We classify things in order to make sense of our world. We do it whenever we call things by group names, based on their important properties. Imagine a world without classifications. Imagine surviving in the woods knowing only that each plant was a plant, not which are edible by people, which attract wildlife, or which are poisonous. Imagine surviving in a city knowing only that each person was a person, not a child or an adult, a male or a female, a police officer, a hoodlum, a friend, a teacher, a potential date, or any of the other categories into which we classify people. So, too, our understanding and management of soils and terrestrial systems would be hobbled if we knew only that a soil was a soil. How could we organize our information about soils? How could we learn from others’ experience or communicate our knowledge to clients, colleagues, or students?

From the time crops were first cultivated, humans noticed differences in soils and classified them according to their suitability for different uses. Farmers used descriptive names such as black cotton soils, rice soils, or olive soils. Other soil names still in common use today suggest the parent materials from which the soils formed: limestone soils, piedmont soils, and alluvial soils. Such terms may convey some valuable meaning to local users but they are inadequate for helping us to organize our scientific knowledge of soils or for defining the relationships among the soils of the world.

In this chapter we will learn how soils are classified as natural bodies on the basis of their profile characteristics, not merely on the basis of their suitability for a particular use. Such a soil classification system is essential to foster global communications about soils among soil scientists and all people concerned with the management of land and the conservation of the soil resource. Soil classification allow us to take advantage of research and experience at one location to predict the behavior of similarly classified soils at another location. Soil names such as Histosols or Vertisols conjure up similar mental images in the minds of soil scientists everywhere, whether they live in the United States, Europe, Japan, developing countries, or elsewhere. A goal of the classification system, is to create a universal language of soils that enhances communication among users of soils around the world.
3.1 CONCEPT OF INDIVIDUAL SOILS

Compared to most sciences, the organized study of soils is rather young, having begun in the 1870s when the Russian scientist V. V. Dokuchaev and his associates first conceived the idea that soils exist as natural bodies in nature. Russian soil scientists soon developed a system for classifying natural soil bodies, but poor international communications and the reluctance of some scientists to acknowledge such radical ideas delayed the universal acceptance of the natural bodies concept. In the United States, it was not until the late 1920s that C. F. Marbut of the U.S. Department of Agriculture, one of the few scientists who grasped the concept of soils as natural bodies, developed a soil classification scheme based on these principles.

The natural body concept of soils recognizes the existence of individual entities, each of which we call a soil. Just as human individuals differ from one another, soil individuals have characteristics distinguishing each from the others. Likewise, just as human individuals may be grouped according to characteristics such as height or gender, soil individuals having one or more characteristics in common may be grouped together. In turn, we may aggregate these groups into higher-level categories of soils, each having some characteristic that sets them apart from the others. Increasingly broad soil groups are defined as one moves up the classification pyramid from a soil to the soil.

Pedon and Polypedon

There are seldom sharp demarcations between one soil individual and another. Rather, properties gradually change as one moves from one soil individual to an adjacent one. The gradation in soil properties can be compared to the gradation in the wavelengths of light as you move from one color to another in a rainbow. The change is gradual, and yet we identify a boundary differentiating between what we call green and what we call blue. Soils in the field are heterogenous; that is, the profile characteristics are not exactly the same in any two points within the soil individual you may choose to examine. Consequently, it is necessary to characterize a soil individual in terms of an imaginary three-dimensional unit called a pedon (rhymes with “head on,” from the Greek pedon, ground; see Figure 3.1). It is the smallest sampling unit that displays the full range of properties characteristic of a particular soil.

Pedons occupy from about 1 to 10 m$^2$ of land area. Because it is what is actually examined during field investigation of soils, the pedon serves as the fundamental unit of soil classification. However, a soil unit in a landscape usually consists of a group of very similar pedons, closely associated together in the field. Such a group of similar pedons, or a polypedon, is of sufficient size to be recognized as a landscape component termed a soil individual.

All the soil individuals in the world that have in common a suite of soil profile properties and horizons that fall within a particular range are said to belong to the same soil series. A soil series, then, is a class of soils, not a soil individual, in the same way that Pinus sylvestris is a species of tree, not a particular individual tree. The more than 20,000 soil series characterized in the United States are the basic units used to classify the nation’s soils. As we shall see in Section 19.7, units delineated on detailed soil maps are not purely one soil, but are usually named for the soil series to which most of the pedons within the unit belong.

Groupings of Soil Individuals

In the concept of soils, the most specific extreme is that of a natural body called a soil, characterized by a three-dimensional sampling unit (pedon), related groups of which (polypedons) are included in a soil individual. At the most general extreme is the soil, a collection of all these natural bodies that is distinct from water, solid rock, and other natural parts of the Earth’s crust. Hierarchical soil classification schemes generally group soils into classes at increasing levels of generality between these two extremes.

Many cultures have traditional names for various classes of soils that help convey the people’s collective knowledge about their soil resources (see Box 3.1). Scientific classification of soils began in the late 1800s stemming from the work of Dokuchaev in

1 Although widely used, the polypedon concept is not without its critics. See Ditzler (2005).
A schematic diagram to illustrate the concept of pedon and of the soil profile that characterizes it. Note that several contiguous pedons with similar characteristics are grouped together in a larger area (outlined by broken lines) called a polypedon or soil individual. Several soil individuals are present in the landscape on the left. (Diagram courtesy of R. Weil)

Russia (see Section 2.2). Australia, Brazil, Canada, China, the United Kingdom, Russia, and South Africa are among the countries that have developed and continue to use their own national soil classification systems.2 To provide a global vocabulary for communicating about soils and a reference by which various national soil classification systems can be compared and correlated, scientists working through the Food and Agriculture Organization of the United Nations have developed a three-tier classification system known as the World Reference Base for Soils (see Appendix Table A.1). At the highest level, the world’s soils are classified into 32 Soil Reference Groups that are differentiated mainly by the pedogenic process (such as the accumulation of clay in the subsoil) or parent material (such as volcanic ash) that is most responsible for creating the soil properties that typify the particular group. The system also uses an extensive list of prefix qualifiers that can provide a second tier of more specific classes within a Soil Reference Group. The prefix qualifiers include typical types found within a Soil Reference Group, as well as intergrades that indicate similarity to one of the 31 other Soil Reference Groups. A third tier of detail is provided by another list of suffix qualifiers that indicates specific soil properties and features.

In the United States, the Soil Survey Staff of the U.S. Department of Agriculture began in 1951 to collaborate with soil scientists from many other countries with the aim of devising a classification system comprehensive enough to address all soils in the world, not just those in the United States. Finally published in 1975, and revised in 1999, the resulting system, Soil Taxonomy, is used in the United States and approximately 50 other countries. This system will be employed throughout this text.

### 3.2 COMPREHENSIVE CLASSIFICATION SYSTEM: SOIL TAXONOMY3

Soil Taxonomy,4 provides a hierarchical grouping of natural soil bodies. The system is based on soil properties that can be objectively observed or measured, rather than on presumed mechanisms of soil formation. The system uses a unique nomenclature that gives a definite connotation of the major characteristics of the soils in question. It is truly international because it is not based on any one national language.

2 See Appendix A for summaries of the World Reference Base for Soils and the Canadian and Australian Systems of Soil Classification. For more information on other national systems and their interrelationships, see Eswaran et al. (2003).

3 For a complete description of Soil Taxonomy, see Soil Survey Staff (1999). The first edition of Soil Taxonomy was published as Soil Survey Staff (1975). For an explanation of the earlier U.S. classification system, see USDA (1938).

4 Taxonomy is the science of the principles of classification. For a review of the achievements and challenges of Soil Taxonomy, see SSSA (1984).
For thousands of years, most societies were primarily agricultural, and almost everyone worked with soils on a daily basis. Raw survival, on a personal and community level, depended on the food that could be coaxed from the different soils that people found in their environment. By trial and error, people learned which soils were best suited to various crops and which responded best to different kinds of management. As farmers passed their observations and traditions from one generation to the next, they summarized their knowledge about soils by developing unique systems of soil classification. In some regions this local knowledge about soils helped shape agricultural systems that were sustainable for centuries. For example, formal Chinese soil classification goes back two millennia. In Beijing one may still visit the most recent (built in 1421) of a series of large sacrificial altars covered with five differently colored types of soils representing five regions of China (listed here with modern names in parentheses): (1) whitish saline soils (Salids) from the western deserts; (2) black organic-rich soils (Mollisols) from the north; (3) blue-grey waterlogged soils (e.g., Aquepts) from the east; (4) reddish iron-rich soils (Oxisols) from the south; and (5) yellow soils (Inceptisols) from the central loess plateau.

Local languages often reflect a sophisticated and detailed knowledge of how soils differ from one another. Ethnopedological studies carried out by anthropologists with an interest in soils (or soil scientists with an interest in anthropology) have documented many hitherto underappreciated indigenous classification systems for local soils. These systems most commonly classify soils using soil color, texture, hardness, moisture, organic matter, and topography, as well as other soil properties (Figure 3.2). Most of these properties are those observable in the surface horizon, the part of the soil with which farmers come into daily contact. In this respect, the local classifications differ from most scientific classification schemes, which tend to focus on the subsurface horizons (as indicated in Figure 1.17). Rather than viewing this as a weakness, the two approaches can be seen as complementary.

History teaches us that people may rapidly degrade their new land and water resources when they move to an environment that is radically different from what they are used to. Whether these newcomers are Europeans settling the North American continent, lowland African tribes migrating into mountainous regions, or development specialists attempting to transfer technology from one country to another, they generally lack sufficient knowledge of the local soils to allow them to manage the resource in a sustainable way. Indigenous soil classification, reflecting knowledge gained over many generations of living in the local environment, can help and is too important to ignore when planning rural development projects.

**BOX 3.1 ETHNOPEDOLOGY: HOW LOCAL PEOPLE CLASSIFY THEIR SOILS**

For thousands of years, most societies were primarily agricultural, and almost everyone worked with soils on a daily basis. Raw survival, on a personal and community level, depended on the food that could be coaxed from the different soils that people found in their environment. By trial and error, people learned which soils were best suited to various crops and which responded best to different kinds of management. As farmers passed their observations and traditions from one generation to the next, they summarized their knowledge about soils by developing unique systems of soil classification. In some regions this local knowledge about soils helped shape agricultural systems that were sustainable for centuries. For example, formal Chinese soil classification goes back two millennia. In Beijing one may still visit the most recent (built in 1421) of a series of large sacrificial altars covered with five differently colored types of soils representing five regions of China (listed here with modern names in parentheses): (1) whitish saline soils (Salids) from the western deserts; (2) black organic-rich soils (Mollisols) from the north; (3) blue-grey waterlogged soils (e.g., Aquepts) from the east; (4) reddish iron-rich soils (Oxisols) from the south; and (5) yellow soils (Inceptisols) from the central loess plateau.

Local languages often reflect a sophisticated and detailed knowledge of how soils differ from one another. Ethnopedological studies carried out by anthropologists with an interest in soils (or soil scientists with an interest in anthropology) have documented many hitherto underappreciated indigenous classification systems for local soils. These systems most commonly classify soils using soil color, texture, hardness, moisture, organic matter, and topography, as well as other soil properties (Figure 3.2). Most of these properties are those observable in the surface horizon, the part of the soil with which farmers come into daily contact. In this respect, the local classifications differ from most scientific classification schemes, which tend to focus on the subsurface horizons (as indicated in Figure 1.17). Rather than viewing this as a weakness, the two approaches can be seen as complementary.

History teaches us that people may rapidly degrade their new land and water resources when they move to an environment that is radically different from what they are used to. Whether these newcomers are Europeans settling the North American continent, lowland African tribes migrating into mountainous regions, or development specialists attempting to transfer technology from one country to another, they generally lack sufficient knowledge of the local soils to allow them to manage the resource in a sustainable way. Indigenous soil classification, reflecting knowledge gained over many generations of living in the local environment, can help and is too important to ignore when planning rural development projects.

**FIGURE 3.2** Soil characteristics used in soil classification among 62 ethnic groups around the world. [Data from Barrera-Bassols et al. (2006); photo courtesy of R. Weil]

Bases of Soil Classification

Soil Taxonomy is based on the properties of soils as they are found today. This does not mean that the processes of soil genesis are ignored. In fact, one of the objectives of the system is to group soils that are similar in genesis. However, the specific criteria used to place soils in these groups are those of observable soil properties.

Most of the chemical, physical, and biological properties presented in this text are used as criteria for Soil Taxonomy. A few examples are moisture and temperature status throughout the year, as well as color, texture, and structure of the soil. Chemical and mineralogical properties, such as the contents of organic matter, clay, iron and aluminum oxides, silicate clays, salts, the pH, the percentage base saturation, and soil depth are other important criteria for classification. While many of the properties used may be observed in the field, others require precise measurements on samples taken to a sophisticated laboratory. This precision makes the system more objective, but in some cases may make the proper classification of a soil quite expensive and time-consuming. Precise measurements are also used to define certain diagnostic soil horizons, the presence or absence of which help determine the place of a soil in the classification system.

