2 Concepts of Soil Formation and Soil Survey

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2.1 Soil Formation

2.1.1 Factors of Soil Formation

One of the earliest concepts in soil science is that soil formation is influenced by five factors: parent material, climate, topography, organisms, and time. These factors were first identified by V.V. Dokuchaev in the late 1800s as he inventoried soils of the Russian steppes. They were popularized in the USA by the book, *The Factors of Soil Formation*, in which Jenny (1941) sought mathematical expressions of soil formation based on the variables he referred to as cl, o, r, p, and t (climate, organisms, relief, parent material, and time). These variables provide an effective context for considering soil formation.

Humans have had considerable influence on soils for thousands of years, but this influence has vastly increased since the beginning of the twentieth century. Now extensive areas of soils worldwide have been irrevocably altered. Because of their huge impact on soils, humans have been considered as a specific agent of soil formation (Amundson and Jenny 1991) and soil change (Chap. 18).

2.1.1.1 Parent Material

The initial material from which soils form is considered the parent material. In the case of Histosols (organic soils), the parent material is plant debris, but for most soils, it is mineral matter. The parent material may be solid rock that weathers in place to form soil (Fig. 2.1), or it may be transported and deposited before having soils form in it (Fig. 2.2). Transported parent materials include those deposited by running water (alluvium), gravity (colluvium), glaciers (till), wind (loess, aeolian sand), and volcanic eruptions (tephra). In certain parts of the country, it is common to find soils with loess, tephra, or other deposits on top of soils formed from other parent materials. In these cases, the soils form in two parent materials: one below and one above (Fig. 2.3).

In any case, the parent material provides the geochemical foundation of the soil. The minerals that compose the parent material are the sources of elements that serve as nutrients for plants or precipitate as clay minerals. A parent material that lacks certain elements may limit the nutrient status of the soils that form from it as well as the kinds of minerals that can form by weathering. For example, ultramafic rock contains high levels of Fe, Mg, and Si, but very low levels of Ca, K, and Al. As a result, the soils support distinctive vegetation communities adapted to low Ca:Mg ratios and minimal K. The silicate clays that form in the soils are enriched in Mg or Fe rather than Al.

Likewise, the parent material limits the textural range of the soils derived from it. Soil textures are typically finer than the grain sizes of the original parent material because weathering reduces the size of the original grains and precipitates clay-size material, thus reducing the grain size overall. Coarse soil textures result from parent materials such as sandstones and granites (Fig. 2.4) that have sand-size quartz grains, which are resistant to weathering. Fine textures result from sediments that are already clay- and silt-rich, such as shale (Fig. 2.5), or rocks that are composed of easily weathered primary minerals, such as basalt.

2.1.1.2 Climate

The influence of climate on soil formation is largely through the combined effects of water and temperature, although wind and solar radiation also play important roles.

Water, delivered to the soil as rain, snowmelt, or fog drip, is required for weathering, biological activity, and the transport of materials through soils. The disposition of water in soils can be considered using the water balance relationship:

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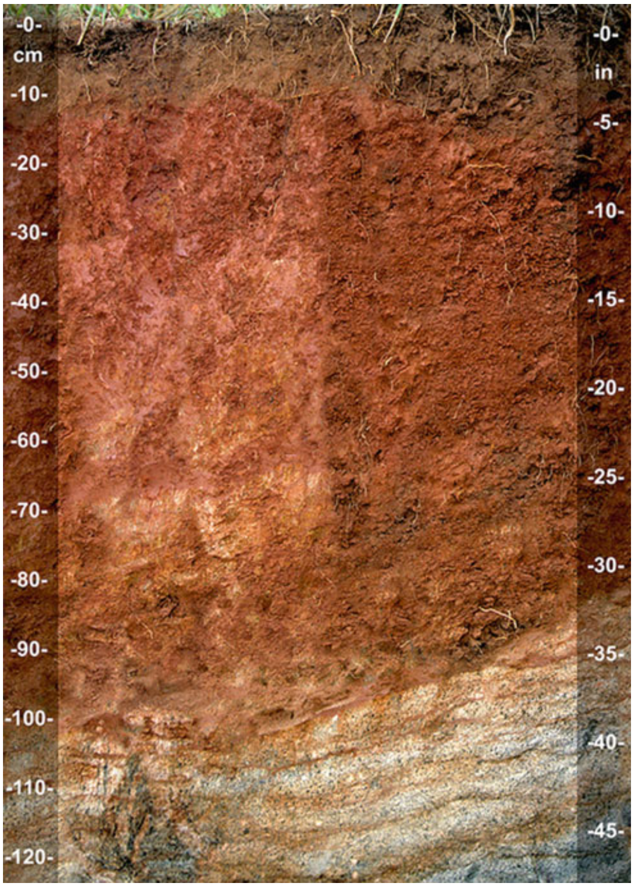

Fig. 2.1 An Ultisol (Bethlehem series) formed from the in situ weathering of schist bedrock on the North Carolina Piedmont. The 10–60 cm depth zone is a kandic horizon and is red due the pigmentation of hematite, an iron oxide. The zone below 100 cm is saprolite (bedrock so thoroughly altered by weathering that it is soft and clay enriched). Photograph credit: John A. Kelley, Soil Scientist, USDA-NRCS

$$\begin{aligned}\text{Change in storage in the soil} &= \text{Precipitation} - \text{Runoff}\\ &\quad - \text{Evapotranspiration}\\ &\quad - \text{Deep percolation}\end{aligned}$$

The water stored in the soil is available for weathering reactions and biological activity, and the influx of water to fill the storage moves materials through the soil in solution and suspension.

Both runoff and deep percolation are dependent on properties of the soil itself. Runoff occurs when water is unable to infiltrate into the soil, either because all of the pores are already filled with water, or because the pores are too few, small, or unconnected to allow infiltration at a rate that can accommodate the rainfall or snowmelt. Deep percolation occurs when more water infiltrates into the whole soil volume than it can retain against the force of gravity. A soil's water-holding capacity varies with texture, such that sandy soils hold less water and have more deep percolation than clayey soils.

Fig. 2.2 An Entisol formed in a debris flow deposit in the San Bernardino Mountains, California. The pine needles, twigs, and other plant parts that compose the O horizon at the surface become more decomposed with depth. Photograph credit: Judith Turk

Fig. 2.3 An Aridisol near Quartzsite, Arizona. Desert pavement overlies a V horizon with columnar structure that formed in eolian dust (0–6 cm depth), which overlies a B horizon formed in alluvium. Photograph credit: Judith Turk

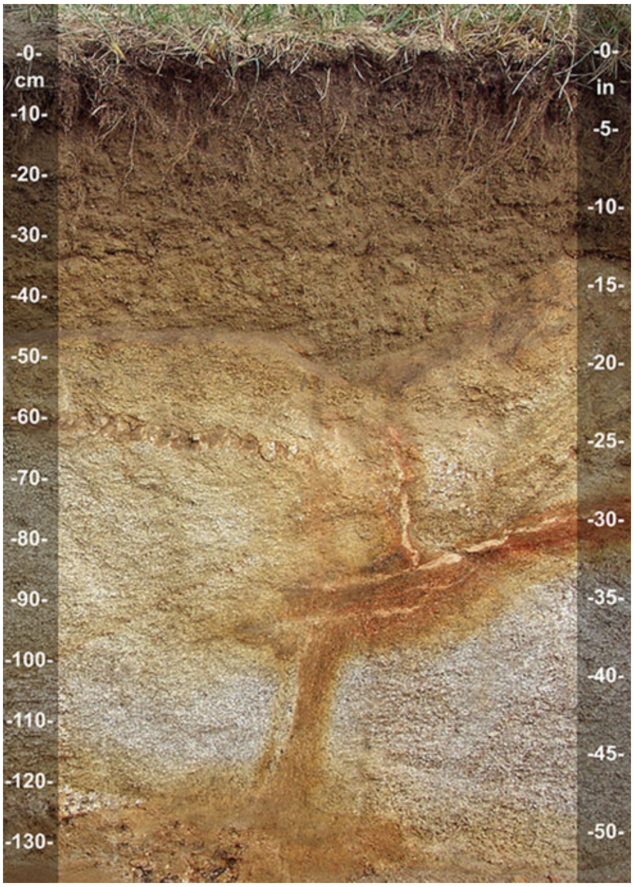

Fig. 2.4 An Entisol (Wake series) formed from weathering of granite on the North Carolina Piedmont. The soil textures above 50 cm are sandy, and below this depth is saprock (bedrock softened by weathering, but not thoroughly altered). Photograph credit: John A. Kelley, Soil Scientist, USDA-NRCS

