CHAPTER 4

Soil Mapping Concepts

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Soil Mapping Process

Soil mapping is the process of delineating natural bodies of soils, classifying and grouping the delineated soils into map units, and capturing soil property information for interpreting and depicting soil spatial distribution on a map.

The soils and miscellaneous areas (e.g., Rock outcrop) in a survey area are in an orderly pattern that is related to the geology, landforms, topography, climate, and natural vegetation. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. Soil scientists delineate these repeating patterns of landform segments, or natural bodies, on a map. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they formed. Thus, during mapping, these models enable the soil scientist to predict with considerable accuracy the kind of soil or miscellaneous area on the landscape (Hudson, 1992).

The repetitive patterns imprinted in soils by the soil-forming factors can be observed at scales ranging from continental to microscopic. These patterns are the basis for soil identification and mapping at different scales. A system of terminology, definitions, and operations can be ascribed to the various scales. Hierarchical systems of classes and subclasses are established to produce groupings at the different scales.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. Some boundaries are sharp, where soils change over a few meters, while others are more gradual. Soil scientists can observe only a limited number of pedons. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil and to determine their boundaries.

Soil scientists record the characteristics of the pedons, associated plant communities, geology, landforms, and other features that they study. They describe the kind and arrangement of soil horizons and their color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to classify and identify soils (see chapters 2 and 3 for details). They describe plant species present (their combinations, productivity, and condition) to classify plant communities, correlate them to the soils with which they are typically associated, and predict their response to management and change. After the soil scientists identify and describe the properties of landscape components, or natural bodies of soils, the components are correlated to an appropriate taxonomic class, which is used for naming map units. Correlation, or comparison of individual soils with similar soils in the same taxonomic class in other areas, confirms data and helps the staff determine the need to assemble additional data. Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil Taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile (Soil Survey Staff, 1999).

While a soil survey is in progress, samples of some of the soils in the area are collected for laboratory analyses. Soil scientists interpret the data from these analyses and tests as well as the field observed characteristics of the soil properties to determine the range of values for key soil properties for each soil. They also use these data to determine the expected behavior of the soils under different uses. Soil property data is organized and stored in a database, where it is used to generate soil interpretations for use and management. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Special studies to document dynamic soil properties that are affected by use and management may be conducted (see chapter 9). Data are assembled from other sources as well, such as research information and field experience of specialists.

After survey staff locate and identify the significant natural bodies of soil in the survey area, they draw the boundaries of these bodies on a map and identify each as a specific map unit by name. Imagery showing trees, buildings, roads, and rivers is commonly used as a base map to help in locating boundaries accurately. Tonal shades and patterns on aerial photographs or digital images are used to indicate potential changes in vegetation, drainage conditions, parent materials, and other factors affecting surface reflectance. As digital mapping techniques are being increasingly integrated into mapping (see chapter 5), additional sources of information, such as multispectral bands, digital elevation models, and other data layers (such as geology), along with global positioning systems (GPS) are used to accurately locate map unit boundaries. Although the processes used in digital mapping techniques are different from nondigital conventional methods, the principles are the same.

In the United States, soil surveys vary in scale and in intensity of observations. The components of map units are designated by taxa in *Soil Taxonomy* (Soil Survey Staff, 1999) or as miscellaneous areas (i.e., nonsoil areas). In naming a map unit, soil taxa names (commonly a soil series name) are modified with phase terms (indicating surface texture, slope, flooding, stoniness, etc.) to convey information that is either more specific than the wider range of properties defined for the series (e.g., surface texture) or that represents a property outside of the soil itself (e.g., flooding). The phase commonly is a portion of the range of properties exhibited by the taxon. For example, a certain soil series may have slopes ranging from 3 to more than 60 percent but the map units are shown with narrower ranges (e.g., 3 to 8, 8 to 15, 15 to 25) to provide information that is useful in managing the soils in the area.

Historically, soil surveys have classified entire polypedons and grouped their properties for interpretative output as vector maps (polygons). Some contemporary surveys classify only certain soil properties, such as surface rock fragment cover, and output the information as raster maps, in which each pixel represents a specific value of the property. With these maps, commonly called "soil property maps," the user can decide how to group or aggregate the information for their needs. Strictly speaking, maps of individual soil properties are not synonymous with soil surveys, which by definition delineate natural soil bodies.

Soil Mapping and the Scientific Method

Soil mapping uses the scientific method, in which the scientist must: (1) develop questions, (2) generate hypotheses that answer those questions, (3) test the hypotheses, and (4) confirm or reject the hypotheses. After a tentative delineation of a soil body is drawn on an aerial photo or digital image, the soil mapper (step 1) questions what type of soil exists within that delineation. Typically, the delineation follows a landscape feature, such as a large flood plain or a ridge summit. Based on previous knowledge about the soils of the region, the mapper (step 2) develops hypotheses, such as the Alpha and/or Beta series occurs within the delineation. The mapper (step 3) tests those hypotheses by augering, backhoe trenching, or observing natural exposures and (step 4) confirms or rejects each hypothesis. After documenting the results, the mapper returns to step 1 (develops questions) and repeats the process for a neighboring area. This process allows the soil scientist to map soils efficiently. Rather than making a large number of observations on a regular grid pattern to discover the kind of soil present, the mapper selects a limited number of strategically located points in the landscape to make observations. The observations confirm or reject the previously developed model. The mapper essentially is predicting the soil beforehand and only making an observation to confirm the prediction, rather than discovering the soil only after each observation is made. As long as the model is accurate, relatively few observations are required to make an accurate map (Hudson, 1992).

The scientific method is also used when investigating soil genesis. Although soil mapping and soil taxonomic classes are based on quantifiable properties rather than soil genesis (Smith, 1963), it is nevertheless useful for the soil mapper to develop conceptual models about soil genesis throughout the mapping process (Arnold, 1965). The most useful is the "multiple working hypotheses" method, which is based on the premise that when a scientist creates multiple hypotheses for an observed feature rather than one hypothesis, they are less likely to develop a parental attachment to "their" hypothesis (Chamberlin, 1897). Instead, the scientist becomes engaged in finding evidence that disproves each of the competing hypotheses. The "working hypothesis" is the one that survives. This method of testing multiple hypotheses simultaneously not only enhances the quality of conceptual models but also lessens antagonistic debates between scientific colleagues (Platt, 1964).

Soil Maps

Historical Approach

Aerial photographs were used as the mapping base in most soil survey areas in the United States during the 20th century. Conventional panchromatic (black and white) photography, color photography, and infrared photography were used for remote sensing and as base maps for the soil survey. Information on the applicability of each type of base map and how the older map products were used is covered in the 1993 *Soil Survey Manual* (Soil Survey Division Staff, 1993).

Aerial Photographs

Even in the current digital age, the use of aerial photographs remains an effective means of mapping soils in areas where suitable digital imagery and data layers or the required skills, resources, or support for digital mapping techniques are not available. Chapter 5 covers the integration of digital soil mapping techniques in conducting soil surveys.

