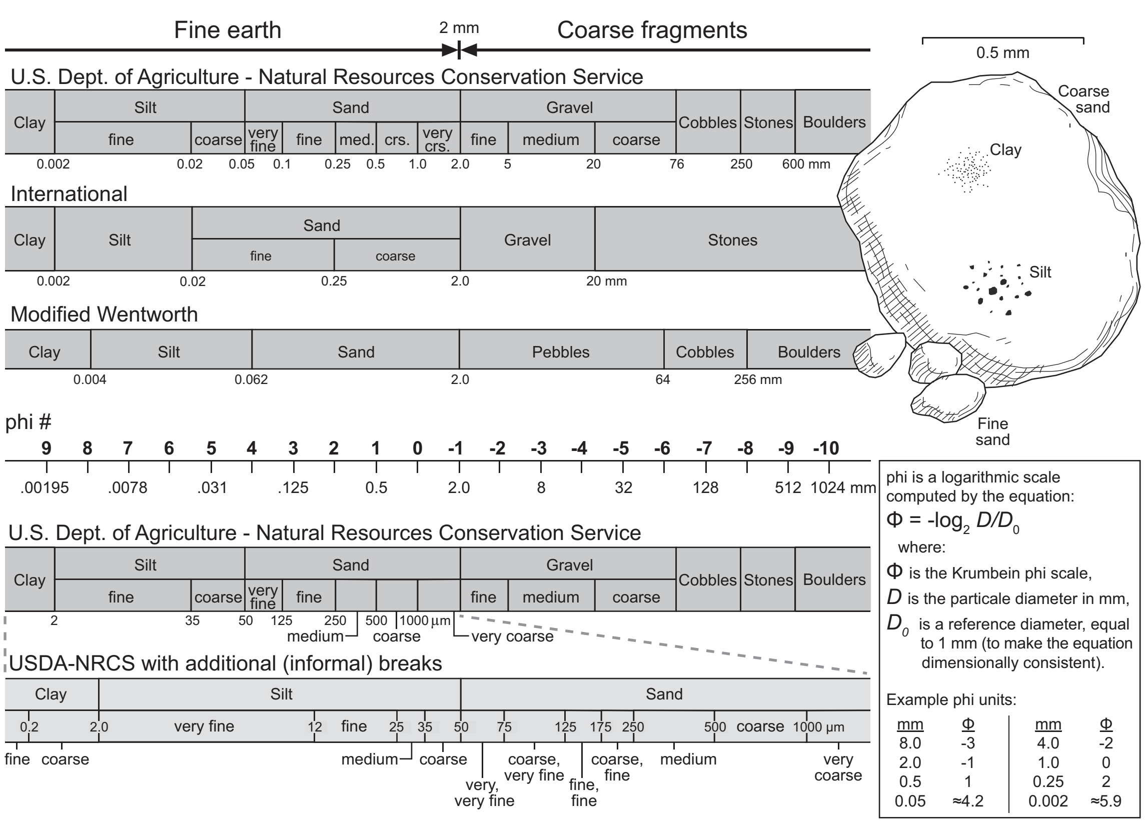

Fig. 2.2 Particle size limits and names in the major systems in use today. The graphical portrayal of clay, silt, and sand grains is drawn to the USDA system.

Table 2.1 | Names given to rock fragments of various sizes and shapes

Shape and size	Name	Adjectival term for soil texture class
Round (spherical, cubelike, or equiaxial)		
2–75 mm diameter	Pebbles	Gravelly
2–5 mm diameter	Fine pebbles	Fine gravelly
5–20 mm diameter	Medium pebbles	Medium gravelly
20–75 mm diameter	Coarse pebbles	Coarse gravelly
75–250 mm diameter	Cobbles	Cobbly
250–600 mm diameter	Stones	Stony
>600 mm diameter	Boulders	Bouldery
Flat		
1–150 mm long	Channers	Channery
150–380 mm long	Flagstones, flags	Flaggy
380–600 mm long	Stones	Stony
>600 mm long	Boulders	Bouldery

Source: Soil Survey Division Staff (1993).

boulders, most coarse fragments in soils are gravel-sized; in the USDA system that includes all clasts between 2 and 76 mm diameter (Fig. 2.2). In all cases, coarse fragments must be strongly cemented or resistant to rupture. Aggregates of fine earth particles are not coarse fragments; they should be disaggregated to determine their true textural composition.

Coarse fragments are very important in soils, as they affect percolation rates and surface area and can greatly impact root growth and tillage operations. Geomorphologists can often infer the genetic history of a sediment or soil by knowing the amounts and kinds of coarse fragments that it comprises.

Another way in which coarse fragments affect soils is through potential void space. Rocks and other coarse fragments can take up considerable volume in soils (Fig. 2.3). Thus, soil processes are compressed into less space than if the same soil had no coarse fragments (Schaetzl 1991b). Rock fragments also help soils resist compaction and erosion and retain good structure (Poesen *et al.* 1990, van Wesemael *et al.* 1995). Indeed, soils with high amounts of coarse fragments tend to have lower bulk densities, probably because the fine earth fraction cannot pack as closely to the large particles as it can to itself (Stewart *et al.* 1970). Many coarse fragments are not impermeable and can retain some soil water, thereby affecting soil water characteristics in ways beyond just their impact on void space (Coile 1953, Hanson and Blevins 1979, Nichols *et al.* 1984, Ugolini *et al.* 1996).

Coarse fragment modifiers are only added to the textural class name, e.g., gravelly loamy sand, when the fragments are present in sufficient amounts. In the USDA scheme, this lower limit is usually set at 15% coarse fragments by volume (Soil Survey Division Staff 1993; Table 2.2). For example, a

Fig. 2.3 A Typic Torriorthent from Imperial County, southern California, with large amounts of coarse fragments within the profile. This extremely gravelly, weakly developed soil is formed in coarse-textured alluvium.