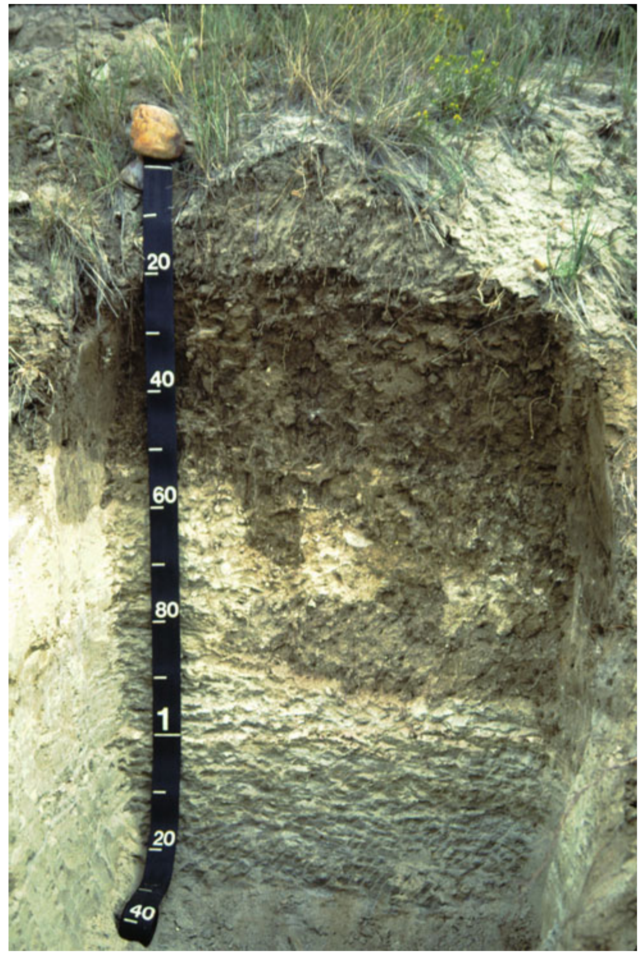

Fig. 2.5 A Mollisol formed from the weathering of shale near Laramie, Wyoming. The A horizon is darkened by humified organic matter from the decomposition of grass roots and other plant parts. The dark, organic-rich soil material is redistributed to the 90 cm depth by burrowing animals (note the backfilled burrows). Photograph credit: R. C. Graham

Precipitation and evapotranspiration are the climatic variables in the water balance equation. The balance between the input of water (precipitation) and its loss to the atmosphere (evapotranspiration) defines the climatic effect on soil moisture. Four climate-dependent soil moisture regimes recognized by the USDA soil taxonomic system are shown in Fig. 2.6. A udic soilmoisture regime occurs mainly in the midwestern and eastern states where precipitation input is greater than evapotranspiration losses, such that deep leaching is expected. The ustic soil moisture regime is mostly in the Plains states where a moderate soil water deficit exists. The aridic soil moisture regime reflects a strong water deficit with no deep leaching and is common in the western states. The xeric soil moisture regime is unique in that it defines soils that are moist in the winter, even to the point of being strongly leached, but are dry during the summer. These soils are mostly in California and Oregon. The aquic soil moisture regime, also shown in Fig. 2.6, is more related to topographic conditions than strictly climate. Aquic soils are found in low-lying areas where the water table is high so that at some time during the year reducing conditions prevail. As a result, these soils generally have reducing conditions and concentrations of iron oxides and an accumulation of organic matter (Fig. 2.7).

Climate dictates soil temperature as well as soil moisture, and temperature affects the rates of chemical and biological reactions in soils. In general, chemical reactions increase exponentially with increasing temperature, so weathering of minerals to produce clays and iron oxides is vastly increased in warm climates (e.g., Hawaii) compared to cold climates (e.g., Alaska), assuming moisture is available. A notable exception is calcite ($CaCO_3$), a common soil mineral. Calcite is more soluble at low temperatures; thus, all else being equal, it is more likely to precipitate and be present in soils with high temperatures.

Soil biological activity is generally minimal below about 5 °C and increases rapidly to the 30–37 °C range, above

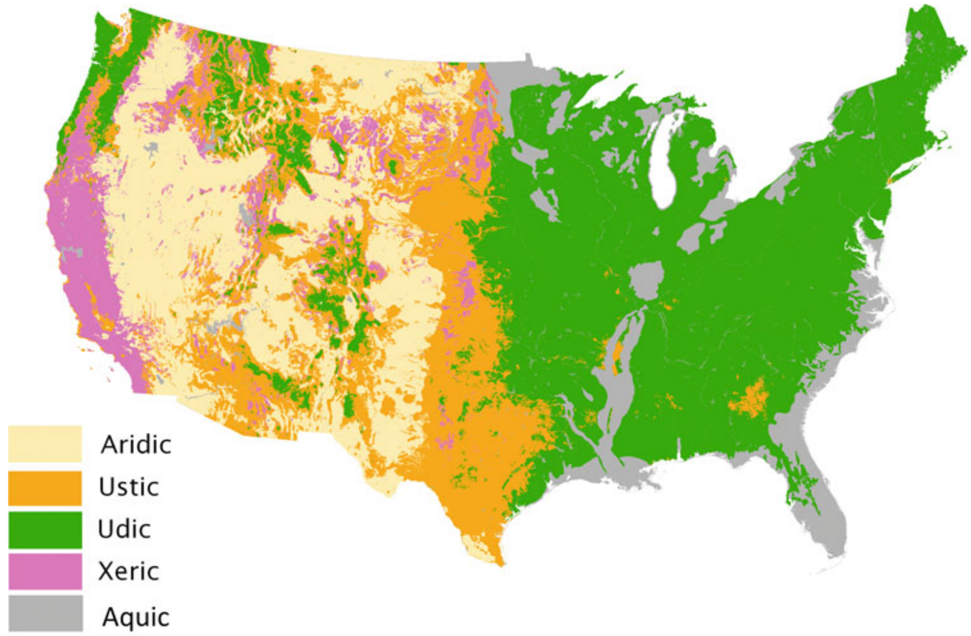

Fig. 2.6 Map of the distribution of soil moisture regimes in the contiguous USA (based on Winzeler et al. 2013)

Fig. 2.7 An Ultisol with an aquic soil moisture regime (Paxville series) formed in a poorly drained depression on a broad interstream divide on the middle Coastal Plain of North Carolina. The 43–120 cm depth is an argillic horizon with gray redox depletions and yellow–red redox concentrations. The A horizon (above the 27 cm depth) is darkened by humified organic matter. Photograph credit: R.C. Graham

which it drops precipitously. Such high temperatures are not sustained in soils, except those influenced by geothermal conditions, but very low soil temperatures are common at high latitudes and altitudes. The inhibitory effect of low temperatures on microbial activity decreases organic matter decomposition rates and results in organic matter accumulation in cold soils. Thus, soils of higher latitudes (and altitudes) generally contain more organic matter than those at low latitudes (and altitudes).

Temperatures within the upper 50 cm, or so, of soil are subject to diurnal fluctuation and are affected by variations in day-to-day weather conditions. Yet, it is the cumulative effect of soil temperature that determines the overall rates of organic matter decomposition and mineral weathering, thereby making a visible imprint on the soil morphology. Thus, soils of higher latitudes tend to be darker in color due to organic matter accumulation and soils of low latitudes tend to be redder due to enhanced weathering and iron oxide (hematite) formation (Fig. 2.1).

Wind is an aspect of climate that impacts soil formation through its role in erosion and deposition. Wind erosion occurs on dry, bare soils, such as those found on glacial outwash, playas, and post-wildfire landscapes. Of course, wind erosion can also occur on soils that are laid bare by human activities such as plowing and over grazing. Severe windstorms can uproot trees over large areas, especially when the soil has lost cohesive strength because it is saturated with water. When the trees fall over, a volume of soil is lifted up by the roots, mixing the soil horizons. Sometimes, large areas of forest are affected so that the soils are essentially plowed by this "tree throw."

Solar radiation is an important climatic factor in soil formation in that it drives photosynthesis that fixes carbon in organic matter, some of which is ultimately incorporated into the soil. Solar radiation is the overall source of heat flux to the soil.

2.1.1.3 Topography

The shape of the land's surface, or topography, influences how water flows onto and off of the soil, as well as how it moves into and through the soil. Consequently, it exerts a strong control on the balance between soil organic matter additions and decomposition, erosion and deposition, leaching and accumulation, and even oxidation and reduction. Topography is formed by depositional features, such as lava flows, moraines, alluvial fans, and dunes, and by geologic erosion, such as stream incision, glaciation, and mass wasting.

Slope shape determines the disposition of water on the landscape. On nearly level surfaces, water flow is largely vertical, into the soil, so runoff and run-on are minimal and so are erosion and deposition. Thus, nearly level land surfaces, such as stream terraces and broad hill summits, are stable locations for prolonged soil development. On the other hand, sloping land removes water from one part of the landscape and delivers it to another. A linear slope simply delivers water from upper slope positions to lower slopes, making these lower slope positions moister than one would infer from the climate. Slopes that are convex across and downslope, such as the nose of a ridge, disperse water flow and are the driest parts of the landscape (Fig. 2.8). Soils are less leached than on other landscape positions, and vegetation density is relatively low; hence, organic matter additions to the soil are also low. Slopes that are concave across and downslope, such as the head slope of a watershed, concentrate water flow so that the lower slopes of these places are the wettest parts of the landscape (Fig. 2.8). As a result, the soils tend to have the highest organic matter contents and

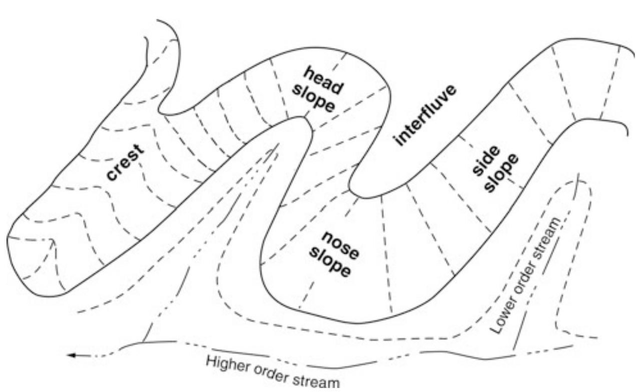

Fig. 2.8 Simplified diagram of landscape components (modified from Schoeneberger et al. 2012)

may experience reducing conditions, at least periodically, qualifying them as having an aquic soil moisture regime or placing them in aquic subgroup classifications.