Aerial photographs are still a viable mapping base in soil survey. They provide important clues about kinds of soil from the shape and color of the surface and the vegetation. The relationships between patterns of soil and patterns of images on photographs for an area can be determined. These relationships can be used to predict the location of soil boundaries and the kinds of soil within them.

Aerial photographs using spectral bands not visible to the eye, such as color infrared, enable subtle differences in plant communities to be observed. Other spectral bands in the infrared are useful in distinguishing differences in mineralogy and moisture on the soil surface and also have better cloud penetration. These data must be interpreted by relating the visual pattern on the photographs to soil characteristics found by inspection on the ground.

Features, such as roads, railroads, buildings, lakes, rivers, and field boundaries, and many kinds of vegetation can be recognized on aerial photographs and serve as location aids. Cultural features commonly are the easiest features to recognize on aerial photos, but they generally do not coincide precisely with differences in soils, except in areas with significant anthropogenic alteration. Chapter 11 provides guidance on mapping human-altered landscapes and human-transported soil materials.

Relief can be perceived by stereoscopic study. Relief features are helpful in locating many soil boundaries on the map. Topographic maps also provide insight to relief, slope, and aspect. Relief also identifies many kinds of landforms commonly related to kinds of soil.

Many landforms (e.g., terraces, flood plains, sand dunes, kames, and eskers) can be identified and delineated reliably according to their shapes, relative heights, and slopes. Their relationship to streams and other landforms provides additional clues. The soil scientist must understand geomorphology (discussed in chapter 2) to take full advantage of photo interpretation.

Accurate soil maps cannot be produced solely by interpretation of aerial photographs. Time and place influence the clues visible on the photographs. Human activities have changed patterns of vegetation and confounded their relationships to soil patterns. The clues must be correlated with soil attributes and verified in the field.

Contemporary Approach

Digital imagery has replaced photographs as the mapping base in 21st century soil survey. The ability to overlay multiple imagery resources for comparisons, the ability to quickly adjust scale, and the use of raster-based soil maps have increased the speed of delivering soil survey products as well as the variety of products available. Customized soil survey products are enhanced by the choice of background imagery (e.g., color imagery and topographic imagery) used to display soil survey information. Methods for digital soil mapping and the products derived from digital imagery are discussed in chapter 5.

Sources of Apparent Error on Existing Soil Maps

Soil surveys in the United States. meet the technical standards and design requirements in place at the time they were completed. However, standards in use varied from State to State or regionally. In addition, standards evolved with increased knowledge about soils and changes in user needs. One should not assume that the soil survey data and maps completed many years ago, which did not have the benefit of recent evaluation and update, meet the standards and expectations of users today.

Soil survey mapping scale and map unit design considerations likely cause the most apparent errors on soil maps. Projects were designed to collect and document soil distribution and properties based upon user needs and were not more detailed than necessary. For low-intensity uses of the soil (e.g., grazing on native rangeland, native forests, watershed, and wildlife habitat), soil mapping was performed on a small-scale photo base of 1:48,000 to 1:63,560, or smaller. Areas of soil that were markedly different in use and management but too small to be delineated at the scale of mapping were described as inclusions in map units or denoted by a spot symbol on the map. When the mapping is presented at a larger scale, these areas may appear to be errors in the map.

Soil surveys in the U.S. were initiated with "memoranda of understanding" between National Cooperative Soil Survey (NCSS) partners and other local partners. These documents included agreed-to scheduled progress targets and completion date. The schedule dictated the scale of mapping and the mapping intensity or order. Map units were designed to meet specific user needs, and fieldwork was conducted to create soil maps that met those needs. If the user needs change due to changes in land use, the map unit design may not adequately meet the new needs. Soils with markedly different potentials or risks based upon use may not be adequately separated in mapping units.

Standards used in the soil correlation process set minimum extent requirements for both a map unit and a soil series included in the soil survey legend. Setting these limits was done prior to computerization to ensure that data and information would remain manageable. At the end of a project, map units and series that did not meet the minimum extent requirements were combined with the most similar map unit or component in the legend and the concepts were expanded to include these soils and areas.

Boundaries of the soil mapping legends generally coincided with county or State lines. Small areas of soils having a different bedrock geology, physiography, or major land resource area (MLRA) that crossed the political soil survey boundary (map legend boundary) were too small in extent to appear in the legend alone, so they were combined with the most similar map unit. When two adjacent survey areas are viewed at the join, fault lines may appear between the two surveys. Under the MLRA approach currently used to update soil survey in the U.S., these faults are being corrected.

Significant changes in the soil resource itself may have occurred since the time of soil mapping. Extensive anthropogenic activities, including mining, excavation, land leveling, and construction, remove or bury native soils. Because of natural processes, such as changes in stream courses, landslides, and volcanic eruptions, soil materials at the surface may differ from those identified on soil maps completed earlier. These changes are generally dramatic and easily recognizable on the landscape. Some, however, may be subtle (e.g., filling of wet areas, alterations to hydrology, and mechanical alterations such as deep ripping and deep mixing).

Other actual errors may be discovered on soil maps, including labeling errors done in the field and map compilation and publication errors. They should be documented and corrected.

Field Operation and Equipment

The efficient operation of a soil survey requires the use of certain kinds of equipment. The three major equipment needs are: (1) tools to examine the soil profile; (2) soil testing, measuring, and recording devices for mapping; and (3) transportation vehicles. While some of the equipment used in soil survey reflects new technology, such as tools for proximal sensing of soil properties (discussed in chapter 6), many of the basic tools for observing soils in the field have changed little in recent years. The 1993 *Soil Survey Manual* contains a detailed discussion and description of many of these items. Short descriptions of commonly used field tools are also provided in the *Field Book for Describing and Sampling Soils* (Schoeneberger et. al., 2012, pp. 8-5 and 8-6).

Tools for Examining and Testing the Soil

A soil scientist examines the soil often in the course of mapping. Examination of both horizontal and vertical variations is essential. The most commonly used tools are spades and soil augers. Augers are used in most areas for routine mapping. In some areas, however, a spade is used to examine the soil. In soils with no rock fragments, samples can be collected quickly and relatively easily using truck-mounted (fig. 4-1) or

Figure 4-1

A truck-mounted hydraulic probe used to quickly obtain soil profiles. The Giddings probe (shown) has the ability to collect a large- or small-diameter core sample, and extensions can be added to it for deep coring. Driver's side-mounted bull probes are preferred in some areas but are limited to collection of smaller diameter core samples. (Photo courtesy of Casey Latta) hand-operated probes. Backhoes and shovels are used to expose larger soil sections for examination, sampling, and photography. Where a probe or auger is regularly used for examining the soil, a large pit exposed by a backhoe (see fig. 4-2, left image) can be used to ensure map unit concepts are as predicted and have not strayed from the conceptual model developed.

