Part I

The building blocks of the soil

Cambridge University Press
0521812011 - Soils: Genesis and Geomorphology
Randall J Schaetzl and Sharon Anderson
Excerpt
More information

Chapter 1

Introduction

Soils form and continually change, at different rates and along different pathways. They continually evolve and are never static for more than short periods of time. Along these lines, we embrace Daniels and Hammer's (1992) statement that soils are four-dimensional systems. They are not simply the two-dimensional profile, nor is the study of the spatial variation in soils (a three-dimensional effort) enough. Soils must be studied in space *and* time (the fourth dimension). We incorporate these ideas by synthesizing complex, overlapping topics and tying them into a cohesive message: soil landscapes – how they form and change through time. To do this, we necessarily take a process-based approach.

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. We will, however, never fully understand the complex patterns of the Earth's soils. Even if we do claim to understand it, 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 material within soils, while every runoff event moves material across their surfaces, changing them ever so slightly. The worms, termites and badgers that continually burrow, mix and churn soils make them more different tomorrow than they were yesterday. 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. Because this can all be quite complex, we provide information, tools, resources and background data to bring the reader closer to deciphering this most complicated of natural systems.

Whitehead (1925) wrote, "It takes a genius to undertake the analysis of the obvious." Soil is seemingly everywhere, yet, we would argue, comparatively few study it. Additionally, soils are usually hidden from view and require excavation to be revealed. Soils are not discrete like trees, insects, lakes or clouds, which have seemingly identifiable outer boundaries. Instead, they seem to grade continuously, one into another, until they end at the ocean, a sheer rock face or a lake. When broken into discrete entities, like 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 argue that a geographic approach to the study of soils is absolutely necessary (Boulaine 1975). Soils are spatial things, varying systematically across space at all scales. To study them fully you must understand not only *what* they are, but also how they relate to their adjoining counterparts. Soil geography focusses upon the geographic distributions of soils with emphasis on 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; it is not simply a part of it. One cannot explain soil patterns without knowing the genesis of the soils

Table 1.1 Some of the academic domains of soil geography

Distribution of soils and soil taxa across the landscape
Soil survey and mapping
Soil genesis, both within and among pedons
Interactions among soils and the natural and human environment
Paleopedology
Soil geomorphology
Soil-slope and soil catena studies
Soil landscape analysis and the study/explanation of soil pattern
Pedometrics
Cartographic representation of soils
Evolution of soils and landscapes

Not an exhaustive list. In no particular order. *Source:* Hole and Campbell (1985).

that comprise that pattern. Soil geography also incorporates geomorphology; one cannot fully explain soil patterns without knowledge of the evolution of the landforms and rocks of which they form the skin. Soil geography involves soil evolution; 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. Soil geography is manifested in soil survey (mapping) operations, which are extremely useful databases but are only as good as our understanding of the evolution of the soil pattern. This book, then, is about soil geography and all that it encompasses. Tandarich *et al.* (1988) used the term geopedology to refer to the interesction of the disciplines of geology, geography and soil science. We embrace that term and view it as a central component of this book.

Pioneers of soil science, soil survey and soil geography

Pedology is the science of soil genesis, classification and distribution; to many it is synonymous simply with *soil science*. Because soils have sustained human life since its inception, one may think that pedology has a long history. In fact, it was a late arrival among the natural sciences (Hole and Campbell 1985). Many attribute its founding to V. V. Dokuchaev (1846–1903), a Russian scholar and teacher. Others place emphasis on the work of Charles Darwin (1809–1882), perhaps the world's most underappreciated soil scientist. Regardless of who gets the credit for jump-starting this discipline, pedology is unquestionably little more than a century old! Our brief overview of the founders of soil science (below) 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).