Diagnostic Surface Horizons of Mineral Soils

The diagnostic horizons that occur at the soil surface are called epipedons (from the Greek epi, over, and pedon, soil). The epipedon includes the upper part of the soil darkened by organic matter, the upper eluvial horizons, or both. It may include part of the B horizon if the latter is significantly darkened by organic matter. Eight are recognized (Table 3.1), but only five occur naturally over wide areas (Figure 3.3). The other two, anthropic and plaggen, are the result of intensive human use. They are common in parts of Europe and Asia where soils have been utilized for many centuries.

The mollic epipedon (Latin mollis, soft) is a mineral surface horizon noted for its dark color (see Plates 8 and 20, after page 112) associated with its accumulated organic matter (>0.6% organic C throughout), for its thickness (generally >25 cm), and for its softness even when dry. It has a high base saturation greater than 50%. Mollic epipedons are moist at least three months a year when the soil temperature is usually 5° C or higher to a depth of 50 cm. These epipedons are characteristic of soils developed under grassland (Figure 3.4 and Plate 8). The umbric epipedon (Latin umbra, shade; hence, dark) has the same general characteristics as the mollic epipedon except the percentage base saturation is lower. This mineral horizon commonly develops in areas with somewhat higher rainfall and where the parent material has lower content of calcium and magnesium.

The ochric epipedon (Greek ochros, pale) is a mineral horizon that is either too thin, too light in color, or too low in organic matter to be either a mollic or umbric horizon. It is usually not as deep as the mollic or umbric epipedons. As a consequence of its low organic matter content, it may be hard and massive when dry (see Plates 1, 4, 7, and 11).

The melanic epipedon (Greek melas, melan, black) is a mineral horizon that is very black in color due to its high organic matter content (organic carbon >6%). It is characteristic of soils high in such minerals as allophane, developed from volcanic ash. It is more than 30 cm thick and is extremely light in weight and fluffy for a mineral soil (see Plate 2).

The histic epipedon (Greek histos, tissue) is a 20 to 60 cm-thick layer of organic soil materials overlying a mineral soil. Formed in wet areas, the histic epipedon is a layer of peat or muck with a black to dark brown color and a very low density.

5 The percentage base saturation is the percentage of the soil’s negatively charged sites (cation exchange capacity) that are satisfied by attracting nonacid (or base) cations (such as Ca²⁺, Mg²⁺, and K⁺) (see Section 9.3).

6 Organic soil material, such as peat and muck, may consist almost entirely of organic matter, but it is technically defined as containing more than a certain minimum amount of organic matter as follows: If the material is not water-saturated in its natural state, its organic matter content must be at least 35% (about 200 g/kg organic C). If it is water-saturated during part of the year in its natural state, then the minimum organic matter content varies with the amount of clay in the material, ranging from 20% (120 g/kg organic C) if no clay is present to 30% (180 g/kg organic C) if the clay content exceeds 600 g/kg. For a discussion of the relationship between organic matter and organic carbon, see Section 12.4 and the footnote in Table 12.1.
TABLE 3.1 Major Features of Diagnostic Horizons in Mineral Soils Used for Differentiation at the Higher Levels of Soil Taxonomy

<table>
<thead>
<tr>
<th>Diagnostic horizon (and typical genetic horizon designation)</th>
<th>Major features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface horizons = epipedons</strong></td>
<td></td>
</tr>
<tr>
<td>Anthropic (A) Human-modified mollic-like horizon, high in available P</td>
<td></td>
</tr>
<tr>
<td>Folistic (O) Organic horizon saturated for less than 30 days per normal year</td>
<td></td>
</tr>
<tr>
<td>Histic (O) Very high in organic content, wet during some part of year</td>
<td></td>
</tr>
<tr>
<td>Melanic (A) Thick, black, high in organic matter (&gt;6% organic C), common in volcanic ash soils</td>
<td></td>
</tr>
<tr>
<td>Mollic (A) Thick, dark-colored, high base saturation, strong structure</td>
<td></td>
</tr>
<tr>
<td>Ochric (A) Too light-colored, low organic content or thin to be Mollic; may be hard and massive when dry</td>
<td></td>
</tr>
<tr>
<td>Plaggen (A) Human-made sodlike horizon created by years of manuring</td>
<td></td>
</tr>
<tr>
<td>Umbric (A) Same as Mollic except low base saturation</td>
<td></td>
</tr>
<tr>
<td><strong>Subsurface horizons</strong></td>
<td></td>
</tr>
<tr>
<td>Agric (A or B) Organic and clay accumulation just below plow layer resulting from cultivation</td>
<td></td>
</tr>
<tr>
<td>Albic (E) Light-colored, clay and Fe and Al oxides mostly removed</td>
<td></td>
</tr>
<tr>
<td>Argillic (Bt) Silicate clay accumulation</td>
<td></td>
</tr>
<tr>
<td>Calcic (Bk) Accumulation of CaCO₃ or CaCO₃ · MgCO₃</td>
<td></td>
</tr>
<tr>
<td>Cambic (Bw, Bg) Changed or altered by physical movement or by chemical reactions, generally nonilluvial</td>
<td></td>
</tr>
<tr>
<td>Duripan (Bqm) Hard pan, strongly cemented by silica</td>
<td></td>
</tr>
<tr>
<td>Fragiipan (Bx) Brittle pan, usually loamy textured, dense, coarse prisms</td>
<td></td>
</tr>
<tr>
<td>Glossic (E) Whittish eluvial horizon that tongues into a Bt horizon</td>
<td></td>
</tr>
<tr>
<td>Gypsic (Bk) Accumulation of gypsum</td>
<td></td>
</tr>
<tr>
<td>Histic (Bt) Accumulation of low-activity clays</td>
<td></td>
</tr>
<tr>
<td>Natric (Bt) Argillic, high in sodium, columnar or prismatic structure</td>
<td></td>
</tr>
<tr>
<td>Oxic (Bo) Highly weathered, primarily mixture of Fe, Al oxides and nonsticky-type silicate clays</td>
<td></td>
</tr>
<tr>
<td>Petrocalcic (Ckm) Cemented calcic horizon</td>
<td></td>
</tr>
<tr>
<td>Petrogypsic (Cym) Cemented gypsic horizon</td>
<td></td>
</tr>
<tr>
<td>Placic (Csm) Thin pan cemented with iron alone or with manganese or organic matter</td>
<td></td>
</tr>
<tr>
<td>Salic (Bz) Accumulation of salts</td>
<td></td>
</tr>
<tr>
<td>Sombric (Bh) Organic matter accumulation</td>
<td></td>
</tr>
<tr>
<td>Spodic (Bh, Bs) Organic matter, Fe and Al oxide accumulation</td>
<td></td>
</tr>
<tr>
<td>Sulfuric (Cj) Highly acid with Jarosite mottles</td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 3.3** Representative profile characteristics of five surface diagnostic horizons (epipedons). The comparative organic matter levels and distribution are indicated by the darkness of colors. The mollic and umbric epipedons have similar organic matter distribution but the percentage base saturation is higher (greater than 50%) in the mollic epipedon and lower (less than 50%) in the umbric epipedon. The ochric epipedon is lower in organic matter content; consequently, it is light in color and sometimes hard when dry. Two other epipedons have very high organic matter contents and are very dark in color. The melanic epipedon is formed on recently deposited volcanic materials, usually in cool wet areas. The histic epipedon is formed from organic deposits laid down over mineral soils, usually in wet, boggy conditions. The relative depth of each epipedon is shown by the brackets.
Diagnostic Subsurface Horizons

Many subsurface diagnostic horizons are used to characterize different soils in Soil Taxonomy (Table 3.1 and Figure 3.5). Each diagnostic horizon provides a characteristic that helps place a soil in its proper class in the system. We will briefly discuss a few of the more commonly encountered subsurface diagnostic horizons.

The **argillic horizon** is a subsurface accumulation of silicate clays that have moved downward from the upper horizons or have formed in place. Examples are shown in Figure 3.4 and in Plate 1 between 50 and 90 cm. The clays often are found as coatings on pore walls (as shown in Figure 4.2) and surfaces of the structural groupings. The coatings usually appear as shiny surfaces or as clay bridges between sand grains. Termed argillans or clay skins, they are concentrations of clay translocated from upper horizons (see Plates 18 and 24).

The **natric horizon** likewise has silicate clay accumulation (with clay skins), but the clays are accompanied by more than 15% exchangeable sodium on the colloidal complex and by columnar or prismatic soil structural units. The natric horizon is found mostly in arid and semiarid areas. Examples are shown in Figures 4.13 and 10.18.

The **kandic horizon** has an accumulation of Fe and Al oxides as well as low-activity silicate clays (e.g., kaolinite), but clay skins need not be evident. The clays are low in activity as shown by their low cation-holding capacities (<16 cmol$_c$/kg clay). The epipedon that overlies a kandic horizon has commonly lost much of its clay content (see Figure 3.6).

The **oxic horizon** is a highly weathered subsurface horizon that is very high in Fe and Al oxides and in low-activity silicate clays (e.g., kaolinite). The cation-holding capacity is <16 cmol$_c$/kg clay. The horizon is at least 30 cm deep and has <10% weatherable
minerals in the fine fraction. It is generally physically stable, crumbly, and not very sticky, despite its high clay content. It is found mostly in humid tropical and subtropical regions (see Plate 9, between about 1 and 3 feet on the scale and Plate 25 at 70 to 170 cm).

The spodic horizon is an illuvial horizon that is characterized by the accumulation of colloidal organic matter and aluminum oxide (with or without iron oxide). It is commonly found in highly leached forest soils of cool humid climates, typically on sandy-textured parent materials (see Plate 10, reddish-brown and black layers below the whitish layer).

The sombric horizon is an illuvial horizon, dark in color because of high organic matter accumulation. It has a low degree of base saturation and is found mostly in the cool, moist soils of high plateaus and mountains in tropical and subtropical regions (Plate 23).

The albic horizon is a light-colored eluvial horizon that is low in clay and oxides of Fe and Al. These materials have largely been moved downward from this horizon (see Plate 10, starting at about 10 cm depth).

FIGURE 3.5  Names and major distinguishing characteristics of subsurface diagnostic horizons. Among the characteristics emphasized is the accumulation of silicate clays, organic matter, Fe and Al oxides, calcium compounds, and soluble salts, as well as materials that become cemented or highly acidified, thereby constraining root growth. The presence or absence of these horizons plays a major role in determining in which class a soil falls in Soil Taxonomy. See Chapter 8 for a discussion of low- and high-activity clays.
Chapter Three

Well-developed argillic horizons may present such a great and abrupt increase in clay content that water and root movement are severely restricted; such a horizon is commonly referred to by the non-taxonomic term, **claypan**.

A number of horizons have accumulations of saltlike chemicals that have leached from upper horizons in the profile. **Calcic horizons** contain an accumulation of carbonates (mostly CaCO₃) that often appear as white chalklike nodules (see the Bk horizon in the lower part of the profiles shown in Figure 3.4 and Plates 13 and 20). **Gypsic horizons** have an accumulation of gypsum (CaSO₄ · 2H₂O), and **salic horizons** have an accumulation of soluble salts. These are found mostly in soils of arid and semiarid regions.

In some subsurface diagnostic horizons, the materials are cemented or densely packed, resulting in relatively impermeable layers called **pans** (**duripan**, **fragipan**, and **placic horizons**). These can resist water movement and the penetration of plant roots. Such pans constrain plant growth and may encourage water runoff and erosion because rainwater cannot move readily downward through the soil. Figure 3.5 explains the genesis of these and the other subsurface diagnostic horizons.

**Soil Moisture Regimes (SMR)**

A soil moisture regime refers to the presence or absence of either water-saturated conditions (usually groundwater) or plant-available soil water during specified periods in the year in what is termed the **control section** of the soil. The upper boundary of the SMR control section is the depth that 2.5 cm of water will penetrate within 24 hours when added to a dry soil. The lower boundary is the depth that 7.5 cm of water will penetrate. The control section ranges from 10 to 30 cm for soils high in fine particles (clay) and from 30 to 90 cm for sandy soils. Several moisture regime classes are used to characterize soils.

**Aquic.** Soil is saturated with water and virtually free of gaseous oxygen for sufficient periods of time for evidence of poor aeration (gleying and mottling) to occur.

**Udic.** Soil moisture is sufficiently high year-round in most years to meet plant needs. This regime is common for soils in humid climatic regions and characterizes about one-third of the worldwide land area. An extremely wet moisture regime with excess moisture for leaching throughout the year is termed **perudic**.