Figure 4-2

Left image—A backhoe excavation providing a large view of the soil profile and improving access for description and sampling. Right image—Shoring, exit ramps, and other safety measures must be used to protect staff in deep trenches. (Photos courtesy of Wayne Gabriel)

Backhoes, however, have limitations. Cost as well as time to perform needed maintenance must be considered. Where available locally, renting a backhoe and operator only when needed may be an option. Some property owners do not want large equipment on their property. Operators must be trained to use the equipment efficiently, and safety standards must be met (see fig. 4-2, right image). Overhead and underground power lines, which pose electrical hazards, and other utilities must be located and avoided. Slopes may be too steep for safe operation of machinery. It is important to recognize soil properties that make trench walls prone to collapsing and thus dangerous for anyone in a pit. Designing backhoe trenches with benching, shoring, and exit ramps can improve safety.

Equipment for unique environments must be considered. Power equipment is commonly used to save time and effort. Vibracore samplers are used to obtain subaqueous soil samples several meters below the water surface. Devices such as core catchers are used to prevent the sandiest materials from falling out of the sample tube. Various small instruments can also be used to examine the soil, such as small handheld digital meters that determine salinity, soil reaction, sodicity, and soil nutrients. Proximal sensing tools, such as XRF meters, electromagnetic induction, and ground-penetrating radar, can also be used. See chapters 6, 10, and 11 for more information on tools suited to proximal sensing and unique environments.

Measuring and Recording Devices for Mapping

A handheld geographic positioning system (GPS) unit can assist in navigation and capture the location of soil descriptions. It can be indispensable as a navigation aide in remote or roadless areas. GPS provides both horizontal position in geographic coordinates and elevation. Most units can store and recall waypoints and so help workers identify and return to specific locations. Some provide background maps of geographic and cultural features to aid navigation.

A small digital camera is useful in capturing quality images of soil profiles and features, landscape settings, and vegetation and documenting land use and management. Smartphones, tablets, and some laptops have built-in cameras that can be used for capturing and storing images. If digital images are used as the mapping base, laptop computers or tablet PCs (provided they are sufficiently ruggedized and suited to outdoor viewing) can be used to display and annotate maps.

Waterproof data loggers can be installed at some study sites to automatically collect measurements of air and soil temperatures, water potential, and more. These data can be collected over 1 or more years as needed and summarized to characterize site conditions for classification and interpretation.

Transportation

Field operations in soil survey require transportation of workers, equipment, supplies, and soil samples. Vehicles are provided to the soil survey team for their daily operations. The time spent by soil scientists traveling to and from the field can be lengthy and mainly unproductive. Enough vehicles are provided to keep travel time as short as possible.

Additional equipment used for special purposes or for short periods is typically rented or supplied as needed. A passenger van, for example, may be furnished by one of the soil survey project's partners during a field review. Some vehicles must carry power equipment or pull trailers. All vehicles should be suited to the needs of the survey area, whether it be for use off road or in paved areas; to carry workers efficiently, comfortably, and safely; to hold the regularly used equipment; to accommodate an extra load; or to protect workers and equipment from adverse weather.

Specialized vehicles are needed in some areas. Aircraft, particularly helicopters, are used in some soil surveys to transport workers and equipment and to provide broad views of landscapes and vegetation. Aircraft are useful for photographing landscapes, soil patterns, and land use. Availability, cost, and lack of conventional landing sites are the main limitations to using aircraft. Snowmobiles provide winter access where travel is impossible or impractical in other seasons. Tracked vehicles, trail bikes, and all-terrain vehicles (ATVs) may be needed in areas that otherwise can be reached only by walking. Pack horses may be the only viable means of transporting people and equipment in wilderness areas. Marsh buggies with large buoyant tires and airboats are used in swamps and marshes. Canoes and small boats may be used to navigate waterways or to access areas consisting of numerous islands. Shallow draft boats are useful in conducting soil surveys in areas consisting of subaqueous soils (see chapter 10). Specialized vehicles must be reliable in remote areas.

Costs of buying or renting equipment, maintaining the equipment, and training operators can be high. Time is needed for transport, maintenance, and training. Some equipment is hazardous to operate. In addition, sensitive ecosystems may be damaged by the equipment.

Soil Identification and Classification

In soil surveys, the individual parts that make up the soil continuum are classified. The classes are defined for bodies of soil of significant kinds and extent. The taxonomic classes are conceptual. Their definitions are based on the knowledge of soils as they occur in nature and the understanding of the genetic processes responsible for their formation. The taxonomic classes themselves are not real soils, but they relate to their representatives in nature—the pedon and the polypedon.

Pedon

A pedon is the smallest body of one kind of soil that is large enough to represent the nature and arrangement of horizons and the variability in the other properties. It lacks boundaries with neighboring pedons (Soil Survey Staff, 1999). It is a unit of observation, sampling, and classification.

A pedon extends down to the lower limit of a soil, through all genetic horizons and, if the genetic horizons are thin, into the upper part of the underlying material. It includes the rooting zone of most native perennial plants. For purposes of most soil surveys, a practical lower limit of the pedon is bedrock or a depth of about 2 m, whichever is shallower. A depth of 2 m allows a good sample of major soil horizons, even in thick soil. It includes much of the volume of soil penetrated by plant roots, and it permits reliable observations of soil properties.

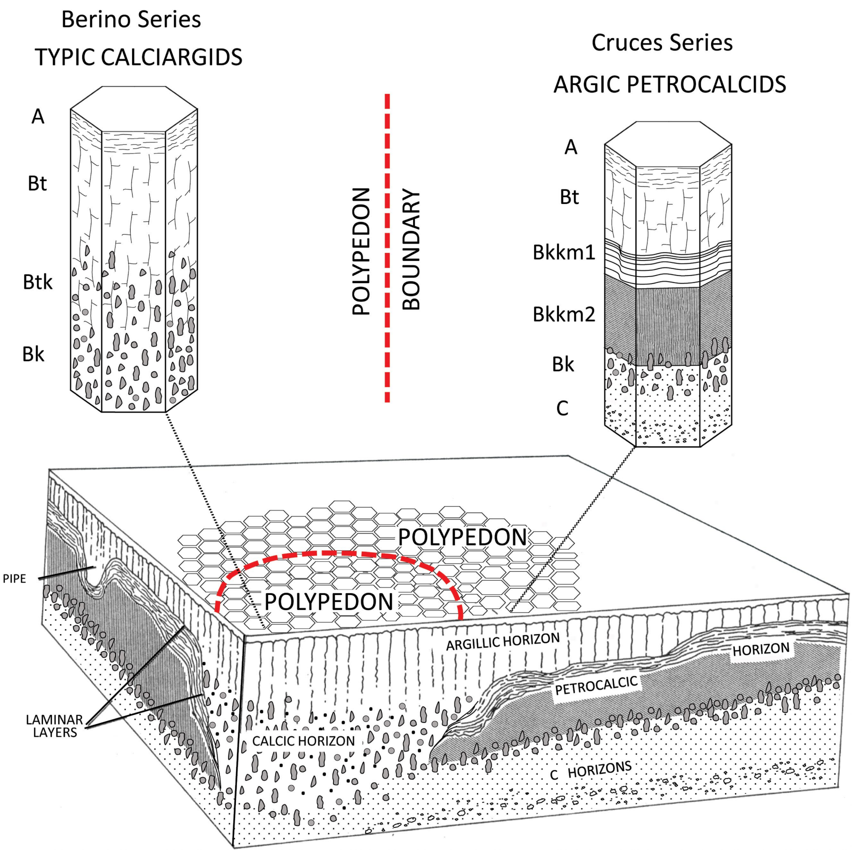
The surface of a pedon is roughly polygonal and ranges from 1 to 10 m^2 in area, depending on the nature of the soil's variability. Where the cycle of variations is less than 2 m and all horizons are continuous and nearly uniform in thickness, the pedon has an area of approximately 1 m^2. Where horizons or other properties are intermittent or cyclic over an interval of 2 to 7 m, the pedon includes one-half of the cycle (1 to 3.5 m). If horizons are cyclic over an interval greater than 7 m, each cycle is considered to contain more than one soil. The range in size, 1 to 10 m^2, permits consistent classification by different observers where important horizons are cyclic or repeatedly interrupted over short distances.