Vasili Vasilevich 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. 1.1). Trained in Russia, he wrote his most reputed works on the soils of the Russian steppes, primarily Chernozems. He developed and used concepts on the nature and genesis of soil profiles, as well as soil landscapes, in his research. His geographic study of soils spanned local to regional scales. Dokuchaev and his students produced the first scientific classification of soils and developed soil mapping methods, laying the foundation for modern soil genesis and soil geography (Buol *et al.* 1997). He is known for developing the basic A–B–C horizon nomenclature, and

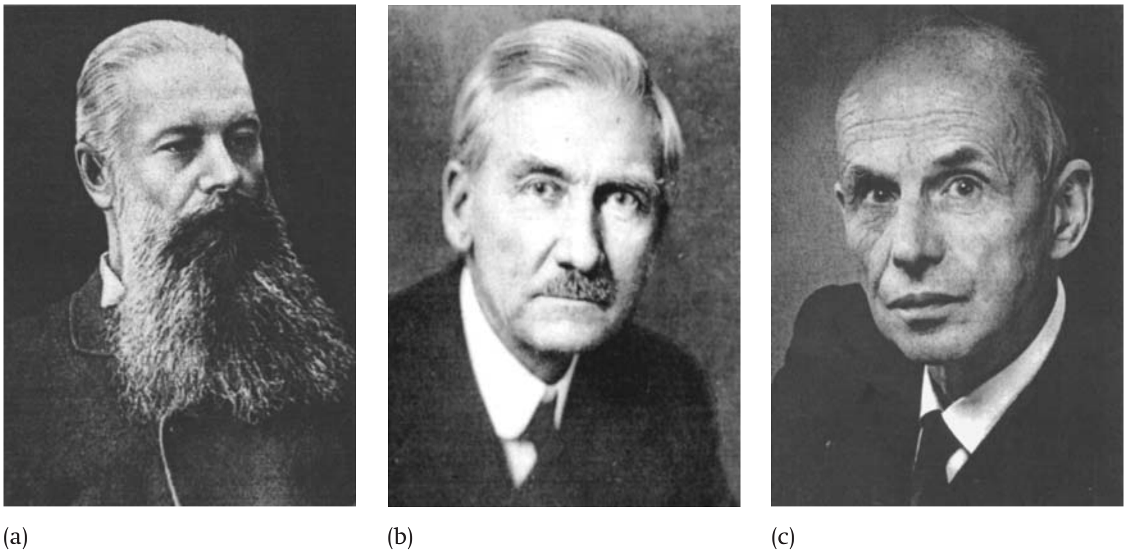
(a) (b) (c)

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 John Tandarich. (b) Curtis F. Marbut (1863–1935), American agriculturalist, soil scientist and early developer of the US soil classification system. Image courtesy of John Tandarich. (c) Hans Jenny (1899–1992), Swiss pedologist and agricultural chemist; professor at the University of California. Image by R. Amundson.

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 11). Using this model, Dokuchaev's work allowed others to develop the concept of the *zonal soil* – one which characterized vast tracts of land and represented the epitome of soil development for that region. Zonal soil concepts, although conceptually flawed, 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.

Unfortunately, by omitting the ideas of Charles Darwin from his writings, Dokuchaev would essentially bury them. Darwin's ideas focussed on local-scale biological origins of many soil properties, and on biomechanical processes in soils, such as mixing by worms (Darwin 1881). The lack of soil terminology in his works, coupled with the growing acceptance of Dokuchaev's factorial model for soil development, doomed *biomechanical soil processes* to the theoretical back seat, until resurrected years later.

In 1899, the United States started its soil survey program, under the direction of Professor Milton Whitney (1860–1927), primarily using geological concepts of soils, e.g., granite soils and alluvial soils (Shaler 1890). This practice continued for some time, e.g., Marbut *et al.* (1913). Shortly after this, Curtis 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 US Bureau of Soils (Tandarich *et al.* 1988) (Fig. 1.1). While at Harvard, Marbut had been influenced by the writings of Konstantin Glinka (1897–1927), a student of Dokuchaev, and the soils-related work of Nathaniel Shaler (1841–1906). He 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 USA 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