Topography also introduces localized variations in soil climate, most commonly in the form of slope aspect. In the Northern Hemisphere, south-facing slopes most directly intercept the sun's rays and, consequently, are warmer and drier than north-facing slopes. Because they are cooler and moister, soils on north-facing slopes tend to contain more organic matter than those on other slope orientations.

2.1.1.4 Organisms

Soils provide habitats for a multitude of organisms, and these plants, animals, and microbes strongly impact the soils as well. Plants are primary producers, acquiring carbon from the atmosphere by photosynthesis. They also scavenge the soil for mineral-derived elements (calcium, magnesium, potassium, phosphorus, etc.), and some have symbiotic relationships with bacteria that obtain nitrogen from the atmosphere. All of the elements that plants incorporate into their biomass are added to the soil via biocycling, so soil A horizons become enriched in carbon, nitrogen, and other nutrient ions. Plant roots also have direct impacts on soil physical properties as they create pores and promote soil aggregation.

Burrowing animals mix the soil, incorporating organic matter, homogenizing soil horizons, and converting parent material into soil (Fig. 2.5). Burrowing animals, including earthworms, ants, gophers, and ground squirrels, create porosity for preferential water flow and root growth. Certain animals create distinctive soil structures, such as earthworm and cicada casts.

The integrated effects of organisms can be observed by comparing surface soil horizons developed under coniferous forest with those developed under grass. Much of the organic matter in coniferous forest soils is derived from foliage that falls from the trees. This material accumulates on the soil surface as an O horizon (Fig. 2.2) and, because it is largely unpalatable to earthworms and burrowing rodents, it is only slowly mixed into the underlying mineral soil. As a result, A horizons are relatively thin. In contrast, grassland soils have virtually no O horizon, but a profusion of fine roots in the near-surface zone contributes abundant organic matter. Roots and above ground plant material serve as food for gophers and other burrowing rodents, which, together with earthworms, mix the soil and create thick, dark A horizons (Fig. 2.5).

Aside from its essential role in the decomposition of organic matter, microbial activity alters soil morphology by reducing iron oxides in water-saturated soils where free oxygen is absent. The yellowish and reddish colors of iron oxides are replaced by the background gray colors of the silicate minerals as the iron is reduced and solubilized (Fig. 2.7).

2.1.1.5 Time

The environmental factors of climate, organisms, topography, and parent material must interact over a period of time to produce soil. The longer these factors are able to act together, the more developed and vertically differentiated and distinctive the soil will become. Thus, the stability of the soil landscape governs the duration of soil formation, and the character of the soil reflects how long the other environmental factors have exerted their influence.

Most landscapes in the USA have been stable (e.g., neither extensively eroded or deposited upon) for much less than a million years. The youngest soils are those formed on recently deposited sediments, such as floodplain alluvium, or very steep slopes with ongoing erosion. The oldest soils are those on long stable geomorphic features, such as alluvial terraces and lava flows. Soils that are tens of thousands of years old and older have generally experienced pronounced changes in climate and organisms over the course of their formation.

Glaciation has affected much of the northern USA and farther south in alpine regions such as the Rocky Mountains, the Cascade Range, and the Sierra Nevada. Glaciers wiped away previously formed soils and deposited fresh parent material (known as drift). In a sense, the clock for soil formation on glaciated landscapes was reset to zero corresponding to the most recent glacial deposits. The last major period of glaciation ended 11,700 years ago (the end of the Pleistocene Epoch), so many soils of high latitudes and altitudes are younger than this.

2.1.2 General Soil Processes

The environmental conditions defined by the five soil-forming factors generate processes that determine how soils function and develop. These processes can be generally categorized as those that cause additions, losses, translocations, and transformations within soils (Simonson 1959). The balance among these processes determines the soil behavior and observable characteristics.

2.1.2.1 Additions

The most notable addition to most soils is organic matter derived from plant parts (Fig. 2.2). Plant litter that falls on the surface of soils is broken down by insects, earthworms, fungi, and other decomposers and mixed into the mineral soil by burrowing animals, including ants, earthworms, and gophers. Organic matter is also added directly to the subsurface by plant roots, which can make up a large proportion of the total plant biomass. Roots are an especially large contributor of organic matter to grassland soils. If the rate of organic matter loss by decomposition is less than the rate of addition, then organic matter will accumulate in the soil, and a thick, dark A horizon will result (Figs. 2.5, 2.7 and 3.2), or in very cold or wet soils, the organic matter will accumulate to form thick O horizons.

Dust is a ubiquitous addition to soils in arid regions. It blows off of dry lakebeds and intermittent stream channels, incorporating very fine sand- and silt-size particles as well as various salts into atmospheric suspension. These materials are blown onto upland parts of the landscape where they are trapped by rough surfaces and incorporated into the soil surface to form a V horizon (Fig. 2.3). Dust originates from any bare surface with fine earth materials. While these conditions are common in deserts, they are also common on the margins of active glaciation. Dust is blown between continents, so, to some degree, all soils on earth receive at least a background input of dust.

Volcanic ash is another material added from the atmosphere. Thin deposits are incorporated into the underlying soil by mixing processes, but thick deposits bury existing soils and soil formation starts anew in the fresh volcanic deposit. In the USA, the influence of volcanic ash is strongest in the Pacific Northwest, Alaska, Hawaii, and the Pacific Islands, but volcanic ash from Cascade Range volcanoes has been deposited at least halfway across the North American continent.

Alluvial deposits added to floodplains build the soils upward and, again, if thin enough, are mixed into the existing soils. These alluvial additions are common on floodplains of major rivers across the country.

2.1.2.2 Losses

The most obvious process leading to loss from a soil is erosion, a process that can occur in any part of the country. Erosion can be by either water or wind, but both processes are facilitated by bare, poorly aggregated soil. Erosion removes the soil surface materials preferentially, and these surface horizons are usually the most enriched in organic matter and nutrients. Erosion not only reduces the overall soil thickness, but specifically removes the soil nutrient supply.

As water percolates through the soil, it carries materials in suspension (colloids) and in solution (ions, dissolved organic matter). If the water balance is such to allow deep percolation, these waterborne materials are carried down into groundwater or otherwise out of the soil zone. This form of loss from soils is most common in the humid regions of the USA, where precipitation greatly exceeds evapotranspiration. Ultimately, this process is depleting the soil of weathering products and is likely to result in the formation of Ultisols.

A less visible loss occurs during soil organic matter decomposition. As microbes decompose organic matter, they respire CO_2 gas. Thus, the loss of carbon from the soil during soil organic matter decomposition occurs through the gas phase and can be substantial on an annual basis—on the order of 200–1000 g m^{-2}, depending on the ecosystem (Raich and Potter 1995). This loss through decomposition is so great in warm, humid regions that organic matter accumulation in soils is minimal. Conversely, in cool regions, the carbon loss via CO_2 respiration is less than the rate of organic matter additions, so the soils become enriched in stored organic matter. When soils are saturated with water, organic matter decomposes slowly by anaerobic processes, and methane (CH_4) is released, not CO_2. The evolution of carbon as gas from decomposing organic matter represents not only a loss from the soil, but a very significant addition of greenhouse gases to the atmosphere. More carbon is stored in soils as organic matter than is contained in the atmosphere or vegetation, so this particular loss from soils is of special interest to climate change modelers.

2.1.2.3 Translocations

Translocations of materials from one part of the soil to another can result in distinctive soil horizons. Materials are commonly moved by water as it percolates through the soil. The zone from which materials are removed is termed the eluvial zone and the zone into which materials are translocated is known as the illuvial zone. Some of the commonly translocated materials and the horizons they form are addressed below.

Clay

Soils are composed of variously sized mineral particles, but the smallest, the clay-sized (<2 µm diameter) particles are most easily moved through the soil matrix. These colloidal particles can be physically dislodged by flowing water, but they are most effectively mobilized for transport if they are chemically dispersed. Chemical dispersion means that the clays electrostatically repel each other so they remain thoroughly suspended in the soil solution. This dispersion is enhanced with increasing pH, Na on the cation exchange sites, dilute soil solutions, and dissolved organic compounds.