[FIGURE 3.6 Vertical variation in clay content and cation exchange capacity (CEC) in a soil with thick albic and kandic horizons (E1-E2-E3 and Bt1-Bt2, respectively). Note the well-expressed "clay bulge" that marks the kandic horizon. Similar clay enrichment (plus clay skins or other visual evidence of clay illuviation) characterizes an argillic horizon. This is a kandic rather than an argillic horizon because there was no visible evidence of clay illuviation and because the accumulated clay is of low-activity types, meaning the CEC of the clay is less than 16 cmol/kg of clay. Note that the CEC of the clay = CEC of the soil x percent clay in the soil + 100. The sharp increase in clay at the upper boundary of the kandic horizon, the considerable thickness (more than 100 cm) of the clay-rich layer, and the low CEC per kg of clay are all indications that this is a very old, highly mature soil. It formed under humid, subtropical conditions in sandy sediments in the upper coastal plain of Georgia. It is classified in the Kandiudults great group in Soil Taxonomy. (Data from Shaw et al., 2000)]
Ustic. Soil moisture is intermediate between Udic and Aridic regimes—generally there is some plant-available moisture during the growing season, although significant periods of drought may occur.

Aridic. The soil is dry for at least half of the growing season and moist for less than 90 consecutive days. This regime is characteristic of arid regions. The term torric is used to indicate the same moisture condition in certain soils that are both hot and dry in summer, though they may not be hot in winter.

Xeric. This soil moisture regime is found in typical Mediterranean-type climates, with cool, moist winters and warm, dry summers. Like the Ustic regime, it is characterized by having long periods of drought in the summer.

These terms are used to diagnose the soil moisture regime and are helpful not only in classifying soils but in suggesting the most sustainable long-term use of soils.

Soil Temperature Regimes

Soil temperature regimes, such as frigid, mesic, and thermic, are used to classify soils at some of the lower levels in Soil Taxonomy. The cryic (Greek kryos, very cold) temperature regime distinguishes some higher-level groups. These regimes are based on mean annual soil temperature, mean summer temperature, and the difference between mean summer and winter temperatures, all at 50 cm depth. The specific temperature regimes will be described in the discussion of soil families (Section 3.17).

3.3 CATEGORIES AND NOMENCLATURE OF SOIL TAXONOMY

There are six hierarchical categories of classification in Soil Taxonomy: (1) order, the highest (broadest) category, (2) suborder, (3) great group, (4) subgroup, (5) family, and (6) series (the most specific category). The lower categories fit within the higher categories (Figure 3.7). Thus, each order has several suborders, each suborder has several great groups, and so forth. This system may be compared with those used for the classification of plants or animals, as shown in Table 3.2. Just as *Trifolium repens* identifies a specific kind of plant, the Miami series identifies a specific kind of soil.
Nomenclature of Soil Taxonomy

Although unfamiliar at first sight, the nomenclature system has a logical construction and conveys a great deal of information about the nature of the soils named. The system is easy to learn after a bit of study. The nomenclature is used throughout this book, especially to identify the kinds of soils shown in illustrations. When reading, if you make a conscious effort to identify the parts of each soil class mentioned in the text and figure captions and recognize the level of category indicated, the system will become second nature.

The names of the classification units are combinations of syllables, most of which are derived from Latin or Greek, and are root words in several modern languages. Since each part of a soil name conveys a concept of soil character or genesis, the name automatically describes the general kind of soil being classified. For example, soils of the order Aridisols (from the Latin aridus, dry, and solum, soil) are characteristically dry soils in arid regions. Those of the order Inceptisols (from the Latin inceptum, beginning, and solum, soil) are soils with only the beginnings or inception of profile development. Thus, the names of orders are combinations of (1) formative elements, which generally define the characteristics of the soils, and (2) the ending sols.

The names of suborders automatically identify the order of which they are a part. For example, soils of the suborder Aquolls are the wetter soils (from the Latin aqua, water) of the Mollisols order. Likewise, the name of the great group identifies the suborder and order of which it is a part. Argiaquolls are Aquolls with clay or argillic (Latin argilla, white clay) horizons. In the following illustration, note that the three letters oll identify each of the lower categories as being in the Mollisols order.

<table>
<thead>
<tr>
<th>Plant classification</th>
<th>Soil classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phylum</td>
<td>Pterophyta</td>
</tr>
<tr>
<td>Class</td>
<td>Angiospermae</td>
</tr>
<tr>
<td>Subclass</td>
<td>Dicotyledoneae</td>
</tr>
<tr>
<td>Order</td>
<td>Rosales</td>
</tr>
<tr>
<td>Family</td>
<td>Leguminosae</td>
</tr>
<tr>
<td>Genus</td>
<td>Trifolium</td>
</tr>
<tr>
<td>Species</td>
<td>repens</td>
</tr>
<tr>
<td>Order</td>
<td>Alfisols</td>
</tr>
<tr>
<td>Suborder</td>
<td>Udalfs</td>
</tr>
<tr>
<td>Great Group</td>
<td>Hapludalfs</td>
</tr>
<tr>
<td>Subgroup</td>
<td>Oxyaquic Hapludalfs</td>
</tr>
<tr>
<td>Family</td>
<td>Fine loamy, mixed, mesic, active</td>
</tr>
<tr>
<td>Series</td>
<td>Miami</td>
</tr>
<tr>
<td>Phase</td>
<td>Miami silt loam</td>
</tr>
</tbody>
</table>

* Technically not a category in Soil Taxonomy but used in field surveying. Silt loam refers to the texture of the A horizon.

In the U.S., “official state soils” share the same level of distinction as official state flowers and birds: http://soils.usda.gov/gallery/state_soils/

TABLE 3.2 Comparison of the Classification of a Common Cultivated Plant, White Clover (Trifolium repens), and a Soil, Miami Series

Family: Leguminosae

Genus: Trifolium

Species: repens

Phasea Miami silt loam

a Technically not a category in Soil Taxonomy but used in field surveying. Silt loam refers to the texture of the A horizon.

In the U.S., “official state soils” share the same level of distinction as official state flowers and birds: http://soils.usda.gov/gallery/state_soils/

86  Chapter Three
practical subunits are called soil phases. Names such as Fort Collins loam, Cecil clay, or Cecil clay loam, eroded phase are used to identify such phases. Note, however, that soil phases, practical as they may be in local situations, are not a category in the Soil Taxonomy system.

With this brief explanation of the nomenclature of Soil Taxonomy, we will now consider the general nature of soils in each of the soil orders.

3.4 SOIL ORDERS

Each of the world’s soils is assigned to one of 12 orders, largely on the basis of soil properties that reflect a major course of development, with considerable emphasis placed on the presence or absence of major diagnostic horizons (Table 3.3). As an example, many soils that developed under grassland vegetation have the same general sequence of horizons and are characterized by a mollic epipedon—a thick, dark, surface horizon that is high in non-acid cations. Soils with these properties are thought to have been formed by the same general genetic processes, but it is because of the properties they have in common that they are included in the same order: Mollisols. The names and major characteristics of each soil order are shown in Table 3.3. Note that all order names have a common ending, sols (from the Latin solum, soil).

The general conditions that enhance the formation of soils in the different orders are shown in Figure 3.8. From soil profile characteristics, soil scientists can ascertain the relative degree of soil development in the different orders, as shown in this figure. Note that soils with essentially no profile layering (Entisols) have the least development, while the deeply weathered soils of the humid tropics (Oxisols and Ultisols) show the greatest soil development. The effect of climate (temperature and moisture) and of vegetation (forests or grasslands) on the kinds of soils that develop is also indicated in Figure 3.8. Study Table 3.3 and Figure 3.8 to better understand the relationship between soil properties and the terminology used in Soil Taxonomy.

To some degree, most of the soil orders occur in climatic regions that can be described by moisture and temperature regimes. Figure 3.9 illustrates some of the relationships among the soil orders with regard to these climatic factors. While only the Gelisols and Aridisols orders are defined directly in relation to climate, Figure 3.9 indicates that orders with the most highly weathered soils tend to be associated with the warmer and wetter climates. Figure 3.10 is a simplified general soil map of North America. Maps and photos of each soil order: http://soils.ag.uidaho.edu/soilorders/index.htm

### TABLE 3.3 Names of Soil Orders in Soil Taxonomy with Their Derivation and Major Characteristics

<table>
<thead>
<tr>
<th>Name</th>
<th>Formative element</th>
<th>Derivation</th>
<th>Pronunciation</th>
<th>Major characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfisols</td>
<td>alf</td>
<td>Nonsense symbol</td>
<td>Pedalifer</td>
<td>Argillic, natic, or kandic horizon; high-to-medium base saturation</td>
</tr>
<tr>
<td>Andisols</td>
<td>and</td>
<td>Jap. ando, black soil</td>
<td>Andesite</td>
<td>From volcanic ejecta, dominated by allophane or Al-humic complexes</td>
</tr>
<tr>
<td>Aridisols</td>
<td>id</td>
<td>L. aridis, dry</td>
<td>Ard</td>
<td>Dry soil, ochric epipedon, sometimes argillic or natic horizon</td>
</tr>
<tr>
<td>Entisols</td>
<td>ent</td>
<td>Nonsense symbol</td>
<td>Recent</td>
<td>Little profile development, ochric epipedon common</td>
</tr>
<tr>
<td>Gelsols</td>
<td>ell</td>
<td>Gk. gelid, very cold</td>
<td>Jely</td>
<td>Permafrost, often with cryoturbation (frost churning)</td>
</tr>
<tr>
<td>Histosols</td>
<td>ist</td>
<td>Gk. histos, tissue</td>
<td>Histology</td>
<td>Peat or bog; &gt;20% organic material</td>
</tr>
<tr>
<td>Inceptisols</td>
<td>ept</td>
<td>L. inceptum, beginning</td>
<td>Inception</td>
<td>Embryonic soils with few diagnostic features, ochric or umbric epipedon, cambic horizon</td>
</tr>
<tr>
<td>Mollisols</td>
<td>oll</td>
<td>L. mollis, soft</td>
<td>Mollify</td>
<td>Mollic epipedon, high base saturation, dark soils, some with argillic or natic horizons</td>
</tr>
<tr>
<td>Oxisols</td>
<td>ox</td>
<td>Fr. oxide, oxide</td>
<td>Oxide</td>
<td>Oxic horizon, no argillic horizon, highly weathered</td>
</tr>
<tr>
<td>Spodosols</td>
<td>od</td>
<td>Gk. spodos, wood ash</td>
<td>Podzol; odd</td>
<td>Spodic horizon commonly with Fe, Al oxides and humus accumulation</td>
</tr>
<tr>
<td>Ultisols</td>
<td>ult</td>
<td>L. ultimus, last</td>
<td>Ultimate</td>
<td>Argillic or kandic horizon, low base saturation</td>
</tr>
<tr>
<td>Vertisols</td>
<td>ert</td>
<td>L. verto, turn</td>
<td>Invert</td>
<td>High in swelling clays; deep cracks when soil is dry</td>
</tr>
</tbody>
</table>
FIGURE 3.8 Diagram showing general degree of weathering and soil development in the different soil orders classified in Soil Taxonomy. Also shown are the general climatic and vegetative conditions under which soils in each order are formed.

FIGURE 3.9 Diagram showing the general soil moisture and soil temperature regimes that characterize the most extensive soils in each of eight soil orders. Soils of the other four orders (Andisols, Entisols, Inceptisols, and Histosols) may be found under any of the soil moisture and temperature conditions (including the area marked EIH). Major areas of Vertisols are found only where clayey materials are in abundance and are most extensive where the soil moisture and temperature conditions approximate those shown inside the box with broken lines. Note that these relationships are only approximate and that less extensive areas of soils in each order may be found outside the indicated ranges. For example, some Ultisols (Ustults) and Oxisols (Ustox) have soil moisture levels for at least part of the year that are much lower than this graph would indicate. (The terms used at the bottom to describe the soil temperature regimes are those used in helping to identify soil families.)
America showing the major areas dominated by each order. Profiles for each soil order are shown in color on Plates 1 through 12. A more detailed color-coded soil map for the United States can be found on the back endpaper of this book; a general world map of the 12 soil orders is printed in color on the front endpaper. In studying these maps, try to confirm that the distribution of the soil orders is in accordance with what you know about the climate in various regions of the world.

Although a detailed description of all the lower levels of soil categories is far beyond the scope of this (or any other) book, a general knowledge of the 12 soil orders is essential for understanding the nature and function of soils in different environments. The simplified key given in Figure 3.11 helps illustrate how Soil Taxonomy can be used to key out the order of any soil based on observable and measurable properties of the soil profile. Because certain diagnostic properties take precedence over others, the key must always be used starting at the top, and working down. It will be useful to review this key after reading about the general characteristics, nature, and occurrence of each soil order.