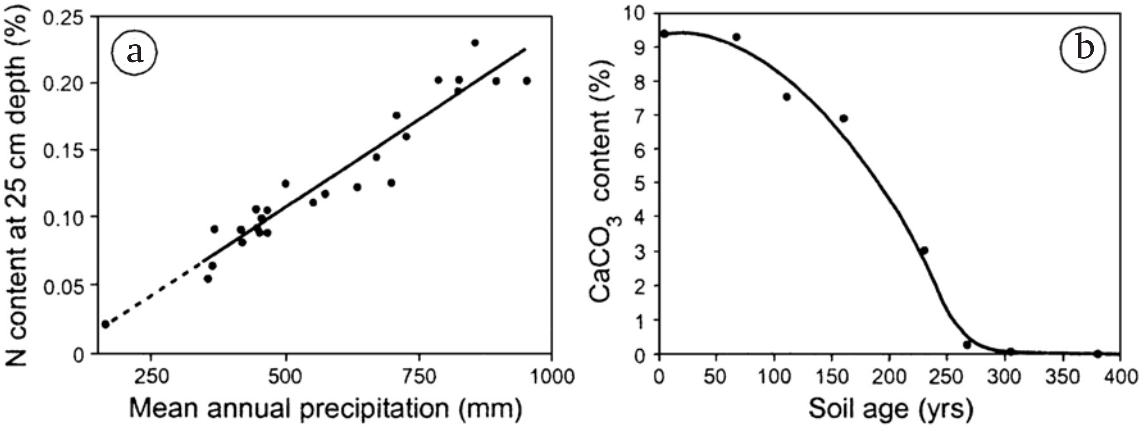

Fig. 1.2 Examples of two functional relationships that Hans Jenny produced for his 1941 book, *Factors of Soil Formation.*

classified and mapped based on horizon and profile characteristics, thereby reducing the influence of geology. Marbut eventually developed a multicategoric soil classification system (Marbut 1928, 1935; see Chapter 7). He thought about soils geographically, and his ideas translated into his classification system.

In 1941, Hans Jenny (1899–1992), at the University of California, published a landmark treatise entitled *Factors of Soil Formation*. Much of this book is devoted to his functional–factorial model of soil formation, in which soils are seen as the product of five interacting factors: climate, organisms, relief, parent material and time (see Chapter 11). Jenny developed many numerical soil functions in this book, each being an equation showing how soils change as four of the factors are held constant and one is allowed to vary (Figs. 1.1, 1.2). In this regard, Jenny (1941a: 262) noted 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 and functional methods provided the most effective pedological research. 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*. Since Jenny's (1941a) model provided the theoretical framework for soil functional relationships, it stands today as perhaps one of the most geographic of the several soil models, because it is used subliminally or overtly by almost every soil mapper and geographer. 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 11.

Things we hold self-evident . . .

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

- Complexity in soil genesis is more common than simplicity.
- Soils lie at the interface of the atmosphere, biosphere, hydrosphere and lithosphere. Therefore, a thorough understanding of soils requires some knowledge of meteorology, climatology, ecology, biology, hydrology, geomorphology, geology and many other earth sciences.
- Contemporary soils carry imprints of pedogenic processes that were active in the past, although in many cases these imprints are difficult to observe or quantify. Thus, knowledge

Cambridge University Press
0521812011 - Soils: Genesis and Geomorphology
Randall J Schaetzl and Sharon Anderson
Excerpt
More information

of paleoecology, paleogeography, glacial geology and paleoclimatology is important for the recognition and understanding of soil genesis and constitute a basis for predicting the future soil changes.