Once clay is in suspension, it moves with the water as it percolates through the soil. The clay is deposited when the water stops moving in a lower part of the soil. Often, the water moves preferentially through macropores, such as root channels or cracks between soil structural units. As the suspension flows down through these pores, capillary forces pull the water into the matrix of the pore walls. When this happens, the clay is filtered out and remains as a "clay film" or "clay lining" on the pore wall surface. Clay can move through the micropores of the soil matrix as well, but just not as far or as fast. Over time, enough translocated clay accumulates in the subsoil to form a distinct horizon labeled as a Bt horizon or, according to Soil Taxonomy, an argillic, natric, or kandic horizon (Figs. 2.1, 2.7). These horizons are common in landscapes that have been stable long enough for significant amounts of clay to accumulate, which is often on the order of thousands of years. Considering that in many soils the clay must be produced by mineral weathering before it can be moved and that mineral weathering is much slower at low temperatures, it is uncommon to find argillic horizons in soils less than ten thousand years old or in very cold climates.

Fe- and Al-Humus Complexes

In certain soils, organic compounds are leached from vegetation and organic material on the soil surface (O horizons). As these dissolved organic molecules move through the soil, they act as chelates to bind with Fe and Al cations, strip them from minerals in the upper part of the soil (E horizon), and transport them in solution to a lower zone. As the organic molecules move through the soil, they pick up more Fe and Al until all their chelate sites are full, at which point they precipitate. The zone in which they precipitate and accumulate takes on a dark reddish-brown color and is known as a Bhs horizon, or a spodic horizon (Fig. 2.9. The organic matter in these horizons undergoes decomposition, losing carbon through microbial respiration, and releasing the Fe and Al to reprecipitate as oxides. Subsequent percolating dissolved chelates become adsorbed on these oxides, furthering the accumulation of organic-metal complexes.

This process operates best in sandy soils, through which water leaches readily. While most prevalent in the northern latitudes or high elevations, it also operates in soils with a fluctuating water table even in warm climates. Soils with spodic horizons are common in the northeastern states, the northern midwestern states, the Pacific Northwest, and along the Atlantic and Gulf coasts in the southeastern USA.

Calcite

As water percolates through the soil, CO_2 from microbial respiration and Ca from mineral weathering, rainfall, dust input, and other sources are dissolved in it. Under certain conditions, the dissolved carbonate and Ca will precipitate as calcite ($CaCO_3$). The most common cause of precipitation is concentration of the solution by evapotranspiration. In arid regions, rainfall is insufficient to cause deep leaching. Instead, percolating water carrying dissolved carbonate and Ca ions only reaches the subsoil. As the soil solution dries, calcite precipitates. As this process is repeated over thousands of years, a distinct subsoil zone of calcite accumulation forms, known as a Bk horizon, or calcic horizon (Figs. 2.10, 3.2). In its initial stages of formation, the calcite occurs as isolated white masses or filaments or as concentrations on the undersides of gravel. With the passage of time for more accumulation, the whole horizon becomes white with powdery calcite (Bkk horizon), and with even more

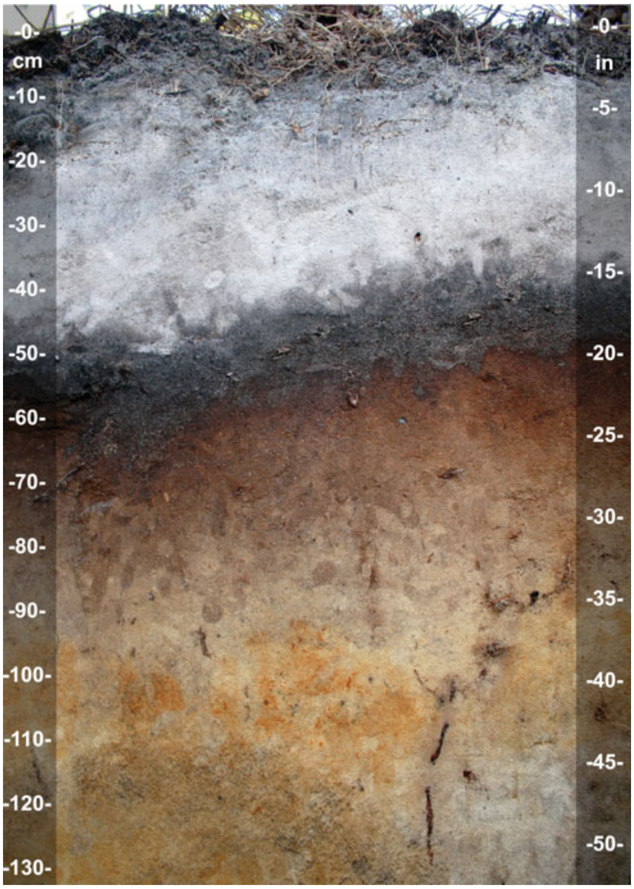

Fig. 2.9 A Spodosol (Leon series) formed in sandy marine sediments on the South Carolina coast at Baruch North Island Reserve. Chelates leached from the O horizon (upper 10 cm) have stripped iron and aluminum from the E horizon (10–40 cm depth). The metal-organic complexes are precipitated in the spodic horizon (50–70 cm). Photograph credit: John A. Kelley, Soil Scientist, USDA-NRCS

time (hundreds of thousands of years), the horizon becomes cemented by calcite so that it is rock hard. At this stage, it is indicated as a Bkkm, or petrocalcic, horizon (Fig. 2.10).

In arid regions, calcite is often added to the soil surface as dust, blowing in from other parts of the landscape. This calcite can be dissolved by infiltrating water and reprecipitated in the subsoil as described above.

Calcium carbonate can be precipitated in another way in moist soils. If CO_2 is lost as a gas from the soil solution, calcite will precipitate, much as it does to form stalactites in caves. This can happen when CO_2 is degassed from a high water table in the soil. A calcic horizon will form in the zone of the water table. These are the kinds of calcic horizons that can occur in the more humid parts of the country.

Soluble Salts

In arid regions, the amount of water supplied by rainfall is much less than can be lost by evapotranspiration. As a result,

Fig. 2.10 An Aridisol (Rotura series) near Las Cruces, New Mexico. An argillic horizon (30–70 cm depth) and a calcic horizon (70–110 cm) overlie a petrocalcic horizon (top at 110 cm). Photograph credit: Curtis Monger

leaching is insufficient to remove soluble salts from the soils. Furthermore, in some basins, capillary rise of groundwater reaches the surface and evaporation concentrates the dissolved salts so they precipitate as a fine powder or a crust on the soil surface (Fig. 2.11).

The ultimate source of the salts is the release of ions during rock weathering, often in more humid regions adjacent to the deserts. In the western US, mountain ranges receive much more precipitation than adjacent deserts. The dissolved ions are transported in solution either into groundwater or in surface streams, both of which flow to the topographic low position, e.g., a basin. Many basins in the western USA are dry lakebeds (playas) that were filled with water during the much wetter, cooler climate of the Pleistocene. The dissolved ions that reach the basins are precipitated as salts as the water dries, often from capillary rise to the surface. Salts on the surface in and around playas are blown with dust onto upland areas, such as alluvial fans and mountains, where infiltrating rainwater carries them into, but not out of, the soils. Over thousands of years, the salts accumulate in the subsoils of these upland soils. Sodium chloride is a common salt, but

Fig. 2.11 A salt crust on the surface of Black Rock Playa near Gerlach, Nevada. Note that the salt crust is only a few millimeters thick and can be scraped away to reveal moist soil material underneath

sulfates, nitrates, and carbonates are also common. When salts are sufficiently concentrated in the soil, the zone in which they are concentrated is called a salic horizon.

Amorphous Silica

Silica is released during the weathering of silicate minerals and volcanic ash. Under conditions of limited leaching, the silica is transported to the subsoil, but not leached entirely from the soil. Over thousands, or more often tens of thousands, of years, the silica precipitates and accumulates as opaline silica, cementing the subsoil to form a rock-hard duripan.

Mixing

While substances translocated by water can accumulate to form soil horizons, there are physical mixing processes in soils that can destroy or prevent those horizons from forming, while forming other types of horizons. Soils can be mixed by animals and plants (bioturbation), freezing and thawing (cryoturbation), and shrink–swell activity (pedoturbation).

Burrowing animals are very effective at mixing the soil. Earthworms, ants, termites, and crayfish are some invertebrates that burrow and move material around within the soil. Gophers and ground squirrels are mammals that move a large amount of soil during their activities. These animals often transport organic matter or A horizon material to some depth, thereby enriching the subsoil with organic matter (Fig. 2.5). Trees can mix the soil when they fall and their roots pull up a volume of soil material.

The expansion and contraction forces associated with the freezing and thawing of soil water mix the surface and subsurface materials of Gelisols into convoluted patterns. Likewise, clayey soils with a large component of swelling-type clays (smectite) can undergo on the order of 10–15 % volume change as they swell when wet and shrink when dry. The expansion–contraction forces involved, together with material falling into cracks that are open to the surface, are effective at mixing these Vertisols.