We will now consider each of the soil orders, beginning with those characterized by little profile development and progressing to those with the most highly weathered profiles (as represented from left to right in Figure 3.8).
3.5 ENTISOLS (RECENT: LITTLE IF ANY PROFILE DEVELOPMENT)

Weakly developed mineral soils without natural genetic (subsurface) horizons or with only the beginnings of such horizons (see Plate 4, after page 112) belong to the Entisols order. Most have an ochric epipedon and a few have human-made anthropic or agric

FIGURE 3.11 A simplified key to the 12 soil orders in Soil Taxonomy. In using the key, always begin at the top. Note how diagnostic horizons and other profile features are used to distinguish each soil order from the remaining orders. Entisols, having no such special diagnostic features, key out last. Also note that the sequence of soil orders in this key bears no relationship to the degree of profile development and adjacent soil orders may not be more similar than nonadjacent ones. See Section 3.2 for explanations of the diagnostic horizons.
Entisols

Suborders are:
- Aquents (wet)
- Arents (mixed horizons)
- Fluvents (alluvial deposits)
- Orthents (typical)
- Psamments (sandy)

16.3% of global and 12.2% of U.S. ice-free land

Distribution and Use

Globally, Entisols occupy about 16% of the total ice-free land area (Table 3.4) and are found under a wide variety of environmental conditions (Figure 3.10 and endpapers). For example, in rocky and mountainous regions, shallow, medium-textured Entisols...
Inceptisols (Orthents) are common. These support mostly rangeland in dry regions and forests in more humid areas. Sandy Entisols (Psamments; Figure 3.12) are found in parts of the Sahara desert, southern Africa, central Australia, northwest Nebraska, and the southeastern U.S. coastal plain. Psamments in the humid southern United States are successfully used for citrus, vegetable, and peanut production. Poorly drained and seasonally flooded Entisols (Aquents) occur in major river valleys. Fluvents on recent alluvium in Asia have produced rice crops for generations.

The agricultural productivity of the Entisols varies greatly depending on their location and properties. Entisols developed on alluvial floodplains are among the world’s most productive soils. Such soils, with their level topography, proximity to water for irrigation, and periodic nutrient replenishment by floodwater sediments, have supported the development of many major civilizations. However, the productivity of most Entisols is restricted by inadequate soil depth, clay content, or water availability.

### 3.6 **Inceptisols (Few Diagnostic Features: Inception of B Horizon)**

9.9% of global and 9.1% of U.S. ice-free land

**Suborders are:**
- Anthrepts (human-made, high phosphorus, dark surface)
- Aquepts (wet)
- Cryepts (very cold)
- Gelepts (permafrost)
- Udepts (humid climate)
- Ustepts (semiarid)
- Xerepts (dry summers, wet winters)

In Inceptisols the beginning or **inception** of profile development is evident, and some diagnostic features are present. However, the well-defined profile characteristics of soils thought to be more mature have not yet developed. For example, a cambic horizon showing some color or structural change is common in Inceptisols, but a more mature illuvial B horizon such as an argillic cannot be present. Other subsurface diagnostic horizons that may be present in Inceptisols include duripans, fragipans, and calcic, gypsic, and sulfuric horizons. The epipedon in most Inceptisols is an ochric, although a plaggan or weakly expressed mollic or umbric epipedon may be present. Inceptisols show more significant profile development than Entisols, but are defined to exclude soils with diagnostic horizons or properties that characterize certain other soil orders. Thus, soils with only slight profile development occurring in arid regions or containing permafrost or andic properties are excluded from the Inceptisols. They fall, instead, in the soil orders Aridisols, Gelisols, or Andisols, as discussed in later sections.

**Distribution and Use**

Inceptisols are widely distributed throughout the world. As with Entisols, Inceptisols are found in most climatic and physiographic conditions. They are often prominent in mountainous areas (Figure 3.13). They are also probably the most important soil order in the lowland rice-growing areas of Asia.

Inceptisols are found in each of the continents (see front papers). Inceptisols of humid regions, called **Udepts**, often have only thin, surface horizons (ochric epipedons). Udepts are common in the mountains from southern New York through the Carolinas. Udepts, along with Xerepts (Inceptisols in xeric climates), also dominate an area extending from southern Spain through central France to Germany and are present as well in Chile, North Africa, eastern China, and western Siberia. Wet Inceptisols or Aquepts are found in areas along the Amazon and Ganges rivers. The natural productivity of Inceptisols is highly variable.
3.7 ANDISOLS (VOLCANIC ASH SOILS)

Andisols are usually formed on volcanic ash and cinders deposited in recent geological times. They are commonly found near the volcano source or in areas downwind from the volcano, where a sufficiently thick layer of ash has been deposited during eruptions. Andisols have not had time to become highly weathered. The principal soil-forming process has been the rapid weathering (transformation) of volcanic ash to produce amorphous or poorly crystallized silicate minerals such as allophane and imogolite and the iron oxy-hydroxide, ferrihydrite. Some Andisols have a melanic epipedon, a surface diagnostic horizon that has a high organic matter content and dark color (see Plate 2). The accumulation of organic matter is quite rapid due largely to its protection in aluminum–humus complexes. Little downward translocation of the colloids, or other profile development, has taken place. Like the

0.7% of global and 1.7% of U.S. ice-free land

Suborders are:
- Aquands (wet)
- Cryands (cold)
- Gelands (very cold)
- Torrands (hot, dry)
- Udands (humid)
- Ustands (moist/dry)
- Vitrands (volcanic glass)
- Xerands (dry summers, moist winters)
Entisols and Inceptisols, Andisols are young soils, usually having developed for only 5000 to 10,000 years.

Unlike the previous two orders of immature soils, Andisols have a unique set of andic properties in at least 35 cm of the upper 60 cm of soil due to common types of parent materials. Materials with andic properties are characterized by a high content of volcanic glass and/or a high content of amorphous or poorly crystalline iron and aluminum minerals. The combination of these minerals and the high organic matter results in light, fluffy soils that are easily tilled, yet have a high water-holding capacity and resist erosion by water. They are mostly found in regions where rainfall keeps them from being susceptible to erosion by wind. Andisols are usually of high natural fertility, except that phosphorus availability is severely limited by the extremely high phosphorus retention capacity of the andic materials (see Section 14.8). Fortunately, proper management of plant residues and fertilizers can usually overcome this difficulty.

Distribution and Use

Andisols are found in areas where significant depths of volcanic ash and other ejecta have accumulated (Figure 3.14). Globally, they make up less than 1% of the soil area. However, in the Pacific rim area they are important and productive soils that support intensive agriculture, especially in cool, high-elevation areas.

Andisols, having an udic (moist) soil moisture regime (Udands), are widely cultivated in Japan, producing enough food to support very high population densities. The somewhat drier Ustands are also used intensively for agriculture. Significant areas of Udands and Ustands occur along the Rift Valley of eastern Africa. Andisols are found to a minor extent in cold climates (Cryands) in Canada and Russia, and in hot, dry climates (Torrands) in Mexico and Syria. Very recent eruptions, such as that of Mount Saint Helens in the northwestern part of the United States and Mount Pinatubo in the Philippines, are giving rise to Vitrands that still have much volcanic glass and lower water-holding capacities.
In the United States, the area of Andisols is not extensive since recent volcanic action is not widespread. However, Andisols do occur in some very productive wheat-and timber-producing areas of Washington, Idaho, Montana, and Oregon. Likewise, this soil order represents some of the best farmland found in Chile, Ecuador, Colombia, and much of Central America.

### 3.8 GELISOLS (PERMAFROST AND FROST CHURNING)

Gelisols are young soils with little profile development. Cold temperatures and frozen conditions for much of the year slow the process of soil formation. The principal defining feature of these soils is the presence of a permafrost layer (see Plates 5 and 14). Permafrost is a layer of material that remains at temperatures below 0° C for more than two consecutive years. It may be a hard, ice-cemented layer of soil material (e.g., designated Cfm in profile descriptions), or, if dry, it may be un cemented (e.g., designated Cff). In Gelisols, the permafrost layer lies within 100 cm of the soil surface, unless cryoturbation is evident within the upper 100 cm, in which case the permafrost may begin as deep as 200 cm from the soil surface.

Cryoturbation is the physical disturbance of soil materials caused by the formation of ice wedges and by the expansion and contraction of water as it freezes and thaws. This frost churning action moves the soil material so as to orient rock fragments along the lines of force and to form broken, convoluted horizons (e.g., designated Cjj) at the top of the permafrost (Figure 3.15). The frost

**FIGURE 3.15** The broken and involuted patterns formed by cryoturbation. This example is actually a relic of cryoturbation during the Pleistocene ice age in Europe, when this soil would most likely have been in the Turbels suborder. However, it is located in Hungary where permafrost no longer occurs and today is found buried beneath a modern Mollisol formed in an overlying layer of windblown silt (loess). The dark round spots are filled-in animal burrows called crotovinas (see Section 2.5). Photograph is about 60 cm across. (Photo courtesy of Ericka Michéli, University of Agricultural Sciences, Gödöllő, Hungary)
churning also may form patterns on the ground surface, such as hummocks and ice-rich polygons that may be several meters across. In some cases rocks forced to the surface form rings or netlike patterns.

Gelisols showing evidence of cryoturbation are called *Turbels*. Other Gelisols, often found in wet environments, have developed in accumulations of mainly organic materials, making them *Histels* (Greek *histos*, tissue; Figure 3.16). Most of the soil-forming processes that occur take place above the permafrost in the *active layer* that thaws every year or two. Various types of diagnostic horizons may have developed in different Gelisols, including mollic, histic, umbric, calcic, and, occasionally, argillic horizons.

**Distribution and Use**

Gelisols cover over 11 million km$^2$ or 8.6% of the Earth’s land area—about 8 million km$^2$ in Northern Russia and another 4 million in Canada and Alaska. Blanketed under snow and ice for much of the year, most Gelisols support tundra vegetation of lichens, grasses, and low shrubs that grow during the brief summers. Large areas of Gelisols consist of bogs, some literally floating on layers of frozen or unfrozen water. Millions of caribou, reindeer, and musk ox survive on this vegetation during the summer, then migrate to the boreal forests during the coldest seasons. The many bogs and pools serve as nesting sites for migratory birds, which feed on the thick clouds of biting flies and mosquitoes. Human populations are very sparse in these inhospitable environments.

Very few areas of Gelisols are used for agriculture. Plant productivity is low because of the extremely short potential growing season in the far northern latitudes, the low levels of solar radiation (except during the fleeting summer), and the waterlogged condition of many Gelisols in which permafrost inhibits internal drainage during the summer thaw (Figure 3.16).

If the vegetation or surface peat layer on Gelisols is disturbed by cultivation or forest fires or if the soil is warmed by construction activities, the permafrost layer may melt. The permafrost in the southern part of the Gelisols region is only 1 or 2° C
below freezing, so even small changes can cause melting. Unless the soil is mainly gravel, the melting is likely to cause the soil to completely lose its bearing strength and collapse. This presents many serious engineering difficulties (see Figure 3.16, right). Houses built directly on Gelisols may sink into the ground as the heat from inside the building penetrates the soil and melts the permafrost. The trans-Alaska oil pipeline had to be constructed on stilts, rather than buried, where it crossed sensitive Gelisols as the heat from the flowing oil would have melted the permafrost, causing the pipes to rupture.

Scientists have observed regional permafrost melting in much of the Arctic. This response of Gelisols is thought to be an early symptom of global climate change caused by greenhouse gas emissions (see Section 12.9). Unfortunately, the melting of permafrost and deepening of the active layer in Gelisols are expected to accelerate this trend as the enormous pools of organic carbon once locked away in the permafrost become exposed to decay, thus releasing yet more greenhouse gases to the atmosphere.

### 3.9 HISTOSOLS (ORGANIC SOILS WITHOUT PERMAFROST)

Histosols are soils that have undergone little profile development because of the anaerobic environment in which they form. The main process of soil formation evident in Histosols is the accumulation of partially decomposed organic parent material without permafrost (which would cause the soil to be classified in the Histels suborder of Gelisols). Histosols consist of one or more thick layers of organic soil material (see footnote 6, page 80). Generally, Histosols have organic soil materials in more than half of the upper 80 cm of soil (Plate 6) or in two-thirds of the soil overlying shallow rock.

Organic deposits accumulate in marshes, bogs, and swamps, which are habitats for water-loving plants such as pondweeds, cattails, sedges, reeds, mosses, shrubs, and even some trees. Generation after generation, the residues of these plants sink into the water, which inhibits their oxidation by reducing oxygen availability and, consequently, acts as a partial preservative (see Figure 2.22).

The organic matter in Histosols ranges from peat to muck. Peat is comprised of the brownish, only partially decomposed, fibrous remains of plant tissues (see Figure 3.17, Plate 26). Some of these soils are mined and sold as peat, a material widely used in containerized plant production (see Box 12.4). Muck, on the other hand, is a black material in which decomposition is much more complete and the organic matter is highly humified (Figure 3.18). Muck is like a black ooze when wet and powdery when dry.