- Five major, external factors of soil formation (climate, organisms, relief, parent material and time), and several smaller, less identifiable ones, drive pedogenic processes and create soil patterns.
- Characteristics of soils and soil landscapes, e.g., the number, sizes, shapes and arrangements of soil bodies, each of which is characterized on the basis of horizons, degree of internal homogeneity, slope, landscape position, age and other properties and relationships, can be observed and measured.
- Distinctive bioclimatic regimes or combinations of pedogenic processes produce distinctive soils. Thus, distinctive, observable morphological features, e.g., illuvial clay accumulation in B horizons, are produced by certain combinations of pedogenic processes operative over varying periods of time.
- Pedogenic (soil-forming) processes act to both create and destroy order (anisotropy) within soils; these processes can proceed simultaneously. The resulting profile reflects the balance of these processes, present and past.
- The geological *Principle of Uniformitarianism* applies to soils, i.e., pedogenic processes active in soils today have been operating for long periods of time, back to the time of appearance of organisms on the land surface. These processes do, however, have varying degrees of expression and intensity over space and time.
- A succession of different soils may have developed, eroded and/or regressed at any particular site, as soil genetic factors and site factors, e.g., vegetation, sedimentation, geomorphology, change.
- There are very few old soils (in a geological sense) because they can be destroyed or buried by geological events, or modified by shifts in climate by virtue of their vulnerable position at the skin of the earth. Little of the soil continuum dates back beyond the Tertiary period and most soils and land surfaces are no older than the Pleistocene Epoch.
- Knowledge and understanding of the genesis of a soil is important in its classification and mapping.
- Soil classification systems cannot be based entirely on perceptions of genesis, however, because genetic processes are seldom observed and because pedogenic processes change over time.
- Knowledge of soil genesis is imperative and basic to soil use and management. Human influence on, or adjustment to, the factors and processes of soil formation can be best controlled and planned using knowledge about soil genesis.
- Soils are natural clay factories (clay includes both clay mineral structures and particles less than 2 μm in diameter). Shales worldwide are, to a considerable extent, simply soil clays that have been formed in the pedosphere and eroded and deposited in the ocean basins, to become lithified at a later date.

The framework for this book

In this book, we introduce the building blocks of soil in Part I, because we do not require that the reader be extremely well grounded in the fundamentals of soil; those with a strong background may choose to skim this section. We continue adding to the basic knowledge base in Part II (Chapters 8–12), but add a great deal more material on theory and soil genesis/processes. In Chapter 11, 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 12. Knowledge of soil genesis provides important information to scientists who classify them. Finally, we pay considerable attention in Part III (Chapters 13–15) to examining soil landscapes over time and how soils can be used as dating tools and as keys to past environments. This is how and when we really bring in the concept of change over time – the fourth dimension. 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. Thus, woven into the book are studies and examples of soil landscapes in three dimensions, often through the use of block diagrams. Hopefully, the reader will gain from such 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 also 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. We also do our best to make this book truly global, by bringing in examples of soil studies and data from as many parts of the world as the literature allows. To be sure, our book has a North American focus – we live there, and it’s the focus of a large proportion of the soil literature. However, we have gone to great lengths to serve 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.

Cambridge University Press
0521812011 - Soils: Genesis and Geomorphology
Randall J Schaetzl and Sharon Anderson
Excerpt
More information

Chapter 2

Basic concepts: soil morphology

Soil means diffferent 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 engineering 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 the pedologist or soil geographer, however, 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, parent materials and time). Its genesis involves past processes and it is likely to change in the future. It varies spatially in the horizontal and vertical dimensions. It is capable of being destroyed and yet it is resilient to perturbations.

Each soil also 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. Soil's other defining characteristics, such as horizonation, chemistry and mineralogy, are discussed in later chapters.

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. We begin with the clastic materials that comprise the soil's *skeleton*.