2.1.2.4 Transformation

During the course of soil formation, some materials are altered but not moved much within the soil. This is the case with mineral weathering. Weatherable minerals, such as feldspars, are often altered to clay minerals while still maintaining their original shape. Subsoil bedrock can be weathered such that its porosity increases and its hardness decreases, while its appearance as rock is maintained. The soft bedrock that results is called saprock (Fig. 2.4) or, if more thoroughly weathered, saprolite (Fig. 2.1).

Soil fabric can be altered by shrink–swell processes to produce distinct horizons of soil structure (Fig. 2.3). Soil color is altered by the production of iron oxides from the weathering of iron-bearing silicate minerals and by the concentrating effects of redox processes. When a soil is saturated with water, iron oxides are chemically reduced and dissolved, but they will reprecipitate in localized oxidized zones. The result is a matrix with gray zones (iron oxides reduced and removed) and reddish or orangish zones where iron oxides precipitated, often around root channels or sandy lenses (Fig. 2.12). Decomposing organic matter, as in soil O horizons, is altered in situ by microorganisms, converting plant parts to humus (Fig. 2.2).

2.2 Soil Survey

The imprint of the soil-forming factors and processes is reflected in the soils that occur on landscapes. The goal of soil survey is to model and record this imprint. The emphasis is on displaying the geographic distribution of soils and making predictions about the soils' behavior (Soil Survey Staff 1951; Soil Survey Division Staff 1993). Soil distributions are commonly displayed in hard copies or digital copies of soil maps, with associated soil descriptions, map

Fig. 2.12 Intact subsoil material from a soil formed in a wetland in Owens Valley, California. The gray matrix was depleted of iron oxides by reducing conditions, while iron oxides precipitated around the oxygenated root channel macropores

unit descriptions, and tabular data that can be used to make predictions about soil behavior. Other forms of presentation include hand-drawn and digital block diagrams that depict soil-landscape relationships and numerous forms of 3-D soil maps that can be generated as a combination of soil maps and digital elevation models.

2.2.1 Soils, Landscapes, and Soil-Landscapes—The Fundamentals of Soil Mapping and Soil Survey

Soils are landscapes as well as profiles (Soil Survey Staff 1951, pp. 5–8; Soil Survey Division Staff 1993, pp. 9–11), and an understanding of both are needed in mapping and depicting the geographic distribution of soils. For the purpose of this chapter, soil is defined as—the unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of climate, macro- and microorganisms, conditioned by relief, acting on parent material over a period of time (Soil Science Society of America 1997). The effects of the genetic and environmental factors are reflected in a soil profile, which is a vertical cut through the soil. A soil profile description (i.e., pedon description) is a record of the soil horizons and the soil properties associated with each horizon. The physical and chemical properties of the soil horizons and the occurrences of the soil horizons are used to classify and name the soils in *Soil Taxonomy* (Soil Survey Staff 1999). Applying *Soil Taxonomy* (Soil Survey Staff 1999) to label soil polygons in soil survey will be discussed in the next section of this chapter.

A landscape is a portion of the land surface that the eye can comprehend in a single view and is a collection of landforms (Ruhe 1969; Peterson 1981). The link between soils and landscapes are soil-landscape units. A soil-landscape unit can be thought of as a landscape unit (landscape, landform, or landform component) modified by one or more of the soil-forming factors (Soil Survey Staff 1999). Within a soil-landscape unit, the five factors of soil formation interact in a distinct manner, and as a result, areas of a soil-landscape unit have a relatively homogenous soil pattern (Soil Survey Staff 1999).

A soil surveyor observes and maps a geographic pattern of soils by grouping soils with similar genesis and separating soils where there is a change in one or more of the soil-forming factors. The soil groupings are shown as delineations (i.e., polygons) on a base map which is typically an aerial photograph or topographic map. There are numerous approaches to accomplishing the mapping and labeling of soil geographic patterns as polygons at various scales. The most common soil-landscape approaches used in US soil survey are presented in detail by Milne (1936), Jenny (1941), Hudson (1990, 1992), and Chap. 5 of *Soil Taxonomy* (Soil Survey Staff 1999).

2.2.2 Soil Survey: Scale, Labels, and Maps

Labeling soil map units (e.g., soil-landscape units) at the various scales is accomplished primarily by using the taxa within *Soil Taxonomy* (Soil Survey Staff 1999). The taxa for Soil Taxonomy are presented in Table 2.1. Chapter 3 of this book presents a more detailed coverage of soil properties, soil classification, and *Soil Taxonomy*.

Table 2.1 Soil classification taxa levels and the complete taxa for a phase of the Fayette Soil Series

Taxa	Example	Concept of group
Order	Alfisol	Soil-forming processes as indicated by the presence or absence of major horizons
Suborder	Udalf	May indicate soil features such as moisture condition, property of parent material or vegetation
Great Group	Hapludalf	Formulated by adding another syllable in front of the suborder to provide more information about the soil properties
Subgroup	Typic Hapludalf	Modifies the great group. Depicts a normal soil condition or special feature
Family	fine-loamy, mixed, mesic Typic Hapludalf	Soil properties such as texture, mineralogy, and temperature
Series	Fayette	Soils with very similar profiles
Type	Fayette silt loam	A subdivision of the soil series based on the texture of the surface soil
Phase	Fayette silt loam, nearly level	Groupings by soil features (e.g., rock fragments, slope) created to serve specific purposes of soil surveys

The Fayette soil series is a fine-loamy, mixed, mesic Typic Halpudalf
Refer to the Soil Survey Manual (Soil Survey Staff 1993) and Soil Taxonomy (Soil Survey Staff 1999) for detailed discussion

A map unit is a collection of areas defined and named the same in terms of their soil components (e.g., taxa) or miscellaneous areas or both. Each individual demarcation of a map unit on a map is a delineation. The three most common kinds of map units in soil surveys are as follows: *consociations, complexes*, and *associations*. In consociations, map units are dominated by a single taxon, and typically, the map unit is named for the dominant taxon, often a soil series. Complexes consist of two or more taxa that occur in a regularly repeating pattern, but cannot be separated at the scale mapped. Associations consist of two or more taxa that could be mapped separately, but it is deemed not necessary to do so because their occurrences are distinct and obvious within each delineation. Complexes are used at scales larger than about 1:24,000 (more detailed coverage), and associations are used at scales smaller than about 1:24,000 (broader coverage).

In all soil surveys, virtually every delineation includes areas of soil components (taxa) or miscellaneous areas that are not identified in the name of the map units. This emphasizes the importance of the map unit description that is included in almost all large- and small-scale soil maps. The map unit description gives more detailed information on the occurrence and distribution of the named soils (major components) in the map unit label, and the occurrence and distribution of the soils that are not named (minor components) in the map unit label. Map unit design, labeling, and description are all important steps in soil survey.

Mapping and labeling soil variability and soil survey are scale dependent (Table 2.2). The US General Soil Map is the smallest scale soil map listed in Table 2.2, and it is labeled with the soil order. As the map scale becomes larger, there is increasing specificity in the taxon or taxa used to name map units. The Digital General Soil Map of the USA or STATSGO2 is a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scales listed in Table 2.2. Map units are named for the dominant soil order, which is the taxon also commonly used for naming map units in regional soil maps such as land resource region (LRR) and major land resource region (MLRA) maps (USDA-NRCS 2006).

State and county general soil maps are commonly produced and displayed at scales ranging from 1:100,000 to 1:500,000. These levels of mapping are still considered small scale and are designed for broad planning, and management uses covering state, regional, and multistate areas. Map units are commonly labeled with the dominant soil order, suborder, or great group or by the most common soil series that occurs in the unit. In the USA, detailed soil surveys are commonly produced at large and intermediate scales ranging from 1:12,000 in areas of intensive land use to 1:24,000 in areas of less intensive land use, and the map units are most commonly labeled by the dominant soil series, soil type, or soil phase consociations or associations.

The detail of a soil survey is primarily a function of the size of the survey area, the complexity of the soil-landscape, the detail required for the intended use of the soil survey, and the ability of the soil scientist to consistently identify the map units through the application of the available knowledge and tools within the constraints of cost and time (Soil Survey Staff 1999). It should also be emphasized that the assignment of taxonomic names, such as the name of a soil order or the name of a soil series, to label a map unit means that if we examine various delineations of the map unit, we expect most locations within the delineations to meet the criteria of the taxon or taxa (Holmgren 1988).

2.2.3 Soil Survey Products

In the USA, the most common soil map unit label is the soil series. The soil series is a foundational concept in soil survey. There are two primary definitions for soil series. Historically, it is defined as a group of soils having the same genetic horizons, that is, horizons that result from the same soil-forming factors and processes (Kellogg 1956). The

Table 2.2 Soil maps, soil map scales, and soil map labels

Map	Approximate scale range	Common taxonomic labels
US General Soil Map and Regional Soil Maps	1:7,500,000–1:3,500,000	Order
Regional Soil Maps and State General Soil Maps	1:1,500,000–1:500,000	Order, suborder, great group, association of soil series
Detailed Soil Survey General Soil Map (e.g., county)	1:250,000–1:63,360	Suborder, great group, associations of soil series
Detailed Soil Survey (Less Intensive Land Use)	1:63,360–1:31,860	Soil series, soil type, soil phase consociations and complexes
Detailed Soil Survey (Intensive Land Use)	1:31,860–1:12,000	Soil series, soil type, soil phase consociations, and complexes

more modern definition describes the series as a group of soils that have horizons similar in arrangement and in differentiating characteristics (Soil Survey Division Staff 1993, p. 20). The first definition has been widely used in the labeling of soil maps with soil series or other taxonomic labels (Table 2.2, e.g., order and suborder). Following are examples of common soil survey products using the various taxonomic labels.