While not all wetlands contain Histosols, all Histosols (except Folists) occur in wetland environments. They can form in almost any moist climate in which plants can grow, from equatorial to arctic regions, but they are most prevalent in cold climates, up to the limit of permafrost. Horizons are differentiated by the type of vegetation contributing the residues, rather than by translocations and accumulations within the profile.

Whether artificially drained for cultivation or left in their natural water-saturated state, Histosols possess unique properties resulting from their high organic matter content.
Histosols are generally black to dark brown in color. They are extremely lightweight (0.15 to 0.4 Mg/m$^3$) when dry, being only about 10 to 20% as dense as most mineral soils. Histosols also have high water-holding capacities on a mass basis. While a mineral soil will absorb and hold from 20 to 40% of its weight of water, a cultivated Histosol may hold a mass of water equal to 200 to 400% of its dry weight. These soils also possess very high cation exchange capacities (typically 150 to 300 cmol+/kg) that increase with increasing soil pH. The water- and cation-holding capacities are much

**FIGURE 3.17** A tidal marsh Histosol. The inset shows the fibric (peaty) organic material that contains recognizable roots and rhizomes of marsh grasses that died perhaps centuries ago, the anaerobic conditions having preserved the tissues from extensive decay. The soil core (held horizontally for the photograph) gives some idea of the soil profile, the surface layer being at the right and the deepest layer at the left. The water level is usually at or possibly above the soil surface. (Photos courtesy of R. Weil)

**FIGURE 3.18** A drained Histosol on which onions are being produced in New York State. The organic soil rests on old lake-bottom (lacustrine) mineral sediment. The organic material is mucky (see insert), placing this soil in the Saprist suborder. The thickness of this Histosol has been much reduced by subsidence during the nearly 100 years of drainage and cultivation. The surface of this black soil appears light-colored because it was dry when photographed. (Photos courtesy of R. Weil)
higher than those of even clay-rich mineral soils on a weight basis, but similar to those of mineral soils rich in 2:1 silicate clays when considered on a volume basis (water or cations held per liter of soil).

**Distribution and Use**

Even though they cover only about 1% of the world’s land area, Histosols, or peat lands, comprise significant areas in cold, wet regions of Alaska, Canada, Finland, Russia, Iceland, Ireland, and Scotland. Of approximately 2 million km² of Histosols worldwide, about 75,000 are found in the contiguous United States. Three-quarters of this peat land is in glaciated areas such as Wisconsin, Minnesota, New York, and Michigan. Other important areas of Histosols are found in the tule-reed beds of California and in low-lying parts of the Atlantic and Gulf coastal plains, especially in the Everglades of Florida, the bayous of Louisiana, and the tidal marshes of the mid-Atlantic states (Figure 3.17).

Because the ecological roles of natural wetland environments have not always been appreciated (or protected by law), more than 50% of the original wetland area in the lower 48 United States has been drained for agricultural or other uses, especially for vegetable and flower production. Some Histosols make very productive farmlands, but the organic nature of the materials requires liming, fertilization, tillage, and drainage practices quite different from those applied to soils in the other 11 orders.

If other than wetland plants are to be grown, the water table is usually lowered to provide an aerated zone for root growth. This practice, of course, alters the soil environment and causes the organic material to oxidize, resulting in the disappearance of as much as 5 cm of soil per year in warm climates. To slow the loss of valuable soil resources and avoid unnecessarily aggravating the global greenhouse effect (see Section 12.9), the water table in forested or agricultural Histosols should be kept no lower than is needed to assure adequate root aeration. A more sustainable approach would be to allow some Histosol areas to revert to their native wetland condition (see Section 7.7).

As the organic matter oxidizes in drained Histosols, the land surface is actually lowered as a result of compression and oxidation, a process termed **subsidence** (see Figure 3.19). To preserve these valuable soils and reduce land subsidence, the water table should be kept as near to the surface as possible. Except for the production of

![Figure 3.19](image-url)
such crops as rice and cranberries under flooded conditions, agriculture on Histosols is
not sustainable in the long term.

In some places, Histosols are also mined for their peat, which is sold for use in potting
media, as a mulch, and to make peat-fiber pots. Peat deposits are also used for fuel in some
countries, especially in Russia, where several power stations are fueled by this material.

3.10 ARIDISOLS (DRY SOILS)

Aridisols occupy a larger area globally than any other soil order except Entisols. Water
deficiency is a major characteristic of these soils. The soil moisture level is sufficiently
high to support plant growth for no longer than 90 consecutive days. The natural vege-
tation consists mainly of scattered desert shrubs and short bunchgrasses. Soil properties,
especially in the surface horizons, may differ substantially between interspersed bare
and vegetated areas (see Section 2.5).

Aridisols are characterized by an ochric epipedon that is generally light in color and
low in organic matter (see Plate 3). The processes of soil formation have brought about
a redistribution of soluble materials, but there is generally not enough water to leach
these materials completely out of the profile. Therefore, they often accumulate at a
lower level in the profile. These soils may have a horizon of accumulation of calcium
carbonate (calcic), gypsum (gypsic), soluble salts (salic), or exchangeable sodium
(natric). Under certain circumstances, carbonates may cement together the soil parti-
cles and coarse fragments in the layer of accumulation, producing hard layers known as
petrocalcic horizons (Figure 3.20). These hard layers act as impediments to plant root
growth and also greatly increase the cost of excavations for buildings.

Some Aridisols (the Argids) have an argillic horizon, most probably formed under a
wetter climate that long ago prevailed in many areas that are deserts today. With time

![FIGURE 3.20](image_url)

Two features characteristic of some Aridisols. *(Left)* Wind-rounded pebbles have given rise to a desert
pavement. *(Right)* A petrocalcic horizon of cemented calcium carbonate. (Photo courtesy of R. Weil)
and the addition of carbonates from calcareous dust and other sources, many argillic horizons become engulfed by carbonates (Calcids). On steeper land surfaces subject to erosion, argillic horizons do not get a chance to form, and the dominant soils are often Cambids (Aridisols with only weakly differentiated cambic subsurface B horizons).

In stony or gravelly soils, erosion may remove all the fine particles from the surface layers, leaving behind a layer of wind-rounded pebbles that is called desert pavement (see Figure 3.20 and Plate 55). The surfaces of the pebbles in desert pavement often have a shiny coating called desert varnish (Plate 57). This coating is thought to be produced by algae that extract iron and manganese from the minerals and leave an oxide coating on the pebbles.

Except where there is groundwater or irrigation, the soil layers are only moist for short periods during the year. These short, moist periods may be sufficient for drought-adapted desert shrubs and annual plants, but not for conventional crop production. If groundwater is present near the soil surface, soluble salts may accumulate in the upper horizons to levels that most crop plants cannot tolerate.

**Distribution and Use**

In the United States, Aridisols occur mostly in the western region. A large area dominated by Argids (Aridisols with an argillic horizon) occupies much of the southern parts of California, Nevada, Arizona, and central New Mexico (endpapers). The Argids also extend down into northern Mexico. Smaller areas of Cambids (simple Aridisols without horizons of clay or salt accumulation) are found in several western states (see Plate 3).

Vast areas of Aridisols are present in the Sahara desert in Africa, the Gobi and Taklimakan deserts in China, and the Turkestan desert of the former Soviet Union. Most of the soils of southern and central Australia are Aridisols, as are those of southern Argentina, southwestern Africa, Pakistan, and much of the Middle East.

Without irrigation, Aridisols are not suitable for growing cultivated crops. Some areas are used for low-intensity grazing, especially with sheep or goats, but the production per unit area is low. The overgrazing of Aridisols leads to increased heterogeneity of both soils and vegetation. The animals graze the relatively even cover of palatable grasses, giving a competitive advantage to various shrubs not eaten by the grazing animals. The scattered shrubs compete against the struggling grasses for water and nutrients. The once-grassy areas become increasingly bare, and the soils between the scattered shrubs succumb to erosion by the desert winds and occasional thunderstorms. The desertification of areas of sub-Saharan Africa and the western United States is evidence of such degradation (Figure 3.21).
Some xerophytic plants, such as a jojoba, have been cultivated on Aridisols to produce various industrial feedstocks such as oil and rubber. Where irrigation water and fertilizers are available, some Aridisols can be made highly productive. Irrigated valleys in arid areas are among the most productive in the world. However, they must be carefully managed to prevent the accumulation of soluble salts (see Section 10.3).

### 3.11 VERTISOLS (DARK, SWELLING, AND CRACKING CLAYS)\(^8\)

2.4% of global and 1.7% of U.S. ice-free land

**Suborders are:**
- Aquerts (wet)
- Cryerts (cold)
- Torrerts (hot summer, very dry)
- Uderts (humid)
- Usterts (moist/dry)
- Xererts (dry summers, moist winters)

The main soil-forming process affecting Vertisols is the shrinking and swelling of clay as these soils go through periods of drying and wetting. Vertisols have a high content (>30%) of sticky, swelling, and shrinking-type clays to a depth of 1 m or more. Most Vertisols are dark, even blackish in color, to a depth of 1 m or more (Plate 12). However, unlike for most other soils, the dark color of Vertisols is not necessarily indicative of a high organic matter content. The organic matter content of dark Vertisols typically ranges from as much as 5 or 6% to as little as 1%.

Vertisols typically develop from limestone, basalt, or other calcium- and-magnesium rich parent materials. In east Africa, they typically form in landscape depressions that collect the calcium and magnesium leached out of the surrounding upland soils. The presence of these cations encourages the formation of swelling-type clays (see Section 8.3).

Vertisols are found mostly in subhumid to semiarid environments in warm regions, but a few (Cryerts) occur where the average soil temperatures are as low as 0°C (see Figure 3.9). The native vegetation is usually grassland. Vertisols generally occur where the climate features dry periods of several months. In dry seasons the clay shrinks, causing the soils to develop deep, wide cracks that are diagnostic for this order (Figure 3.22a). The surface soil generally forms granules, of which a significant number may slough off into the cracks, giving rise to a partial inversion of the soil (Figure 3.23a). This accounts for the association with the term invert, from which this order derives its name.

When the rains come, water entering the large cracks moistens the clay in the subsoils, causing it to swell. The repeated shrinking and swelling of the subsoil clay results in a kind of imperceptibly slow “rocking” movement of great masses of soil. As the subsoil swells, blocks of soil shear off from the mass and rub past each other under pressure, giving rise in the subsoil to shiny, grooved, tilted surfaces called slickensides (Figure 3.23c). Eventually, this back-and-forth motion may form bowl-shaped depressions with relatively deep profiles surrounded by slightly raised areas in which little soil development has occurred and in which the parent material remains close to the surface (see Figure 3.23b). The resulting pattern of micro-highs and micro-lows on the land surface, called gilgai, is usually discernable only where the soil is untillled (Figure 3.22b).

---

\(^8\) See Coulombe, et al. (1996) for a detailed review of the properties and mode of formation of Vertisols.
Vertisols are high in swelling-type clay and have developed wedgelike structures in the subsoil horizons. (a) During the dry season, large cracks appear as the clay shrinks upon drying. Some of the surface soil granules fall into cracks under the influence of wind and animals. This action causes a partial mixing, or inversion, of the horizons. (b) During the wet season, rainwater pours down the cracks, wetting the soil near the bottom of the cracks first and then the entire profile. As the clay absorbs water, it swells the cracks shut, entrapping the collected granular soil. The increased soil volume causes lateral and upward movement of the soil mass. The soil is pushed up between the cracked areas. As the subsoil mass shears from the strain, smooth surfaces or slickensides form at oblique angles. These processes result in a Vertisol profile that typically exhibits gilgai, cracks more than 1 m deep and slickensides in a Bss horizon. (c) An example of a slickenside in a Vertisol. Note the grooved, shiny surface. The white spots in the lower right of the photo are calcium carbonate concretions that often accumulate in a Bkss horizon. (Diagrams and photo courtesy of R. Weil)
Distribution and Use

Globally, Vertisols comprise about 2.5% of the total land area. Large areas of Vertisols are found in India, Ethiopia, the Sudan, and northern and eastern Australia (see front papers). Smaller areas occur in sub-Saharan Africa and in Mexico, Venezuela, Bolivia, and Paraguay. These latter soils probably are of the Usterts or Xererts suborders, since dry conditions persist long enough for the wide cracks to stay open for periods of three months or longer.

There are several small but significant areas of Vertisols in the United States (see Figure 3.10 and endpapers). Two areas are located in humid areas, one in eastern Mississippi and western Alabama (the so-called black belt) and the other along the southeast coast of Texas. These soils are of the Uderts suborder, because their moist condition prevents cracks from persisting for more than three months of the year.

Two other Vertisol areas are found in east central and southern Texas, where the soils are drier. Since cracks persist for more than three months of the year in these areas, the soils belong to the Usterts suborder, characteristic of areas with hot, dry summers. An area of Cryerts is located in the Dakotas and Saskatchewan. Xererts (Greek xeros, dry) are also located in California.