Texture

Generally, the clastic mineral particles in a soil are divided into the fine earth fraction (<2 mm dia.) and a coarser fraction. Geologists commonly use the phi scale when referring to the sizes of individual particles, whereas pedologists usually refer to particle diameters in mm or μm (Fig. 2.2). Within the fine earth fraction, particles are divided, based on size, into sand, silt and clay (Soil Survey Division Staff 1993) (Fig. 2.2). Sand, silt and clay are each referred to as soil separates. Each of these three components imparts its own character to the soil and has distinct mineralogy (Table 2.1, Fig. 2.3). Sand and most of the silt fraction is composed of primary minerals, while many clay-sized particles are secondary minerals, formed from the weathering of primary minerals. This brings up an important point – *clay* is a size fraction irrespective of mineralogy, while the term *clay mineral* is thought of, by many, as a family of phyllosilicate minerals such as kaolinite, chlorite, smectite and vermiculite, along with oxide clays like hematite and goethite. Not all clay-size particles, however, are phyllosilicate minerals; many are quartz and/or amorphous materials.

Soil texture refers to the relative proportions of sand, silt and clay within the fine earth fraction (Fig. 2.4). It is commonly described as the "feel" of the sample. In the field, texture can be approximated by rubbing a sample between the thumb and forefinger. Clayey soils form a ribbon while sandy soils feel gritty. Silt imparts a smooth feel.

Cambridge University Press
0521812011 - Soils: Genesis and Geomorphology
Randall J Schaetzl and Sharon Anderson
Excerpt
More information

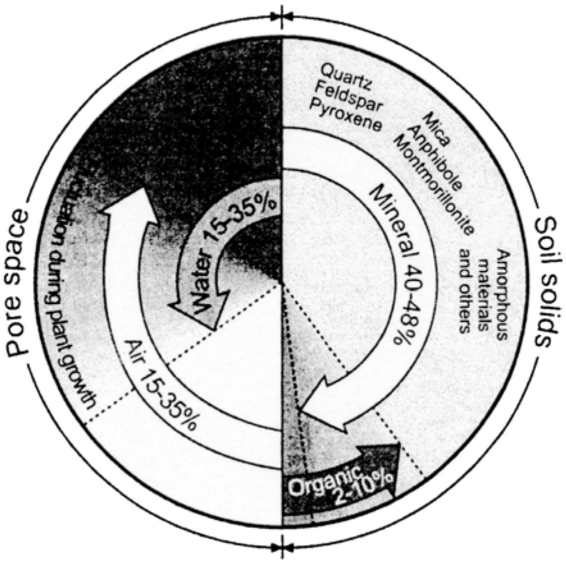

Fig. 2.1 Volumetric composition of a soil under normal conditions. The broken line between water and air indicates that these proportions fluctuate as the soil wets and dries. Similarly, organic matter contents of soils vary from zero to nearly 100%, although 2–8% is a common range for many mineral, i.e., non-organic soils.

After a bit of practice, most people can become quite proficient at determining soil texture by its feel alone.

Texture is quantitatively determined in the laboratory by first dispersing the sample so that the sand, silt and clay particles behave as an independent units, and then wet-sieving out the sand fractions. The silt and clay are both placed in a cylinder with water and mixed to disperse them evenly throughout the suspension. Then, the silt is allowed to settle and a sample is removed that is, in theory, clay and water only. The weight of the clay (and the sand, from the sieving) in the sample is, by use of an equation, used to determine the percentage of clay in the sample. Silt content is determined by subtraction.

Data on sand, silt and clay contents, when plotted on a type of ternary diagram called a *textural triangle*, place the sample within a specific texture class. The standard textural triangle (Fig. 2.4a) has been in use for decades. However, almost a half century ago, Elghamry and Elashkar (1962) realized that the textural class of any soil could be determined if one knows the percentages of only two of the three fractions. This led them to develop a textural triangle that looks quite different but functions similarly (Fig. 2.4b). It has the advantage of allowing textures to be determined by plotting data from only two variables, much like an *X*–*Y* plot in a traditional Cartesian coordinate system, making it adaptable to spreadsheet programs (Gerakis and Baer 1999).