2.2.3.1 General Soil Region/Association Maps

The US General Soil Region Map (Fig. 2.13) and the Illinois General Soil Region Map (Fig. 2.14) are considered schematic soil maps. Schematic soil maps are made by using many sources of information such as climate, vegetation, geology, landforms, detailed soil maps, and other factors related to soil (Soil Survey Division Staff 1993; Soil Survey Staff 1999). The labels for these General Soil Region/Association Maps use the dominant soil order.

Figure 2.15 shows a General Soil Association Map of Perry County, Illinois (Grantham and Indorante 1988). Associations of soil series are used to label this map, and each association has a distinctive pattern of soils, relief, and drainage. Each association is a unique natural landscape. Typically, an association consists of one or more major soil and some minor soils. It is named for the major soils. The soils making up one association can occur in another, but in a different pattern. The general soil map can be used to compare the suitability of large areas for general land uses. Areas of suitable soils can be identified on the map. Likewise, areas where the soils are not suitable can be identified. Because of its small scale, the map is not suitable for planning the management of a specific area. The soils in any one association differ from place to place in slope, soil depth, drainage, parent material, climate and microclimate, and other characteristics. These all affect management.

2.2.3.2 Detailed Soil Maps

The detailed soil map in Fig. 2.16 includes the Homen–Hickory–Bunkum Association, the Marine–Stoy–Pierron Association, and the Flood Plain Soils Association (Fig. 2.15). The legend for this soil map is presented in Table 2.3. Each map unit delineation on the detailed map

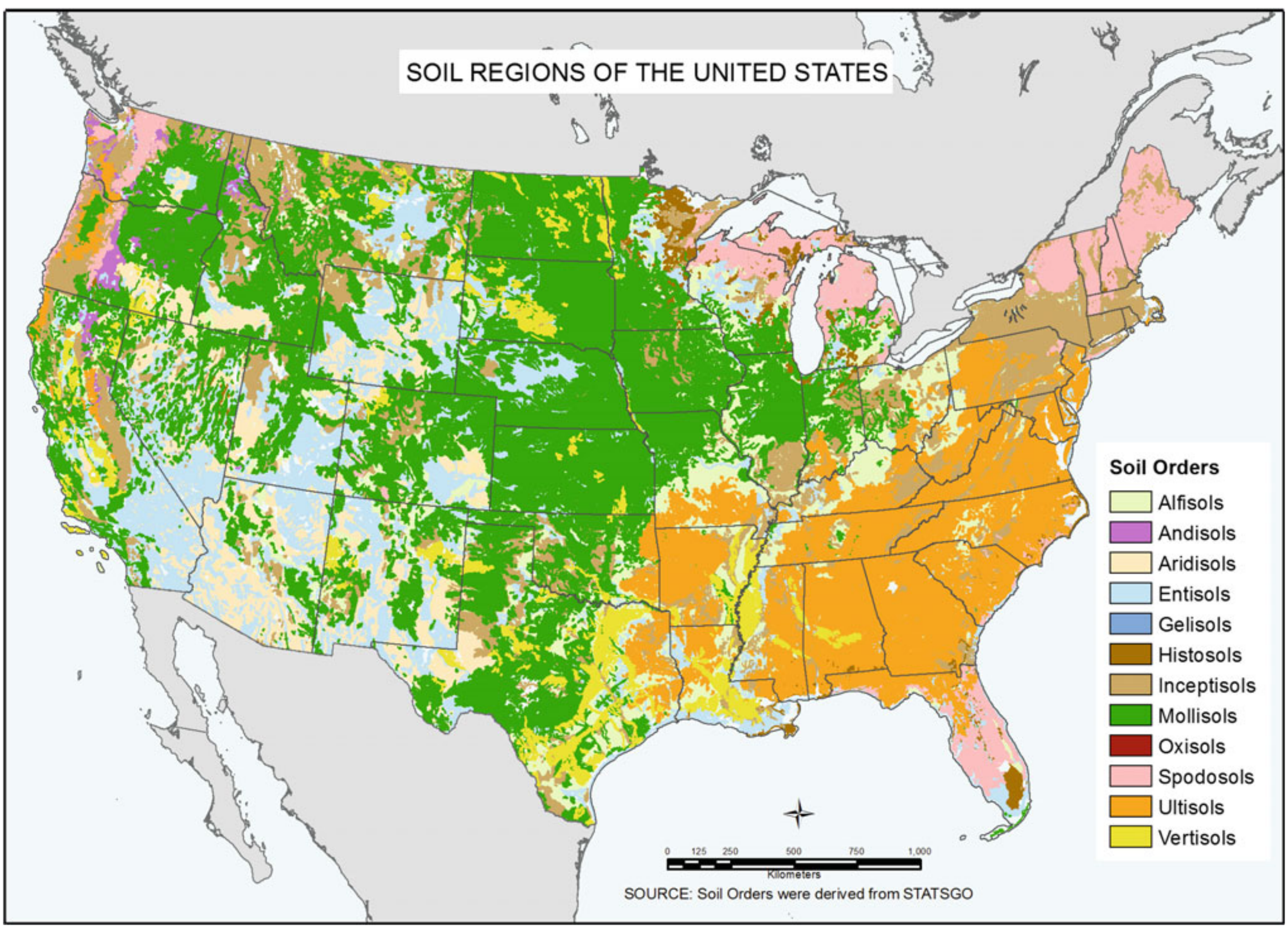

Fig. 2.13 A General Soil Map of Soil Regions of the contiguous USA. Soil orders are the taxonomic labels (Table 2.2) used in this map

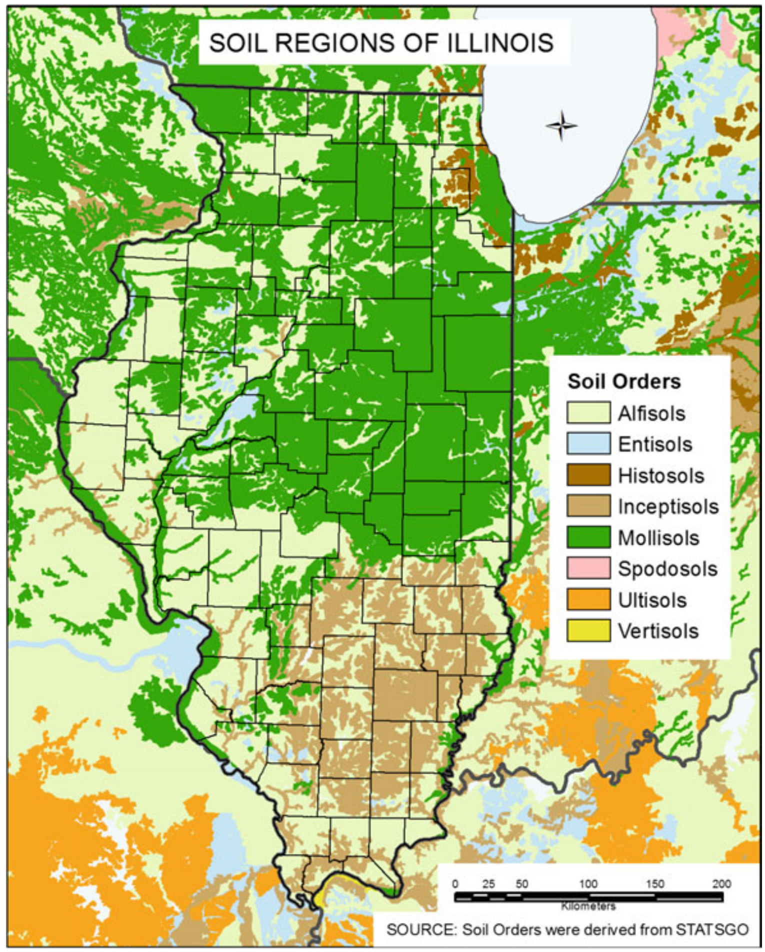

Fig. 2.14 A General Soil Map of Soil Regions of Illinois. The soil order is the taxonomic level of labels (Table 2.2) used in this map

represents an area on the landscape and consists of one or more soils (soil series) for which the unit was named.

Soils of one series can differ in texture of the surface layer or substratum. They can also differ in slope, stoniness, wetness, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into soil phases. Most of the areas on a detailed soil map, and in Fig. 2.16, are phases of soils series. For example, "Blair silty clay loam, 10–18 % slopes, severely eroded" is a phase of the Blair series. This phase of the Blair series was determined by surface texture, slope, and erosion.