The high shrink-swell potential of Vertisols makes them extremely problematic for any kind of highway or building construction (Figure 8.33 and Plate 43). This property also makes agricultural management very difficult. Because they are very sticky and plastic when wet and become very hard when dry, the timing of tillage operations is critical. Some farmers refer to Vertisols as 24-hour soils, because they are said to be too wet to plow one day and too dry the next.

Even when the soil moisture is near optimal, the energy requirement for tillage is high. Therefore, except where heavy equipment is used for tillage, the operations are slow, and the amount of land a farmer can cultivate is much smaller than for other soil orders. In areas such as those in India and the Sudan, where slow-moving animals or human power are commonly used to till the soil, farmers cannot perform tillage operations on time and are limited to the use of very small tillage implements that their animals can pull through the heavy soil.

Recent research shows that the large areas of Vertisols in the tropics can produce greatly increased yields of food crops with improved soil management practices. Soils in this order are, however, very susceptible to physical degradation and erosion (despite their mainly gentle slopes), and conservation practices or reversion to rangeland are important management options to consider.

3.12 MOLLISOLS (DARK, SOFT SOILS OF GRASSLANDS)

6.9% of global and 22.4% of U.S. ice-free land

Suborders are:
- Albolls (albic horizon)
- Aquolls (wet)
- Cryolls (cold)
- Gelolls (very cold)
- Rendolls (calcareous)
- Udolls (humid)
- Ustolls (moist/dry)
- Xerolls (dry summers, moist winters)

The principal process in the formation of Mollisols is the accumulation of calcium-rich organic matter, largely from the dense root systems of prairie grasses, to form the thick, soft Mollic epipedon that characterizes soils in this order (Plates 8, 13, and 20). This humus-rich surface horizon is often 60 to 80 cm in depth. Its cation exchange capacity
is more than 50% saturated with base cations (Ca²⁺, Mg²⁺, etc.). Mollisols in humid regions generally have higher organic matter and darker, thicker mollic epipedons than their lower-moisture-regime counterparts (see Section 12.8).

The surface horizon generally has granular or crumb structures, largely resulting from an abundance of organic matter and swelling-type clays. In many cases, the highly aggregated soil is not hard when dry, hence the name Mollisol, implying softness (Table 3.3). In addition to the mollic epipedon, Mollisols may have an argillic (clay), natric, albic, or cambic subsurface horizon, but not an oxic or spodic horizon.

Most Mollisols have developed under grass vegetation (Figure 3.24). Grassland soils of the central part of the United States, lying between Aridisols on the west and the Alfisols on the east, typify the central concept of this order. However, a few soils developed under forest vegetation (primarily in depressions) have a mollic epipedon and are included among the Mollisols.

**Distribution and Use**

Mollisols cover a larger land area in the United States than any other soil order. Mollisols are dominant in the Great Plains of North America, as well as in Illinois (see Figure 3.10). Where soil moisture is not limiting, Udolls are found. They are associated with nearby wet Mollisols termed Aquolls. A region characterized by Ustolls (intermittently dry during the summer) extends from Manitoba and Saskatchewan in Canada to southern Texas. Farther west are found sizable areas of Xerolls (with a Xeric moisture regime, which is very dry in summer but moist in winter). Landscapes common for Udolls and Ustolls can be seen in Figure 3.25. Conservation of soil water is a major consideration in the management of Ustolls, in particular. Two Mollisols profiles are included in Figure 3.26.
The largest area of Mollisols in the world stretches from east to west across the heartlands of Kazakhstan, Ukraine, and Russia. Other sizable areas are found in Mongolia and northern China and in northern Argentina, Paraguay, and Uruguay. Mollisols occupy only about 7% of the world’s total soil area, but because of their generally high fertility, they account for a much higher percentage of total crop production.

In the United States, efforts are underway to preserve the few remnants of the once vast and diverse prairie ecosystem. Because the high native fertility of Mollisols makes them among the world’s most productive soils, few Mollisols have been left uncultivated in regions with sufficient rainfall for crop production. When they were first cleared and plowed, much of their native organic matter was oxidized, releasing nitrogen and other nutrients in sufficient quantities to produce high crop yields even without the use of fertilizers. Even after more than a century of cultivation, Mollisols are among the most productive soils, although some fertilization is generally required. However, continuous cultivation with row crops has led to serious deterioration of soil structure and to soil erosion where the land is sloping.

**FIGURE 3.25** Typical landscapes dominated by Ustolls (Montana, top) and Udolls (Iowa, bottom). These productive soils produce much of the food and feed in the United States. (Photos courtesy of R. Weil)
3.13 ALFISOLS (ARGILLIC OR NATRIC HORIZON, MODERATELY LEACHED)

The Alfisols are more strongly weathered than soils in the orders just discussed, but less so than Spodosols and Ultisols (see following). They are found in cool to hot humid areas (see Figure 3.9) as well as in the semiarid tropics and Mediterranean climates. Most often, Alfisols develop under native deciduous forests, although in some cases, as in California and parts of Africa, savanna (mixed trees and grass) is the native vegetation.

Alfisols are characterized by a subsurface diagnostic horizon in which silicate clay has accumulated by illuviation (see Plate 1). Clay skins or other signs of clay movement are present in such a B horizon (see Plates 18 and 24). In Alfisols, this clay-rich horizon is only moderately leached, and its cation exchange capacity is more than 35% base saturated (Ca$^{2+}$, Mg$^{2+}$, etc.). In most Alfisols this horizon is termed argillic because of its accumulation of silicate clays. The horizon is termed natric if, in addition to having an accumulation of clay, it is more than 15% saturated with sodium and has prismatic or columnar structure (see Figure 4.13). In some Alfisols in subhumid tropical regions, the accumulation is termed a kandic horizon (from the mineral kandite) because the clays have a low cation exchange capacity.

Alfisols very rarely have a mollic epipedon, for such soils would be classified in the Argiudolls or other suborder of Mollisols with an argillic horizon. Instead, Alfisols

**Suborders are:**
- Aqualfs (wet)
- Cryalf (cold)
- Udalfs (humid)
- Ustalfs (moist/dry)
- Xeralfs (dry summers, moist winters)
typically have a relatively thin, gray to brown ochric epipedon (Plate 1 shows an example) or an umbric epipedon. Those formed under deciduous temperate forests commonly have a light-colored, leached albic E horizon immediately under the A horizon (see Plate 21 and Figures 1.15 and 3.26).

Distribution and Use

Udalfs (humid region Alfisols) dominate large areas in Ohio, Indiana, Michigan, Wisconsin, Minnesota, Pennsylvania, and New York in the United States (see Figure 3.10), as well as in central China, England, France, central Europe, and southeastern Australia. There are sizable areas of Xeralfs (Alfisols in regions of dry summers and moist winters) in central California, southwestern Australia, Italy, and central Spain and Portugal (Figure 3.27). Cryalfs (very cold) can be found in the Rocky Mountains; in south-central Canada; in Minnesota; in northern Europe, extending from the Baltic States through western Russia; and in Siberia. Where summers are hot and dry, including areas in Texas, New Mexico, sub-Saharan Africa, eastern Brazil, eastern India, and southeastern Asia, Ustalfs are prominent. Many Alfisols landscapes include wet depressions characterized by Aqualfs.

In general, Alfisols are productive soils. Good hardwood forest growth and crop yields are favored by their medium- to high-base-saturation status, generally favorable texture, and location (except for some Xeralfs) in regions with sufficient rainfall for plants for at least part of the year. In the United States these soils rank favorably with the Mollisols and Ultisols in their productive capacity. Many Alfisols, especially the sandier ones, are quite susceptible to erosion by heavy rains if deprived of their natural surface litter. Alfisols in Udic moisture regimes are sufficiently acidic in the A horizon to require amendment with limestone for many kinds of plants (see Chapter 9).

3.14 ULTISOLS (ARGILLIC HORIZON, HIGHLY LEACHED)

8.5% of global and
9.6% of U.S. ice-free land

Suborders are:
Aquults (wet)
Humults (high humus)
Udults (humid)
Ustults (moist/dry)
Xerults (dry summers, moist winters)
The principal processes involved in forming Ultisols are clay mineral weathering, translocation of clays to accumulate in an argillic or kandic horizon, and leaching of base-forming cations from the profile. Most Ultisols have developed under moist conditions in warm to tropical climates. Ultisols are formed on old land surfaces, usually under forest vegetation, although savanna or even swamp vegetation is also common. They often have an ochric or umbric epipedon, but are characterized by a relatively acidic B horizon that has less than 35% of the exchange capacity satisfied with base cations. The clay accumulation may be either an argillic horizon or, if the clay is of low activity, a kandic horizon. Ultisols commonly have both an epipedon and a subsoil that is quite acid and low in plant nutrients.

Ultisols are more highly weathered and acidic than Alfisols, but less acid than Spodosols and less highly weathered than the Oxisols. Except for the wetter members of the order, their subsurface horizons are commonly red or yellow in color, evidence of accumulations of oxides of iron (see Plate 11). Certain Ultisols that formed under fluctuating wetness conditions have horizons of iron-rich mottled material called plinthite (see Plates 15 and 37). This material is soft and can be easily dug from the profile so long as it remains moist. When dried in the air, however, plinthite hardens irreversibly into a kind of ironstone that is virtually useless for cultivation (Plates 29 and 33), but can be used to make durable bricks for building (Plate 48).

**Distribution and Use**

Most of the soils of the southeastern part of the United States fall in the suborder Udults (see Figure 3.10 and endpapers). Large areas of Udults are also located in southeastern Asia and in southern China. Extensive areas of Ultisols are found in the humid tropics in close association with some Oxisols. Important agricultural areas are found in southern Brazil and Paraguay.

Humults (high in organic matter) are found in the United States in Hawaii and in western California, Oregon, and Washington. Humults are also present in the highlands of some tropical countries. Xerults (Ultisols in Mediterranean-type climates) occur locally in southern Oregon and northern and eastern California. Ustults are found in semiarid areas with a marked dry season. Together with the Ustalfs, the Ustults

**FIGURE 3.28** The soils in this high-elevation, tropical area of South Asia are Ultisols in the suborder Humults. These soils are being intensively used both for house construction and for market gardens. The combination of a favorable climate and soils that are high in organic matter (Humults have at least 9% down to the upper part of the B horizon) and respond well to fertilizer has encouraged local residents to use every bit of the land in producing vegetables to supplement their incomes. (Photo courtesy of R. Weil)
occupy large areas in Africa and India. Ultisols are prominent on the east and northeast coasts of Australia (see front papers).

Although Ultisols are not naturally as fertile as Alfisols or Mollisols, they respond well to good management. They are located mostly in regions of long growing seasons and of ample moisture for good crop production (Figure 3.28). The silicate clays of Ultisols are usually of the nonsticky type, which, along with the presence of iron oxides and aluminum, assures ready workability. Where adequate levels of fertilizers and lime are applied, Ultisols are quite productive. In the United States, well-managed Ultisols compete well with Mollisols and the Alfisols as first-class agricultural soils. They also support the most productive commercial softwood and hardwood forests in the country.

3.15 SPODOSOLS (ACID, SANDY, FOREST SOILS, HIGHLY LEACHED)

Spodosols occur mostly on coarse-textured, acid parent materials subject to ready leaching. They occur only in moist to wet areas, commonly where it is cold or temperate (see Figure 3.9), but also in some tropical and subtropical areas. Intensive acid leaching is the principal soil-forming process. They are mineral soils with a spodic horizon, a sub-surface accumulation of illuviated organic matter, and an accumulation of aluminum oxides with or without iron oxides (see Plates 10 and 31 and Figure 3.26). This usually thin, dark, illuvial horizon typically underlies a light, ash-colored, eluvial albic horizon.

Spodosols form under forest vegetation, especially under coniferous species whose needles are low in base-forming cations like calcium and high in acid resins. As this acid litter decomposes, strongly acid organic compounds are released and carried down into the permeable profile by percolating waters. Some of the leaching organic compounds may precipitate and form a black-colored Bh horizon. Leaching organic acids bind with iron and aluminum, removing these metals from the A and E horizons and carrying them downward. This iron and aluminum eventually precipitates in a reddish-brown-colored Bs horizon, usually just below the black-colored Bh horizon. Together, the Bh and Bs horizons constitute the spodic diagnostic horizon that defines the Spodosols. The depth at which the spodic horizon forms can vary from less than 20 cm to several meters. As iron oxides (and most other minerals except quartz) are stripped from the E horizon by the organic leaching process, this horizon may become a nearly white albic diagnostic horizon that consists mainly of clean quartz sand.

The leaching and precipitation often occur along wavy wetting fronts, thus yielding the striking profiles seen in Spodosols (Figure 3.29).