Polypedon

A pedon by itself is too small to be the unit of soil mapping because it cannot account for features such as slope and surface stoniness. In addition, it is too small to embody the full range of variability occurring within a soil series. Instead, the polypedon is used to define a soil series and is the unit of soil mapping. It is the three-dimensional soil body or soil individual that is homogeneous at the soil series level of classification. It is big enough to exhibit all the soil characteristics considered in the description, classification, and mapping of soils (fig. 4-3).

The concept of the polypedon is, from a practical standpoint, more or less equivalent to the *component* in soil mapping, but with one technical difference. Since the polypedon is defined as being homogenous at the series level of classification, each pedon making up the polypedon must fall within the class limits for all the properties (texture, color, reaction, thickness, etc.) of that series. When the limits of taxa are superimposed on the pattern of soil in nature, areas of taxonomic classes rarely, if ever, coincide precisely with mappable areas. In contrast, the map unit component represents a miscellaneous area or a natural soil body that includes all of the pedons making up the polypedon, as well as other very similar pedons within the mapped area that are just slightly outside the property ranges assigned for the series. A polypedon and similar or non-contrasting soils (discussed later in this chapter) occur within the concept and boundaries of the map unit component. Soil map units may consist of one or more components.

Figure 4-3



Polypedons vary in size. This figure illustrates a small polypedon formed in a pipe through a petrocalcic horizon (Gile et al., 2003). It also illustrates the concept that pedons have no lateral boundaries with neighboring pedons, unlike polypedons, which do have boundaries with neighboring polypedons.

The polypedon represents the minimum unit of interpretation and soil management. If the boundaries of an individual polypedon are gradual and diffuse, the polypedon is virtually impossible to delineate because its properties are confined by the taxonomic class it represents (series) and these properties vary in a sinuous or continuous manner in either vertical or horizontal dimensions. Boundaries between map unit components, however, are commonly evident where the differences produce contrasting native plant communities or changes in properties that impact soil use and management. Boundaries of both map unit components and polypedons may be easily observed at discontinuities, such as erosional facies and geologic contacts, and following human alteration.

Polypedons link the real bodies of soil in nature to the mental concepts of taxonomic classes and are the basis of soil components used in mapping, interpreting, and managing soils.

Soil Map Units

Soil map units are designed to efficiently deliver soil information to meet user needs for management and land use decisions. Map units can appear as individual areas (i.e., polygons), points, or lines on a map. A map unit is a collection of areas defined and named the same in terms of their soil components, miscellaneous areas, or both (components and miscellaneous areas are described below). Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. A map unit description is a written characterization of the component within a map unit and the relationship of one map unit to another. Appendix 2 provides an example of a map unit description.

Soil map units consist of one or more components (defined below). A delineation of a map unit generally contains the major (dominant) components included in the map unit name, but it may not always contain a representative of each kind of minor component. In older soil surveys, minor components were neither described nor interpreted in detail and were referred to as inclusions within a map unit. A dominant or major component is represented in a delineation by a part of a polypedon, a complete polypedon, or several polypedons. A part of a polypedon is represented when the phase criteria, such as slope, require that a polypedon be divided. A complete polypedon occurs if there are no phase criteria that require the subdivision of the polypedon or the features exhibited by the individual polypedon do not cross the limits of the phase. Several polypedons of a component may be represented if the map unit consists of two or more dominant components and the pattern is such that at least one component is not continuous but occurs as an isolated body or polypedon. Similarly, each minor component in a delineation is represented by a part of a polypedon, a complete polypedon, or several polypedons. Their extent, however, is small relative to the extent of the major component(s). Because soil boundaries can seldom be shown with complete accuracy on soil maps, parts and pieces of adjacent polypedons are inadvertently included or excluded from delineations.

Some map unit delineations may not contain any of the dominant components named in the map unit description but contain what are termed "similar soils." In most survey areas, there are soils that occur as mappable bodies but have very limited total extent within a specific survey area. They are typically included with other map units if, for all practical purposes, their soil interpretations are the same. The allowance of similar soils in map units is by design—it permits the number of map units and named components to be reduced without reducing the interpretative value of the soil map.

The kinds of map units used in a survey depend primarily on the purposes of the survey and the pattern of the soils and miscellaneous areas in the landscape. The pattern in nature is fixed, and it is not exactly the same in each delineation of a given map unit. In soil surveys, these patterns must be recognized and map units designed to meet the major objectives of the survey based upon known or projected user needs. It is important to remember that soil interpretations are made for areas of land and the most useful map units are those that group soils based upon their similarities.

Component

Within the context of a map unit, a component is an entity that can be delineated at some scale. It is commonly a soil but may be a miscellaneous area. Components consisting of soil are named for a soil series or a higher taxonomic class. Those that are miscellaneous areas are given an appropriate name, such as "Rock outcrop" or "Urban land." In either case, each component that makes up a map unit can be identified on the ground and delineated separately at a sufficiently large scale. Map unit components describe the properties of natural bodies of soils, or miscellaneous areas of nonsoil, in a particular landscape. Components can be major or minor in extent, depending upon the kind of map unit and percent composition. Designation of components as major or minor in soil databases is helpful for interpretive groupings. Typically, only major components are used in a map unit name.

Table 4-1 lists the kinds of map unit components used in soil survey. Soil components typically represent less than the full range of some properties allowed in a taxonomic class, which is defined by limits of key diagnostic properties. They may also differ from taxonomic classes and be slightly outside the class limits of some properties that define the taxa. Soils having properties that are slightly outside the defined taxonomic limits but that do not adversely impact major land uses are called similar soils. Map unit components are commonly a subset of the dominant taxonomic class or series in the delineation and similar soils. By identifying and naming components in map units, a soil scientist can quickly communicate interpretive information about a map unit and still indicate its complexity.