A soil survey is both an inventory (i.e., soil maps) and an evaluation of the soils in an area. Using detailed soil maps to make predictions and interpretations about the soils is a key component of soil survey. The soil surveys in the USA include interpretations for the growth of plants, such as crops, forage species, trees, and ornamental shrubs. They also include interpretations for urban, rural, and recreational development and for conservation and wildlife habitat planning (Soil Survey Staff 1999). Figure 2.17 shows an example of a common soil survey interpretation, corn yield (*Zea mays* L.), for a farm field in Perry County, Illinois. Historical yield data on the various soil types were used to produce the map. Field experience and collected data on soil properties and performance are used as a basis in predicting soil behavior and creating various interpretations (Soil Survey Division Staff 1993; Soil Survey Staff 1999).

2.2.3.3 General Soil Association Maps and Soil-Landscape Block Diagrams

The soil-landscape Block Diagram is one of the most powerful tools for depicting the impacts of soil-forming factors and soil-forming processes on the landscape (Indorante 2011). Figure 2.18 presents the detailed soil map in Fig. 2.16

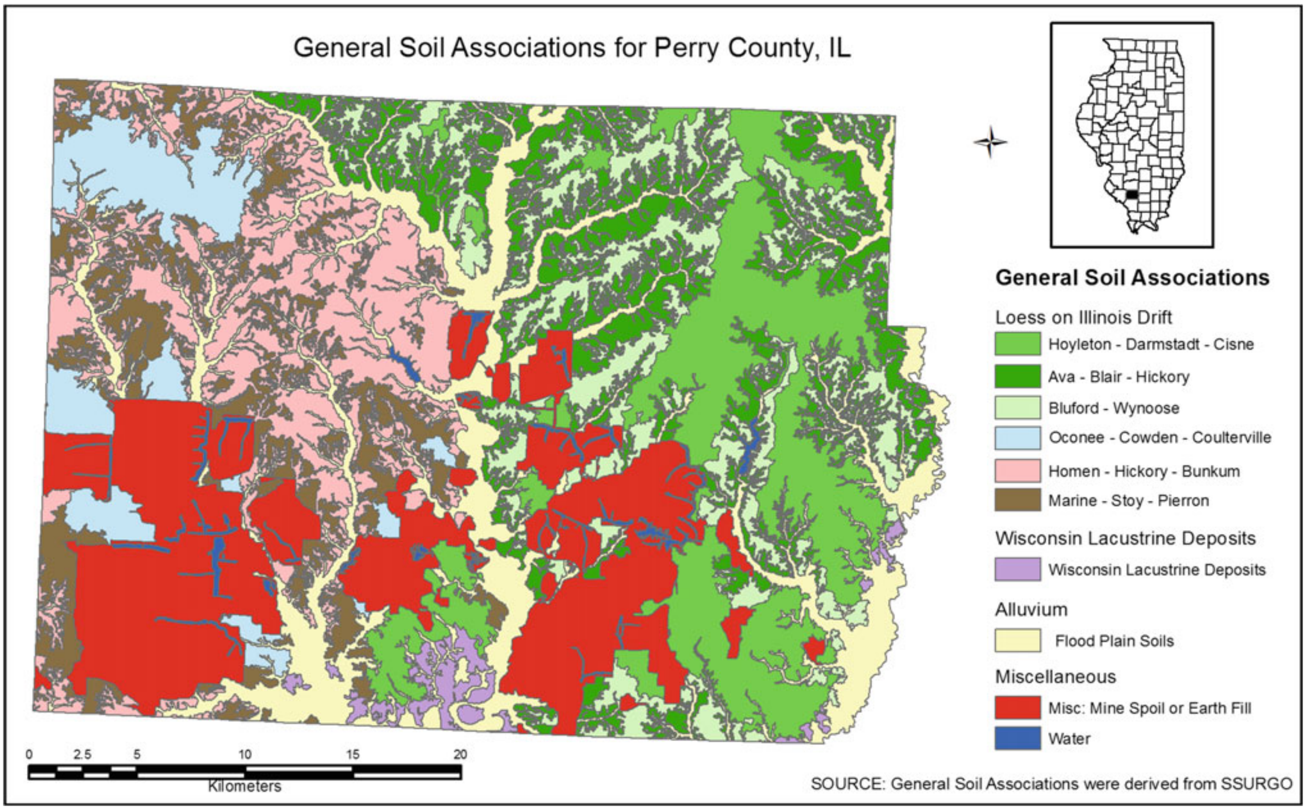

Fig. 2.15 General Soil Associations for Perry County, Illinois. Associations of soil series are the taxonomic labels (Table 2.2) used in this map. The associations are also grouped by parent material

as a General Soil Association Map and as a soil-landscape Block Diagram. This block diagram emphasizes the impact of parent material and topography on soil distribution. Even though parent material and topography are the two soil-forming factors that are emphasized in this diagram, climate and microclimate can be inferred by topographic position, and time can be inferred from parent material (e.g., alluvium as a relatively younger parent material). Soil-landscape block diagrams are available in many published (hard copy) and digital soil surveys or are available at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_05431.

2.3 Chapter Summary

Soil formation reflects the impact of environmental conditions on the landscape. The soil-forming factors of topography, climate, and biology produce a variety of processes that imprint soil parent materials with distinct morphological and chemical properties. The expression of this imprinting is enhanced as the processes act over longer periods of time. Ultimately, the types of soil horizons that form and their degree of expression record the influences of the environments in which they formed and the consequent processes that have operated within them. Soil surveys are designed to

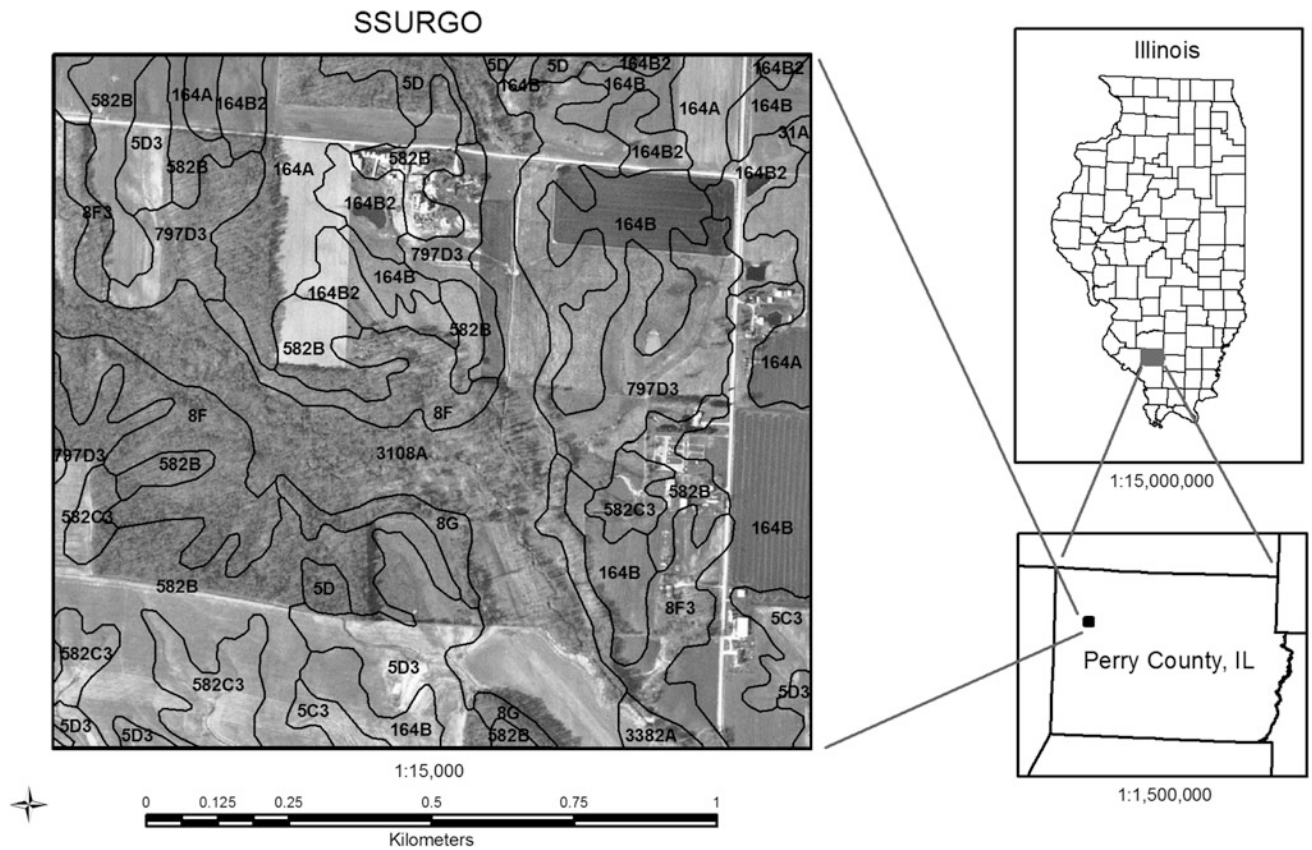

Fig. 2.16 An example of a detailed soil map from Perry County, Illinois. Soil series, soil type, soil phase consociations, and complexes are the taxonomic labels used in this map