Distribution and Use

Large areas of Spodosols are found in northern Europe and Russia and central and eastern Canada. Many of the soils in the northeastern United States, as well as those of northern Michigan and Wisconsin and southern Alaska, belong to this order (see Figures 3.10 and 3.29). Spodosols are found on about 3% of the land area both globally and in the United States. Small but important areas occur in the southern part of South America and in the cool mountainous areas of temperate regions.

Most Spodosols are Orthods, soils that typify the central concept of Spodosols described previously. Some, however, are Aquods because they are seasonally saturated

2.6% of global and 3.3% of U.S. ice-free land

Suborders are:
- Aquods (wet)
- Cryods (cold)
- Gelods (very cold)
- Humods (humus)
- Orthods (typical)
with water and possess characteristics associated with this wetness. Important areas of Aquods occur in Florida and other areas with warm climates.

Spodosols are not naturally fertile. When properly fertilized, however, these soils can become quite productive. For example, most potato-producing soils of northern Maine are Spodosols, as are some of the vegetable- and fruit-producing soils of Florida, Michigan, and Wisconsin. Because of their sandy nature and occurrence in regions of high rainfall, groundwater contamination by leaching of soluble fertilizers and pesticides has proved to be a serious problem where these soils are used in crop production. They are now covered mostly with forests, the vegetation under which they originally developed. Most Spodosols should remain as forest habitats. Because they are already quite acid and poorly buffered, many Spodosols and the lakes in watersheds dominated by soils of this order are susceptible to damage from acid rain (see Section 9.6).

### 3.16 OXISOLS (OXIC HORIZON, HIGHLY WEATHERED)

7.6% of global and <0.01% of U.S. ice-free land

**Suborders are:**
- Aquox (wet)
- Perox (very humid)
- Torrox (hot, dry)
- Udox (humid)
- Ustox (moist/dry)
The Oxisols are the most highly weathered soils in the classification system (see Figure 3.8). They form in hot climates with nearly year-round moist conditions; hence, the native vegetation is generally thought to be tropical rain forest. However, some Oxisols (Ustox) are found in areas that are today much drier than was the case when the soils were forming their oxic characteristics. Their most important diagnostic feature is a deep oxic subsurface horizon. This horizon is generally very high in clay-size particles dominated by hydrous oxides of iron and aluminum. Weathering and intense leaching have removed a large part of the silica from the silicate materials in this horizon. Some quartz and 1:1-type silicate clay minerals remain, but the hydrous oxides are dominant (see Chapter 8 for information on the various clay minerals). The epiipedon in most Oxisols is either ochric or umbric. Usually the boundaries between subsurface horizons are indistinct, giving the subsoil a relatively uniform appearance with depth.

The clay content of Oxisols is generally high, but the clays are of the low-activity, nonsticky type. Consequently, when the clay dries out it is not hard and cloddy, but is easily worked. Also, Oxisols are resistant to compaction, so water moves freely through the profile. The depth of weathering in Oxisols is typically much greater than for most of the other soils, 20 m or more having been observed. The low-activity clays have a very limited capacity to hold nutrient cations such as Ca$^{2+}$, Mg$^{2+}$, and K$^+$, so they are typically of low natural fertility and moderately acid. The high concentration of iron and aluminum oxides also gives these soils a capacity to bind so tightly with what little phosphorus is present, that phosphorus deficiency often limits plant growth once the natural vegetation is disturbed.

Road and building construction is relatively easily accomplished on most Oxisols because these soils are easily excavated, do not shrink and swell, and are physically very stable on slopes. The very stable aggregation of the clays, stimulated largely by iron compounds, makes these soils quite resistant to erosion.

**Distribution and Use**

Oxisols occupy old land surfaces that have not been disturbed by glaciation or erosion. Although nearly all Oxisols occur in the tropics, most tropical soils are not Oxisols. Large areas of Oxisols occur in South America and Africa (see front papers). New data from Brazilian soil scientists suggests that some of the areas of the Amazon basin currently mapped as Oxisols are in reality dominated by Ultisols and other soils. Udox (Oxisols having a short dry season or none) occur in northern Brazil and neighboring countries as well as in the Caribbean area (see Plates 9 and 25). Important areas of Ustox (hot, dry summers) occur in Brazil to the south of the Udox. In the humid areas of central Africa, Oxisols are prominent and in some cases dominant.

Relatively less is known about Oxisols than about most other soil orders. They occur in large geographic areas, often associated with Ultisols. Millions of people in the tropics depend on them for food and fiber production. However, because of their low natural fertility, most Oxisols have been left under forest vegetation or are farmed by shifting cultivation methods. Nutrient cycling by deep-rooted trees is especially important to the productivity of these soils. Probably the best use of Oxisols, other than supporting rain forests, is the culture of mixed-canopy perennial crops, especially tree crops. Such cultures can restore the nutrient cycling system that characterized the soil–plant relationships before the rain forest was removed.

**3.17 LOWER-LEVEL CATEGORIES IN SOIL TAXONOMY**

**Suborders**

As indicated next to the global distribution maps in previous sections, soils within each order are grouped into suborders on the basis of soil properties that reflect major environmental controls on current soil-forming processes. Many suborders are indicative of the moisture regime or, less frequently, the temperature regime under which the soils are found. Thus, soils formed under wet conditions generally are identified under separate suborders (e.g., Aquents, Aquerts, and Aquepts), as being wet soils.
To determine the relationship between suborder names and soil characteristics, refer to Table 3.4. Here the formative elements for suborder names are identified and their connotations given. Thus, the Ustolls are dry Mollisols. Likewise, soils in the Udults suborder (from the Latin *udus*, humid) are moist Ultisols.

**Great Groups**

The great groups are subdivisions of suborders. More than 400 great groups are recognized. They are defined largely by the presence or absence of diagnostic horizons and the arrangements of those horizons. These horizon designations are included in the list of formative elements for the names of great groups shown in Table 3.5. Note that these formative elements refer to epipedons such as umbric and ochric (see Table 3.1 and Figure 3.3), to subsurface horizons such as argillic and natric, and to certain diagnostic impervious layers such as duripans and fragipans (see Figure 3.30).

Remember that the great group names are made up of these formative elements attached as prefixes to the names of suborders in which the great groups occur. Thus, Ustolls with a natric horizon (high in sodium) belong to the Natrustolls great group. As can be seen in the example discussed in Box 3.2, soil descriptions at the great group level can provide important information not indicated at the higher, more general levels of classification.

The names of selected great groups from two orders are given in Table 3.6. This list illustrates again the usefulness of *Soil Taxonomy*, especially the nomenclature it employs. The names identify the suborder and order in which the great groups occur. Thus, Argiudolls are Mollisols of the Udolls suborder characterized by an argillic horizon. Cross-reference to Table 3.5 identifies the specific characteristics separating the great group classes from each other.

Note from Table 3.6 that not all possible combinations of great group prefixes and suborders are used. In some cases a particular combination does not exist. For example, Aquolls occur in lowland areas but not on very old landscapes. Hence, there are no “Paleaquolls.” Also, since all Ultisols contain an argillic horizon, the use of terms such as “Argiudults” would be redundant.
Subgroups

Subgroups are subdivisions of the great groups. More than 2500 subgroups are recognized. The central concept of a great group makes up one subgroup, termed Typic. Thus, the Typic Hapludoll subgroup typifies the Hapludoll great group. Other subgroups may have characteristics that intergrade between those of the central concept and soils of other orders, suborders, or great groups. A Hapludoll with restricted drainage would be classified as an Aquic Hapludoll. One with evidence of intense earthworm activity would fall in the Vermic Hapludolls subgroup. Some intergrades may have properties in common with other orders or with other great groups. Thus, soils in the Entic Hapludolls subgroup are very weakly developed Mollisols, close to being in the Entisols order. The subgroup concept illustrates very well the flexibility of this classification system.

### TABLE 3.5 Formative Elements for Names of Great Groups and Their Connotation

These formative elements combined with the appropriate suborder names give the great group names.

<table>
<thead>
<tr>
<th>Formative element</th>
<th>Connotation</th>
<th>Formative element</th>
<th>Connotation</th>
<th>Formative element</th>
<th>Connotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>acr</td>
<td>Extreme weathering</td>
<td>fol</td>
<td>Mass of leaves</td>
<td>petr</td>
<td>Cemented horizon</td>
</tr>
<tr>
<td>agr</td>
<td>Agric horizon</td>
<td>fragi</td>
<td>Fragipan</td>
<td>plac</td>
<td>Thin pan</td>
</tr>
<tr>
<td>al</td>
<td>High aluminum, low iron</td>
<td>fragloss</td>
<td>Combination of fragi and gloss</td>
<td>plagg</td>
<td>Plaggen horizon</td>
</tr>
<tr>
<td>alb</td>
<td>Albic horizon</td>
<td>fulv</td>
<td>Light-colored melanic horizon</td>
<td>plinth</td>
<td>Plinthite</td>
</tr>
<tr>
<td>and</td>
<td>Ando-like</td>
<td>gyps</td>
<td>Gypsic horizon</td>
<td>quartz</td>
<td>High quartz</td>
</tr>
<tr>
<td>anhy</td>
<td>Anhydrous</td>
<td>gloss</td>
<td>Tongue</td>
<td>psammi</td>
<td>Sand texture</td>
</tr>
<tr>
<td>aqu</td>
<td>Water saturated</td>
<td>hal</td>
<td>Salty</td>
<td>rhod</td>
<td>Dark red colors</td>
</tr>
<tr>
<td>argi</td>
<td>Argilllic horizon</td>
<td>hapl</td>
<td>Minimum horizon</td>
<td>sal</td>
<td>Salic horizon</td>
</tr>
<tr>
<td>calc, calci</td>
<td>Calcic horizon</td>
<td>hem</td>
<td>Intermediate decomposition</td>
<td>sapr</td>
<td>Most decomposed</td>
</tr>
<tr>
<td>camb</td>
<td>Cambic horizon</td>
<td>hist</td>
<td>Presence of organic materials</td>
<td>somb</td>
<td>Dark horizon</td>
</tr>
<tr>
<td>chrom</td>
<td>High chroma</td>
<td>hum</td>
<td>Humus</td>
<td>sphagn</td>
<td>Sphagnum moss</td>
</tr>
<tr>
<td>cry</td>
<td>Cold</td>
<td>hydr</td>
<td>Water</td>
<td>sulf</td>
<td>Sulfuric</td>
</tr>
<tr>
<td>dur</td>
<td>Duripan</td>
<td>kand</td>
<td>Low-activity 1:1 silicate clay</td>
<td>torr</td>
<td>Usually dry and hot</td>
</tr>
<tr>
<td>dystr, dys</td>
<td>Low base saturation</td>
<td>lithic</td>
<td>Near stone</td>
<td>ud</td>
<td>Humid climates</td>
</tr>
<tr>
<td>endo</td>
<td>Fully water saturated</td>
<td>luv, lu</td>
<td>Illuvial</td>
<td>umbr</td>
<td>Umbric epipedon</td>
</tr>
<tr>
<td>epi</td>
<td>Perched water table</td>
<td>melan</td>
<td>Melanic epipedon</td>
<td>ust</td>
<td>Dry climate, usually hot in summer</td>
</tr>
<tr>
<td>eutr</td>
<td>High base saturation</td>
<td>molli</td>
<td>With a mollic epipedon</td>
<td>vern</td>
<td>Verm, or mixed by animals</td>
</tr>
<tr>
<td>ferr</td>
<td>Iron</td>
<td>natr</td>
<td>Presence of a natic horizon</td>
<td>xir</td>
<td>Glass</td>
</tr>
<tr>
<td>fibr</td>
<td>Least decomposed</td>
<td>pale</td>
<td>Old development</td>
<td>xer</td>
<td>Dry summers, moist winters</td>
</tr>
<tr>
<td>fluv</td>
<td>Floodplain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 3.30** A forested fragiudalf in Missouri containing a typical well-developed fragipan with coarse prismatic structure (outlined by gray, iron-depleted coatings). Fragipans (usually Bx or Cx horizons) are extremely dense and brittle. They consist mainly of silt, often with considerable sand, but not very much clay. One sign of encountering a fragipan in the field is the ringing noise that your shovel will make when you attempt to excavate it. Digging through a fragipan is almost like digging concrete. Plant roots cannot penetrate this layer. Yet, once a piece of a fragipan is broken loose, it fairly easily crushes with hand pressure. It does not squash or act in a plastic manner as a claypan would; instead, it bursts in a brittle manner. (Photo courtesy of Fred Rhoton, Agricultural Research Service, U.S. Department of Agriculture)
Soil Taxonomy is a communications tool that helps scientists and land managers share information. In this box we will see how misclassification, even at a lower level in Soil Taxonomy, such as the great group, can have costly ramifications.