Table 4-1

Kinds of Map Unit Components Used in Soil Survey

Component kind	Description
Soil series	Most common component. It is the lowest categorical level of Soil Taxonomy.
Taxonomic categories above the series	Components given a taxonomic reference term that implies no specific range of properties beyond what is given in the map unit description.
Taxadjuncts	Components that are named for a soil series they resemble but have one or more differentiating characteristics that are outside the taxonomic class limits of that series. Their use and management is similar to that of the named soil series.
Miscellaneous areas	Components that are not soil as defined in *Soil Taxonomy* (such as Rock outcrop) or are bodies of soil that are no longer capable of supporting plants, such as soils heavily contaminated by toxic substances. Examples are given in table 4-2.
Phases of components	Components that are assigned a descriptive term to help distinguish between multiple components of the same taxonomic or miscellaneous area occurring within the same map unit legend or geographically associated map units.

Soil Series

The series represents a three-dimensional soil body having a unique combination of properties that distinguish it from neighboring series. The soil series concept was developed more than 100 years ago and somewhat followed the logic of the series as used to describe sediments in the geologic cross-section. Like the geologic formation, the soil series has served as the fundamental mapping concept. In geology, strata closely related in terms of their properties and qualities were members of a series in the sedimentary record. Initially, the soil series did not conform to a specific taxonomic class nor property class limits but rather to the predominant properties and qualities of the soil landscape, climate, and setting in which the soil occurred.

Today, the soil series category is the lowest level and the most homogeneous category in the U.S. system of taxonomy. As a class, a series is a group of soils or polypedons that have horizons similar in arrangement and in differentiating characteristics. The soils of a series have a relatively narrow range in sets of properties. Although part of *Soil Taxonomy*, soil series are not recorded in it. In the United States, they are in the Official Soil Series Descriptions database (Soil Survey Staff, 2016a). Appendix 1 provides an example of a soil series.

The soil series is not the object mapped in soil survey. Natural soil bodies are mapped and then described and classified. Each map unit soil component is correlated to a soil series or other taxonomic class. Soil series serve as a bridge between real soil bodies and conceptual taxonomic classes. They are an important tool for naming, remembering, and communicating information about soils. They also serve as a tool for transferring knowledge about soil genesis, properties, and interpretations from place to place, wherever a given soil series was correlated to a map unit component.

Soil series are differentiated on all the diagnostic features of the higher categories in Soil Taxonomy plus those additional and significant characteristics in the series control section (Soil Survey Staff, 1999). Some of the characteristics commonly used to differentiate series are the kind, thickness, and arrangement of horizons and their structure, color, redoximorphic features, texture, reaction, consistence, content of carbonates and other salts, content of humus, content of rock fragments, temperature, kinds and thickness of human-altered materials, and mineralogical composition. A significant difference in any one of these can be the basis for recognizing a different series. Very rarely, however, do two soil series differ in just one of these characteristics. Most characteristics are related, and generally several change together.

Some soils are outside the limits of any recognized soil series and have unique sets of properties. These are potential new series. When such a soil is first recognized, it is described and identified as a taxon of the lowest category in which it can be classified. A phase of that taxon can be used to identify a map unit. In some surveys, including virtually all detailed surveys, definitions need to be further refined. For these, the soil is proposed as a new series. The new series remains tentative until its properties can be described in detail, its extent determined, and any conflicts with established series resolved. If the tentative series remains through the correlation process, it is established as a new series at the time of final correlation. A taxonomic unit description includes the ranges in soil properties exhibited within the mapped areas for that taxonomic unit. The limits of these ranges are set for the taxonomic class, but generally the full range allowed by the taxonomic class is not exhibited in a survey area.

Taxa Above the Soil Series

The first level above the series is the family. Components mapped to the family level match the classification of a series, but not the series criteria. The name of a representative series belonging to the component taxonomic classification is used as the component name (e.g., Ezbin family). The component name represents the range in characteristics for many series within the family classification. Use of family-level components is generally limited to soil survey orders 3 and 4.

Components mapped to levels higher than the family use the classification as a reference term and may include the range in characteristics for many families within the referenced classification. An example is coarse-loamy Typic Cryaquolls. In this example, the higher taxa is the subgroup Typic Cryaquolls and it is modified by the family-level particle-size class term "coarse-loamy" to provide additional information. These components are used especially on small-scale maps in soil survey orders 3 through 5.

During a survey, the taxonomic system is tested and retested many times. The results of these tests are reported at field reviews and the field correlation. Problems in mapping or identifying soils and inconsistencies between the system and observed properties of the soils are recorded in field review reports and correlation memoranda. After appraising these reports, supervisory soil scientists bring any inadequacies to the attention of the office responsible for keeping the system up to date.

Taxadjuncts

Taxadjuncts are polypedons that have properties outside the range in characteristics of any recognized series and are outside higher category class limits by one or more differentiating characteristics of the series. A taxadjunct is given the name of an established series that is most similar in characteristics. These components classify differently taxonomically but have the same interpretations for use and management as the named series. Because the differences in properties between the named series and its taxadjunct are small and do not affect major interpretations, a new series is not established. The taxadjunct is treated as if it were a member of the named series, and its interpretations are similar to those for comparable phases of the series for which it is named. Differences from the established series are described. For example, a fine-silty map unit component differs slightly from an established fine-loamy series in only particle size, and no current soil series exist to accommodate the fine-silty classification. The fine-silty soil is correlated as a taxadjunct to the established fine-loamy series and a new series is not proposed.

Miscellaneous Areas

Miscellaneous areas are land that has little or no identifiable soil and thus supports little or no vegetation without major reclamation. Examples of miscellaneous areas are shown in table 4-2. The areas can be a result of active erosion, washing by water, unfavorable soil conditions, or human activities. Some miscellaneous areas can be made productive but only after major reclamation efforts. Map units are designed to accommodate miscellaneous areas, and most map units named for miscellaneous areas include areas of soil. If the amount of soil exceeds the standards for minor components defined for the survey, the map unit is named as a complex or association of miscellaneous area and soil. One must be careful in determining that an area is a miscellaneous area rather than a soil. For example, not all areas that are mined should be named "Mined land." If they are able to support vegetation and thus meet the definition of soil, they should be classified as soil. This is particularly important if it is possible to populate at least some major soil property data in the soil database and so provide meaningful interpretive information. The National Cooperative Soil Survey maintains an official list of miscellaneous areas and their definitions for use in the U.S. soil survey (USDA-NRCS, 2016).