Table 2.3 Legend* for detailed soil map in Fig. 2.16

Map unit symbol	Series	Map unit label (phase of soil series)
5C3	Blair	Blair silty clay loam, 5–10 % slopes, severely eroded
5D	Blair	Blair silty clay loam, 10–18 % slopes
5D3	Blair	Blair silty clay loam, 10–18 % slopes, severely eroded
8F	Hickory	Hickory silt loam, 18–35 % slopes
8F3	Hickory	Hickory clay loam, 18–35 % slopes, severely eroded
8G	Hickory	Hickory silt loam, 35–70 % slopes
31A	Pierron	Pierron silt loam, 0–2 % slopes
164A	Stoy	Stoy silt loam, 0–2 % slopes
164B	Stoy	Stoy silt loam, 2–5 % slopes
164B2	Stoy	Stoy silt loam, 2–5 % slopes, eroded
582B	Homen	Homen silt loam, 2–5 % slopes
582C3	Homen	Homen silt loam, 5–10 % slopes, severely eroded
797D3	Hickoy, Homen	Hickory–Homen silty clay loams, 10–18 % slopes, severely eroded
3108A	Bonnie	Bonnie silt loam, 0–2 % slopes, frequently flooded

*For more information refer to: Soil Survey Staff. Web Soil Survey. USDA Natural Resources Conservation Service, Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [07/09/2014]

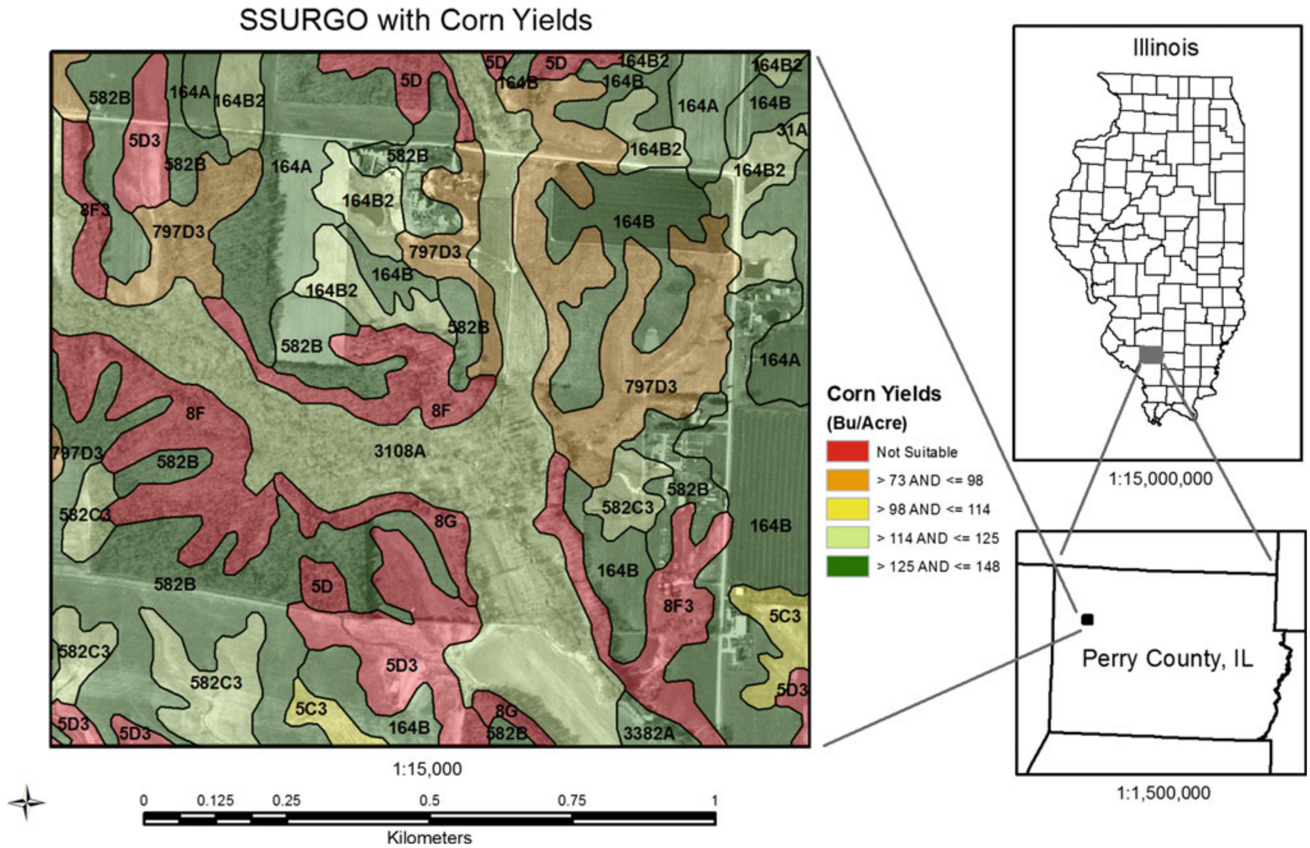

Fig. 2.17 Expected corn yields (*Zea mays* L.) by soil type for a field in Perry County, Illinois

spatially identify the imprint of soil formation across landscapes and to provide information on the properties and use potentials of the soils. Different scales of soil surveys, from highly detailed to very broad coverage, are used to serve different purposes. Parts of the landscape with similar soil taxa are grouped into map units, which serve as the basis for soil descriptions and interpretations.

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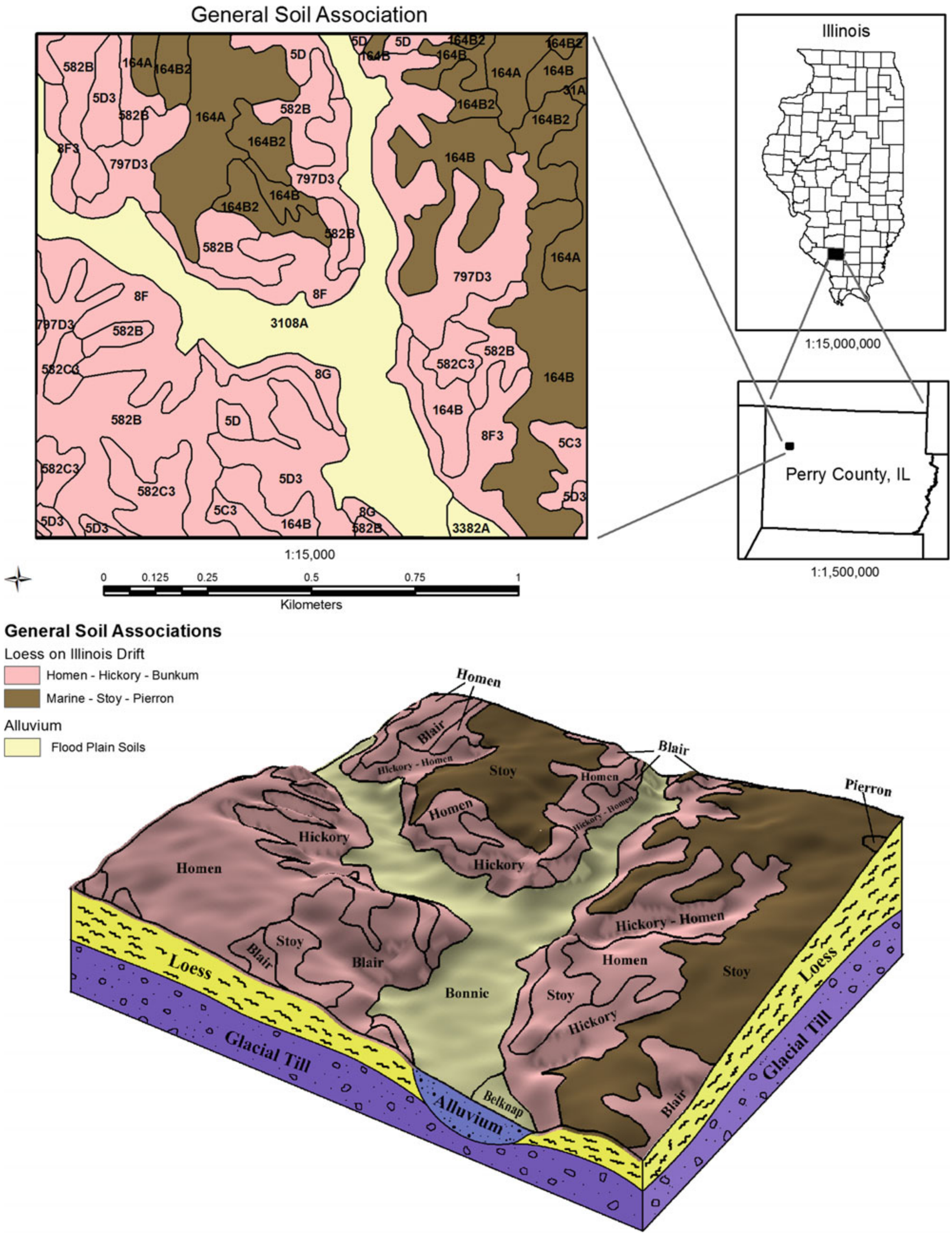

Fig. 2.18 The detailed soil map from Fig. 2.16 presented as a General Soil Association Map and as a soil-landscape block diagram

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