In order to preserve our historical and prehistorical heritage, laws require that an archaeological impact statement be prepared prior to starting major construction work on the land. The archaeological impact is usually assessed in three phases. Selected sites are then studied by archaeologists, with the hope that at least some of the artifacts can be preserved and interpreted before construction activities obliterate them forever. Only a few relatively small sites can be subjected to actual archaeological digs because of the expensive skilled hand labor involved (Figure 3.31).

Such an archaeological impact study was ordered as a precursor to construction of a new highway in a mid-Atlantic state. In the first phase, a consulting company gathered soils and other information from maps, aerial photographs, and field investigations to determine where neolithic people may have occupied sites. Then the consultants identified about 12 ha of land where artifacts indicated significant neolithic activities. The soils in one area were mapped mainly as Typic Dystrudepts. These soils formed in old colluvial and alluvial materials that, many thousands of years ago, had been along a riverbank. Several representative soil profiles were examined by digging pits with a backhoe. The different horizons were described, and it was determined in which horizons artifacts were most likely to be found. What was not noted was the presence in these soils of a fragipan, a dense, brittle layer that is extremely difficult to excavate using hand tools.

A fragipan is a subsurface diagnostic horizon used to classify soils, usually at the great group or subgroup level (see Figure 3.30). Its presence would distinguish Fragiudepts from Dystrudepts.

When it came time for the actual hand excavation of sites to recover artifacts, a second consulting company was awarded the contract. Unfortunately, their bid on the contract was based on soil descriptions that did not specifically classify the soils as Fragiudepts—soils with very dense, brittle, hard fragipans in the layer that would need to be excavated by hand. So difficult was this layer to excavate and sift through by hand that it nearly doubled the cost of the excavation—an additional expense of about $1 million. Needless to say, there ensued a controversy as to whether this cost would be borne by the consulting firm that bid with faulty soils data, the original consulting firm that failed to adequately describe the presence of the fragipan, or the highway construction company that was paying for the survey.

This episode gives us an example of the practical importance of soil classification. The formative element Fragi in a soil great group name warns of the presence of a dense, impermeable layer that will be very difficult to excavate, will restrict root growth (often causing trees to topple in the wind or become severely stunted), may cause a perched water table (epiaquic conditions), and will interfere with proper percolation in a septic drain field.
Families

Within a subgroup, soils fall into a particular family if, at a specified depth, they have similar physical and chemical properties affecting the growth of plant roots. About 8000 families have been identified. The criteria used include broad classes of particle size, mineralogy, cation exchange activity of the clay, temperature, and depth of the soil penetrable by roots. Table 3.7 gives examples of the classes used. Terms such as loamy, sandy, and clayey are used to identify the broad particle-sized classes. Terms used to describe the mineralogical classes include smectitic, kaolinitic, siliceous, carbonatic, and mixed. The clays are described as superactive, active, semiactive, or subactive with regard to their capacity to hold cations. For temperature classes, terms such as cryic, mesic, and thermic are used. The terms shallow and micro are sometimes used at the family level to indicate unusual soil depths.

Thus, a Typic Argiudoll from Iowa, loamy in texture, having a mixture of moderately active clay minerals and with annual soil temperatures (at 50 cm depth) between 8 and 15°C, is classed in the Typic Argiudolls loamy, mixed, active, mesic family. In contrast, a sandy-textured Typic Haplorthod, high in quartz and located in a cold area in eastern Canada, is classed in the Typic Haplorthods sandy, siliceous, frigid family (note that clay activity classes are not used for soils in sandy textural classes).

TABLE 3.7 Some Commonly Used Particle-Size, Mineralogy, Cation Exchange Activity, and Temperature Classes Used to Differentiate Soil Families

The characteristics generally apply to the subsoil or 50 cm depth. Other criteria used to differentiate soil families (but not shown here) include the presence of calcareous or highly aluminium toxic (allic) properties, extremely shallow depth (shallow or micro), degree of cementation, coatings on sand grains, and the presence of permanent cracks.

<table>
<thead>
<tr>
<th>Soil temperature regime class</th>
<th>Cation exchange activity class&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mean annual between summer and winter</th>
<th>&gt;6°C difference between summer and winter</th>
<th>&lt;6°C difference between summer and winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashy</td>
<td>Mixed</td>
<td>Subactive</td>
<td>0.60</td>
<td>&lt;−10</td>
</tr>
<tr>
<td>Fragmental</td>
<td>Micaceous</td>
<td>Active</td>
<td>0.4 to 0.6</td>
<td>−4 to −10</td>
</tr>
<tr>
<td>Sandy-skeletal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Siliceous</td>
<td>Semiactive</td>
<td>0.24 to 0.4</td>
<td>+1 to −4</td>
</tr>
<tr>
<td>Sandy</td>
<td>Kaolinitic</td>
<td>Subactive</td>
<td>&lt;0.24</td>
<td>&lt;+8</td>
</tr>
<tr>
<td>Loamy</td>
<td>Smectctic</td>
<td>Superactive</td>
<td>0.60</td>
<td>&gt;+8</td>
</tr>
<tr>
<td>Clayey</td>
<td>Gibbritic</td>
<td>Active</td>
<td>0.4 to 0.6</td>
<td>+8 to +15</td>
</tr>
<tr>
<td>Fine-silty</td>
<td>Gypsic</td>
<td>Semiactive</td>
<td>0.24 to 0.4</td>
<td>+15 to +22</td>
</tr>
<tr>
<td>Fine-loamy</td>
<td>Carbonic</td>
<td>Subactive</td>
<td>&lt;0.24</td>
<td>&gt;+22</td>
</tr>
</tbody>
</table>

<sup>a</sup> Skeletal refers to presence of up to 35% rock fragments by volume.

<sup>b</sup> Cation exchange activity class is not used for taxa already defined by low CEC (e.g., kandic or oxic groups).

<sup>c</sup> Permatrost present.

<sup>d</sup> Frigid is warmer in summer than cryic.
**Series**

The series category is the most specific unit of the classification system. It is a subdivision of the family, and each series is defined by a specific range of soil properties involving primarily the kind, thickness, and arrangement of horizons. Features such as a hard pan within a certain distance below the surface, a distinct zone of calcium carbonate accumulation at a certain depth, or striking color characteristics may aid in series identification.

In the United States, each series is given a name, usually from some town, river, or lake such as Fargo, Muscatine, Cecil, Mohave, or Ontario. There are about 23,000 soil series in the United States.

The complete classification of a Mollisol, the Kokomo series, is given in Figure 3.32. This figure illustrates how *Soil Taxonomy* can be used to show the relationship between the soil, a comprehensive term covering all soils, and a specific soil series. The figure deserves study because it reveals much about the structure and use of *Soil Taxonomy*. If a soil series name is known, the complete *Soil Taxonomy* classification of the soil may be found on the Internet at the URL in the margin. Box 3.3 illustrates how soil taxonomic information can assist in understanding the nature of a landscape such as shown in Figure 3.33.

**3.18 CONCLUSION**

The soil that covers the Earth is actually comprised of many individual soils, each with distinctive properties. Among the most important of these properties are those associated with the layers, or horizons, found in a soil profile. These horizons reflect the physical, chemical, and biological processes soils have undergone during their development. Horizon properties greatly influence how soils can and should be used.

Knowledge of the kinds and properties of soils around the world is critical to humanity’s struggle for survival and well-being. A soil classification system based on
In real-world landscapes, different soils exist alongside each other, often in complex patterns. Adjacent soils on a tract of land may belong to different families, subgroups, great groups, or even different soil orders. Figure 3.33 depicts a landscape in a humid temperate region (Iowa) where 2 to 7 m of loess overlies leached glacial till and the native vegetation was principally tall grass prairie interspersed with small areas of trees. This landscape demonstrates how diagnostic horizons and other features of soil taxonomy are used to organize soils information. It also highlights the relationships among soils that allow us to make soil maps and interpret geographic soils information to help in planning projects on the land (see Chapter 19).

Seven soil map units are shown in the block landscape diagram, along with a profile diagram for the dominant soil series in each map unit. The soils include two Alfisols (Fayette and Downs) and five Mollisols (Tama, Wabash, Dinsdale, Muscatine, and Garwin). The particular set of soil horizons present in each profile relates to the (1) parent material, (2) vegetation, and (3) topography and drainage. Find the Dinsdale and Tama soils and notice where they occur in the landscape. The Dinsdale soil differs from the Tama because two parent materials (loess and glacial till) contributed to the Dinsdale profile, but the Tama soil is found where the loess layer by itself is thick enough to accommodate the entire profile. Both the Tama and Fayette soils exhibit argillic B horizons, but the Fayette has a thin ochric epipedon and a bleached albic horizon because it formed under forest vegetation, while the Tama has a thick mollic epipedon because it formed under grassland vegetation. The influence of topography can be seen by noting that soils on concave or level positions (the Garwin and Muscatine soils, which have slopes ranging from 0 to 1% and 1 to 3%, respectively) are wetter and less permeable than those on the steeper slopes (Tama and Dinsdale soils). In the less sloping, wetter soils, restricted drainage has retarded the development of an argillic horizon, so that only a gleyed (waterlogged) cambic B horizon (Bg) is present.

Are these relationships reflected in the soil taxonomy names? Note that the formative element aqu appears in the taxonomic name of the three wetter soils. Aqu appears at the suborder level (Endoaquolls) for the very wet, poorly drained soils, but only at the subgroup level for the less wet, somewhat poorly drained soil (Aquic Hapludoll). The formative element argi is used in the name of two soils (Argiudolls) to indicate that enough clay has accumulated in the B horizon of these Mollisols to develop into an argillic diagnostic horizon. Argi does not appear in the names of the two Alfisols, because an accumulation of clay (argillic or similar horizon) is a required feature of all Alfisols. Subgroup modifiers also provide important information about the interrelationships of these soils in the landscape. For example, the modifier Cumulic indicates that the Wabash soil has an unusually thick mollic epipedon because soil material washing off the uplands and carried by local streams has accumulated in the low-lying floodplains where this soil is found. The modifier Mollic used for the Downs soil indicates that this soil is transitional between the Alfisols and Mollisols, the A horizon in the Downs soils being slightly too thin to classify as a mollic epipedon.
these properties is equally critical if we expect to use knowledge gained at one
location to solve problems at other locations where similarly classed soils are found. Soil
Taxonomy, a classification system based on measurable soil properties, helps fill this
need in more than 50 countries. Scientists constantly update the system as they
learn more about the nature and properties of the world’s soils and the relationships
among them. In the remaining chapters of this book we will use taxonomic names
whenever appropriate to indicate the kinds of soils to which a concept or illustration
may apply.

STUDY QUESTIONS

1. Diagnostic horizons are used to classify soils in Soil Taxonomy. Explain the dif-
ference between a diagnostic horizon (such as an argillic horizon) and a genetic
horizon designation (such as a Bt1 horizon). Give a field example of a diagnos-
tic horizon that contains several genetic horizon designations.

2. Explain the relationships among a soil individual, a polypedon, a pedon, and a
landscape.

3. Rearrange the following soil orders from the least to the most highly weathered:
Oxisols, Alfisols, Mollisols, Entisols, and Inceptisols.

4. What is the principal soil property by which Ultisols differ from Alfisols?
Inceptisols from Entisols?

5. Use the key given in Figure 3.11 to determine the soil order of a soil with the
following characteristics: a spodic horizon at 30 cm depth, permafrost at 80 cm
depth. Explain your choice of soil order.

6. Of the five soil-forming factors discussed in Chapter 2 (parent material, climate,
organisms, topography, and time), choose two that have had the dominant
influence on developing soil properties characterizing each of the following soil
orders: Vertisols, Mollisols, Spodosols, and Oxisols.

7. To which soil order does each of the following belong: Psamments, Udolls,
Argids, Udepts, Fragiuudalfs, Haplustox, and Calciusterts.

8. What’s in a name? Write a hypothetical soil profile description and land-use
suitability interpretation for a hypothetical soil that is classified in the Aquic
Argixerolls subgroup.

9. Explain why Soil Taxonomy is said to be a hierarchical classification system.

10. Name the soil taxonomy category and discuss the engineering implications of
these soil taxonomy classes: Aquic Paleudults, Fragiuudults, Haplusterts, Sapristts,
and Turbels.

REFERENCES

and management of soil and land resources in indigenous communities:
Ethnopedology at global, regional and local scales,” Catena 65:118–137.
Characteristics and impacts on society,” Advances in Agronomy 17:289–375.
Ditzler, C. A. 2005. “Has the polypedon’s time come and gone?” HPSSS Newsletter,
February 2005, pp. 8–11. Commission on History, Philosophy and Sociology of Soil
(verified 20 October 2005).
desk reference. CRC Press, Boca Raton, FL.
Riecken, F. F., and G. D. Smith. 1949. “Principal upland soils of Iowa, their occurrence
and important properties,” Agron 49 (revised). Iowa Agr. Exp. Sta.