Phases

Phase terms added to map unit component names convey important information about a map unit and differentiate it from other map units on the map unit legend. A property of a taxon that has too wide a range for the interpretations needed or some feature outside the soil itself that is significant for use are a basis for phasing map units. Phases commonly include only part of the range of features exhibited by a taxon within a soil map unit. Soil phases can be based on attributes, such as frost hazard, character of the deeper substratum, or physiographic position, that are not characteristics used to identify taxa but nevertheless affect use and

Table 4-2

Miscellaneous Areas Used as Map Unit Components

Area	Description
Badland	Moderately steep to very steep barren land dissected by many intermittent drainage channels in soft geologic material. Ordinarily, it is not stony and occurs in semiarid and arid areas.
Beaches	Sandy, gravelly, or cobbly shores washed and rewashed by waves. The areas may be partly covered with water during high tides or storms.
Chutes	Elongated areas on steep mountain slopes that lack vegetation and have exposed bedrock, rock fragments, and woody debris. Avalanche or mass movement activity is evident.
Cinder land	Loose cinders and other scoriaceous magmatic ejecta. The water-holding capacity is very low, and trafficability is poor.
Dams	Artificial structures that are oriented across a watercourse or natural drainage area for the purpose of impounding or diverting water.
Dumps	Areas of smoothed or uneven accumulations or piles of waste rock and general refuse. "Dumps, mine" is an area of waste rock from mines, quarries, and smelters.
Dune land	Unstable sand in ridges and intervening troughs that shifts with the wind.
Glaciers	Large masses of ice formed by the compaction and recrystallization of snow. The ice front may be advancing or retreating. Areas may include incidental amounts of soil or rock.
Gullied land	Areas where erosion has cut a network of V-shaped or U-shaped channels deep enough to inhibit or prevent crossing.
Lava flows	Areas covered with lava. Most flows have sharp, jagged surfaces, crevices, and angular blocks characteristic of lava. Others are relatively smooth and have a ropy, glazed surface. A small amount of earthy material may occur in a few cracks and sheltered pockets.
Mined land	Areas that are significantly altered by mining activities. Soil material and rock have been moved into, out of, or within the areas designated. Because access to mined land may be limited by permissions or hazardous materials, identification of soil components can be difficult or impossible.

Table 4-2.—continued	
Area	**Description**
Oil-waste land	Areas where liquid oily wastes, principally saltwater and oil, have accumulated. They include slush pits and adjacent areas affected by the liquid wastes. The land is barren, although some of it can be reclaimed at high cost.
Pits	Open excavations from which soil and commonly underlying material have been removed, exposing either rock or other material. Examples are “Pits, mine,” “Pits, gravel,” and “Pits, quarry.”
Playas	Barren flats in closed basins in arid regions. Many areas are subject to wind erosion and many are saline, sodic, or both. The water table may be near the surface at times.
Riverwash	Unstabilized sandy, silty, clayey, or gravelly sediment that is flooded, washed, and reworked frequently by rivers.
Rock outcrop	Exposures of bare bedrock other than lava flows and rock-lined pits. If needed, map units can be named according to the kind of rock, e.g., “Rock outcrop, chalk,” “Rock outcrop, limestone,” and “Rock outcrop, gypsum.” If small, they can be identified by spot symbols on maps.
Rubbleland	Areas of cobbles, stones, and boulders commonly at the base of mountains or left on mountainsides by glaciation or periglacial processes.
Slickens	Accumulations of fine textured material from placer-mine and ore-mill operations. They may have undergone chemical extractions. They are typically confined in constructed basins.
Urban land	Land mostly covered by streets, parking lots, buildings, and other structures of urban areas.
Water	Streams, lakes, ponds, and estuaries that are covered with water, deep enough or moving, that growth of rooted vegetation is precluded. Many areas are covered with water throughout the year.

management. Common phases are slope, surface texture, flooding and ponding, surface fragments, degree of erosion, and climate (see table 4-3 in the “Naming Map Units” section). Overlying water depth is used as a phase term for some subaqueous soils. Phases such as “filled,” “graded,” or “landscaped” are used for some map units consisting of soils that formed in human-altered or human-transported material.

Phase terms are devised and used as needed to differentiate map units. The usefulness of each phase must be repeatedly tested and verified during a survey. Separate phases of a taxon must differ significantly in behavior. If no useful purpose is served by separating them in mapping, similar phases of different taxa may be combined and the combination described. The interpretations prepared during the course of a survey provide evidence of similarities and differences among map units.

The justification for most phases rests on the behavior of the soils under various uses. At least one statement about soil behavior must be unique to each phase of a taxon, and the differences of soil properties must exceed normal errors of observation. The use of phase terms is described in greater detail in the section “Naming Map Units” below.

Classes

Classes of soil properties are not necessarily used directly as phases. Defined class limits of properties are designed for a convenient description of soil, but they can also be used to define phases of soil map units in some cases. For example, a map unit may be named as a moderately saline phase to distinguish it from another map unit with the same name but whose soils have no significant salinity. However, property class terms are not useful for all soils. Distinctions significant for one kind of soil are not significant for every other kind. Any single property is significant only through its interactions with other properties.

Kinds of Map Units

Soils differ in size and shape of their areas, in degree of contrast with adjacent soils, and in geographic relationships. Four kinds of map units are used in soil surveys: consociations, complexes, associations, and undifferentiated groups.

In most map units, areas of soil occur that do not meet all of the taxonomic criteria of the soil (series or higher taxa) used to name the map unit. However, because these soils have properties similar to those of the named soils and interpret similarly for the dominant land uses, they are included as part of the named component. They are referred to as similar or non-contrasting soils. Conversely, minor components and unnamed soils which interpret differently for major uses, whether they are well suited (less limiting) or poorly suited (more limiting), are called dissimilar or contrasting soils.

The total amount of dissimilar minor components in a map unit generally does not exceed about 15 percent if they are limiting and 25 percent if they are nonlimiting. A single dissimilar limiting component generally does not exceed 10 percent if it is very contrasting.

In most cases, soil map units can be delineated as polygons. However, in some cases a polygon cannot be drawn to conform to cartographic standards due to size or shape constraints. In these cases, lines or points may be used to designate map units. If this is necessary, the narrow width or small size is included in the map unit description to indicate the nature of the soils on the landscape.

Consociations

In a consociation, delineated areas are dominated by a single soil component (or miscellaneous area). Commonly, at least one-half of the pedons in each delineation are of the same soil taxa as the named soil. The remainder of the delineation mostly consists of soil so similar to the named soil that major interpretations are not significantly affected. The map unit component thus consists of soil meeting the criteria for the taxonomic class (series or higher taxa) used to name the map unit plus similar soils. The soil in a consociation may be identified at any taxonomic level.

A consociation that is named for a miscellaneous area (such as Rock outcrop) dominantly consists of that kind of area, and any minor components present do not significantly affect the use of the map unit. Generally, less than about 15 percent of any delineation is soil or less than about 25 percent is other kinds of miscellaneous areas. Percentages may vary, depending upon the kind of miscellaneous area and the kind, size, and pattern of the minor components.

Complexes

Complexes consist of two or more dissimilar major components that occur in a regularly repeating pattern or in an unpredictable pattern. The major components of a complex cannot be mapped separately at a scale of about 1:24,000 (fig. 4-4). Typically, each major component occurs in each delineation, although the proportions may vary appreciably from one delineation to another. The major components are sufficiently different from each other in morphology or behavior that the map unit cannot be a consociation.