Particle size classes that are totally dominated by one size fraction are simply named for that fraction, e.g., *sand*. Alternatively, *loamy* textures are not dominated by any one size fraction. Note that a sample with equal proportions of clay, silt

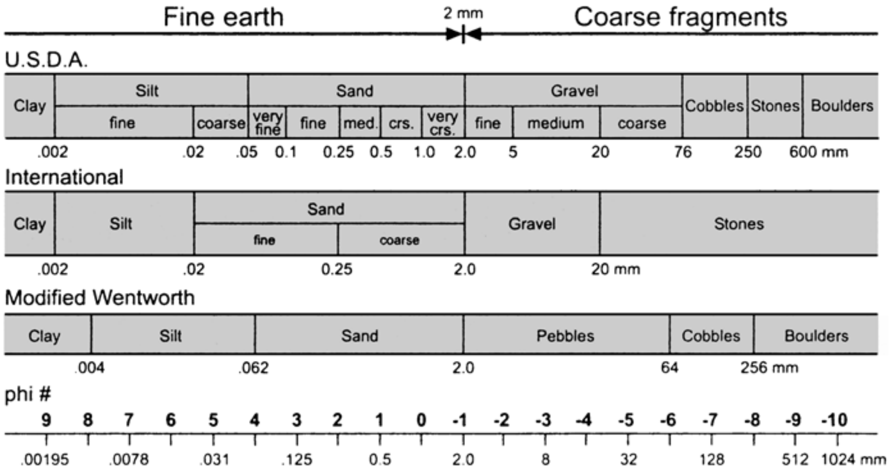

Fig. 2.2 Relationships among particle size class names in three commonly used systems.

Table 2.1 Some general properties of sand, silt and clay[a]

Property	Sand	Silt	Clay
Size range (mm)	2.0–0.05	0.05–0.002	<0.002
Means of observation	Naked eye	Light microscope	Electron microscope
Dominant mineral types	Primary	Primary and secondary	Mostly secondary
Attraction of particles for each other	Low	Medium	High
Attraction of particles for water	Low	Medium	High
Surface area	Very low	Low–medium	High–very high
Water-holding capacity	Low	Medium–high	High
Aeration	Good	Medium	Poor
Potential to be compacted	Low	Medium	High
Resistant to pH change	Low	Medium	High
Ability to retain chemicals and nutrients	Very low	Low	Medium–high
Susceptibility to wind erosion	Moderate (esp. fine sand)	High	Low
Susceptibility to water erosion	Low (unless fine sand)	High	Depends on degree of aggregation
Consistency when wet	Loose, gritty	Smooth	Sticky, malleable
Consistency when dry	Very loose, gritty	Powdery, some clods	Hard clods

[a] These are very generalized relationships and exceptions do occur.

Source: Brady and Weil (1999).

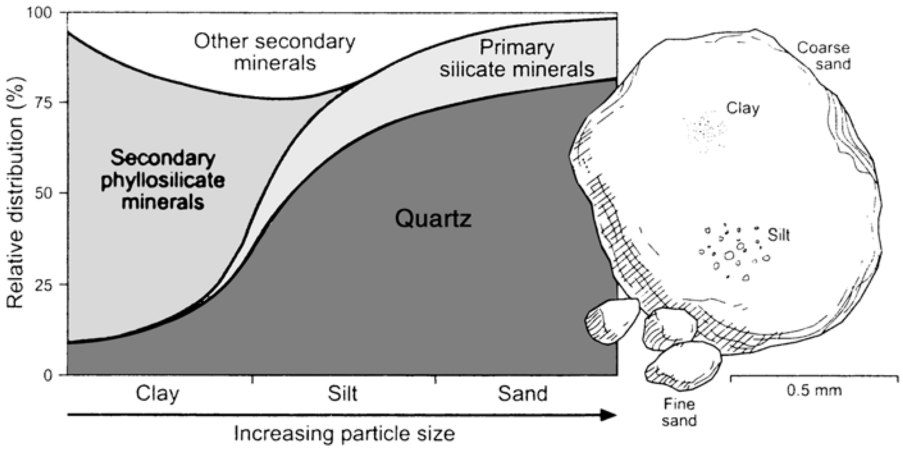

Fig. 2.3 General relationship between particle size and particle mineralogy.