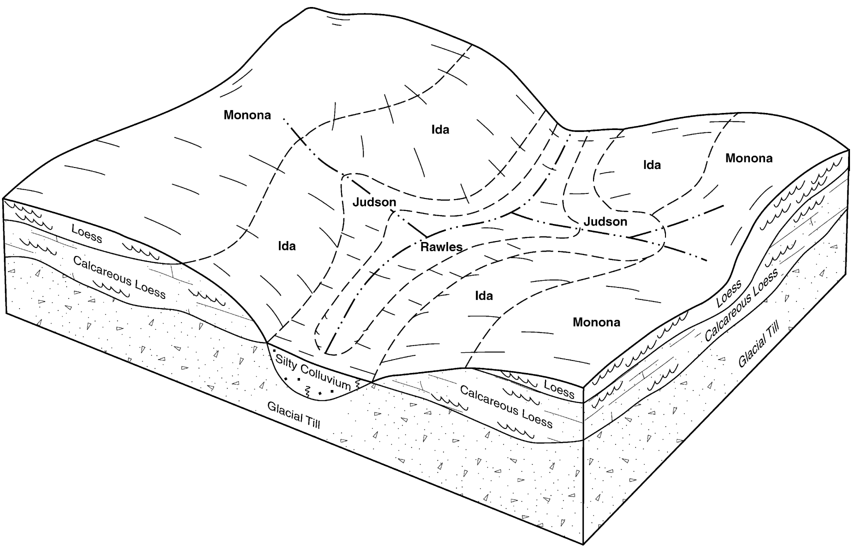
Figure 4-4

An area that meets the definition of a soil complex—the major components cannot be mapped separately at a scale of about 1:24,000. The bottom photo shows the profile of the Bluepoint series (Typic Torripsamments) that has formed as a coppice dune. The middle photo shows the distribution of the coppice dunes on the eroded phase of the Rotura series (Typic Petroargids). The top photo shows a landscape of the Bluepoint-Rotura complex in southern New Mexico.

Associations

Associations consist of two or more dissimilar major components occurring in a regular and repeating pattern on the landscape. The major components of an association can be separated at a scale of about 1:24,000, but due to land use or user needs, the map unit design integrates the predictable and repeating pattern of soil occurrence. Many general soil maps use soil associations because they are at scales much smaller than 1:24,000 and can depict only the characteristic landscapes of associated soils, not the individual soils (fig. 4-5). The major components are sufficiently different in morphology or behavior that the map unit cannot be a consociation.

Figure 4-5



Block diagram depicting the relationship of the soils in the Monona-Ida-Judson association in the general soil map (published scale of 1:125,000) of Woodbury County, Iowa (USDA-NRCS, 2006). Because a general soil map cannot show the location of each soil making up an association, accompanying diagrams such as this are commonly used. Monona soils are classified as Typic Hapludolls, Ida soils as Typic Udorthents, Judson soils as Cumulic Hapludolls, and Rawles soils as Oxyaquic Udifluvents.

Undifferentiated Groups

An undifferentiated group is a map unit of dissimilar soils that are not consistently associated geographically and, therefore, do not always occur together in the same map unit delineation. These components are included in the same named map unit because use and management are the same or very similar for common uses. Generally, some common feature outside of the soil itself, such as steepness, stoniness, or flooding, determines use and management. If two or more very steep soils that are geographically separated are so similar in their potentials for use and management that defining two or more additional map units would serve no useful purpose, they may be placed in the same unit. Every delineation has at least one of the major components and some may have all of them.

Minor Components Within Map Units

In all soil surveys, virtually every delineation of a map unit includes areas of soil components or miscellaneous areas that are not identified in the name of the map unit. Many areas of these components are too small to be delineated separately. Examples are small areas of steeper slopes or small areas of wet soils in an upland map unit. The location of some components cannot be identified by practical field methods. Some minor components are deliberately included in delineations identified as another map unit to avoid excessive detail on the map or the legend. These soils of very limited extent were referred to simply as "inclusions" in mapping before the mid-1990s, but are now identified as minor components and correlated to the lowest level of classification, as appropriate. Minor components are not indicated in the map unit name, but they are observed and documented in the map unit description.

Minor components reduce the homogeneity of map units and may affect interpretations. The objective is to define map units that contain as few as possible minor components that behave differently from the named components. Map units must be defined, recognized, and delineated consistently in the field.

The number of minor components reflects the taxonomic purity of map units. This number and the degree that contrasting minor components differ from the major components can be used to estimate the interpretative purity of map units. The actual amount of minor components is estimated from observations made during the survey. Adjustments in mapping and map unit design may be needed.

In the definition of map units, a scientist must judge the effects of minor components on management against the amount of work required to minimize the number of minor components. Determining the impact of the differences between the major and minor components is useful. If differences are small, the components are compared as similar. If differences are large, the components are contrasted as dissimilar.

Similar components are alike in most properties and share diagnostic properties and limits. Interpretations for most common uses are alike or reasonably similar and the interpretative value of the map unit is not affected. In contrast, dissimilar components differ appreciably in one or more properties, and the differences are great enough to affect major interpretations. Some dissimilar components are limiting and others are nonlimiting relative to the interpretations being considered.

If a minor component does not restrict the use of entire areas or impose limitations on the feasibility of management practices, its impact on predictions for the map unit is small. Minor components that have restrictions on use less severe than those of the dominant soil do not adversely affect predictions about the unit as a whole. They may even be beneficial. Such minor components are nonlimiting, and the interpretative purity of a map unit for most interpretations is not altered. For example, including small areas having slopes of 4 to 8 percent in an area having slopes mainly of 15 to 25 percent has no adverse effect on use of the area for most purposes. However, if the minor component has significantly lower potential for use than the dominant component in the map unit or affects the feasibility of meeting management needs, a small amount in a map unit can greatly affect predictions. These are the most critical minor components because they decrease the interpretative purity of map units. Even a small area having slopes of 15 to 25 percent in a map unit dominated by slopes of 4 to 8 percent can seriously affect the use of the area for many purposes. Even small minor components of wetter soils (such as Typic Epiaqualfs) in areas of upland soils (such as Aquic Hapludalfs) may control and limit the uses of the dominant soil component.

Soils that cannot be used feasibly for the same purposes as the surrounding soils are especially important to identify. They are delineated separately if the map scale is small enough and if delineating them will improve the usefulness of the map for the major anticipated uses. Areas too small to delineate may be identified and located on the map by special symbols.

Limiting Dissimilar Soils

Standards of purity are adjusted according to the precision required by the survey objectives. Generally, all delineations contain soils other than those identified in the map unit name. These minor components reduce purity. Different kinds of minor components, however, have different effects on the value of the map for use. The minor components that most detract from purity are those that are distinctly more limiting for use than the named soil. These are called limiting dissimilar soils. A soil may be a limiting dissimilar soil for some uses but not for others. The survey objectives must be considered when assigning limiting dissimilar soils. Not only the amount of limiting soils but also the size of their individual areas is important. Soil survey standards for both are set at levels that do not seriously detract from the validity of interpretations based on the named soil.

Standards of purity are attained by adjusting the field operations. For example, if the standards require that areas of limiting dissimilar soils as small as 0.1 ha be delineated, the area must be traversed at intervals close enough to locate areas that small and the soil must be examined at enough places along each traverse to detect them.

Designing and Documenting Map Units

Designing Map Units

Well designed map units are based on accurate soil-landscape models. They can be consistently associated with features observable on the surface (e.g., vegetation and geomorphic position) and consistently delineated by the survey team. Initial investigations identify the pattern of occurrence for each component making up the map unit. In most cases, well designed map units require a relatively few number of observations to delineate accurately.

Knowing the Parameters

Guidance documents (such as a memorandum of understanding or other project plan) outline considerations for the order of mapping, scale of mapping, minimum size delineation, base imagery (if used), documentation requirements, and specific interpretive needs of the user. The survey team is responsible for collecting complete and accurate soil data, assessing the complexity of the soil landscape, and designing map units that support land use decisions and meet the objectives of the survey project. If the information is too broad or too complex, the objectives of the survey will not be met.

While studying the soil patterns in different landscapes, soil scientists must keep in mind how best to relate the patterns observed to the appropriate map units. They must determine the kinds of map units, the level of soil taxa, and the phases needed to satisfy the survey objectives. By definition, a map unit differs from all others in the survey area and should be uniquely identified. This requires many judgements and hypothesis testing. Every map unit that is tentatively identified is evaluated by three tests: (1) Does it capture the characteristic signature in the landscape that can be recognized from remote sensing imagery or field observation? (2) Is it recognizable and repeatable for consistent mapping? (3) Is it needed to meet the objectives of the survey?

Delineating the Areas

The landscape is partitioned either in the field or using remotely sensed data. The first step is to group areas having the same soil-forming factors (chapter 1) and known catenas or conceptual models of related soils. This premapping step groups defined landscapes, landforms, geology, vegetation, and climatic areas. Areas that have these same repeating patterns are delineated and labeled as the same map unit. It is recommended that broad groupings are established first. The lines can be adjusted as the survey team completes fieldwork to verify map units and refine concepts.

Most Important Soil Line

Designing map units to indicate significant differences in behavior among soils is particularly important for meeting the current objectives of a survey. Map units separated according to differences in geomorphic processes (e.g., parent material, relief, and time) are considered the most important soil lines on the landscape. These lines should be the first delineated on a map. Indicating differences in geomorphic processes is important, even if no immediate differences in interpretations are known. Differences in soil properties that do not affect current interpretations may be important in the future. Too many delineations may greatly reduce the immediate usefulness of a soil map. The potential benefit of extra delineations (the value of the additional information) must be weighed carefully against the costs incurred in making additional separations. Every soil survey is designed to record knowledge about soils; however, this does not mean that the soil map must show the location of every kind of soil in a survey area or that the publication must record everything that is known about the soils. Capturing and managing all observations of soil data on maps, even if the data is not used for publication, is invaluable in later analysis to develop new maps or update soil information.

Defining the Components

The objectives of a survey determine the kind of map units and the kind of components used to define the map units (see table 4-1).

Taxonomic classes provide the framework upon which the basic sets of soil properties distinguishing soil map units are defined. They summarize an immense amount of research and experience related to the significance of soil properties and combinations of properties. They provide predefined sets of soil properties that have been tested for genetic relationships and interpretative value. Taxa provide a firm base for recognizing the components of potential map units in an unfamiliar area. Using established taxa is much easier than independently sorting out sets of properties and determining significant class limits.

Within each survey, soil maps can be designed with components correlated to a taxonomic level that reflects narrowly or broadly defined ranges of soil properties. In addition, map units can be designed with different compositions of major and minor components. Design flexibility allows the development of map units that will be useful for the purposes of a specific survey while maintaining as much uniformity in mapping as possible.

Traverses

Traverses are used to identify different components on a landform. The observation points along a traverse can be any distance apart. The distance is adjusted to the direction and scale of the soil boundaries and the variability of the important properties in each component. Sites for each observation are chosen to represent specific areas on a landform. For example, one recommended way to lay out a traverse in a field is to travel in a direction perpendicular to local drainage patterns. The soil components can then be documented in a swale where it is darkest, on a ridge where it is lightest in color, and also in the footslope and backslope positions (for observations of transitions between areas). Once the soil component is known for each position, a landform model can be developed for use in similar areas throughout the survey area.

Transects

Transects are used to determine the composition and design of map units. They have fixed length intervals between observation points. Observations made at points along a transect are typically identified as belonging to a particular taxon, or soil component, but can also be a combination of properties, such as depth, thickness, color, or vegetation.

When selecting delineations for transecting, it is essential to eliminate bias by stratifying transects randomly. One simple method is to separate the survey into several subdivisions and conduct transects within each subdivision. The different land uses (e.g., cropland and forestland) in each delineation of a map unit should be considered, and transects should be conducted in map units under each land use. Transects must be positioned to encounter the maximum variation in each delineation. The transect should be oriented so that the line does not follow a contour around a hill. Transects should go up and down the hill and across drainages.

Systematic variation is quantified and more easily understood with a transect. A map unit complex consisting of a soil component in concave positions and another soil component in convex positions is an example of a map unit exhibiting systematic variation. Interval spacing in the transect must be small enough to capture the variability of the landform. Narrow map units can be problematic because a straight line transect may not fit or may miss the variability visually observed. In such cases, measured line segment transects can be used to ensure all components are captured and quantified. Typically, only a small percentage of the map unit delineations contain transects. As the order of survey increases, the length and intervals in a transect also increase. In all cases, transecting is not the same as line mapping used to determine the placement of map unit boundaries on a landform.

Random variation (i.e., variation that is not understood and therefore cannot be readily explained) can also be quantified using transects. Areas containing soil properties that are not readily observed or explained, as in stratified layers of alluvium or depth to bedrock on a loess-covered basalt plain, are well suited to grid or stratified random transects. Random variation methods for transecting can also be used to accurately quantify components having systematic variation. Methods designed specifically to document systematic variation transecting should not be used to quantify components having random variation.

Other statistical methods to determine composition, such as Latin hypercube sampling, are employed in digital soil mapping techniques (see chapter 5). Site selection using digital techniques can be used when digital mapping is performed. Latin hypercube sampling is especially useful if the field investigator is inexperienced or lacks the intrinsic knowledge of the landscape and soil patterns.

Naming Map Units

A map unit is uniquely named to distinguish it from all others in the survey area. Different conventions are used for each of the four kinds of map units so that the kind of unit is easily recognizable. In general, names are as short as possible. Map unit names typically include the named major components, both soil and nonsoil, that occur in the map unit. Miscellaneous areas are named if they occur as a major component. Commonly an extra term, such as surface texture, which is not needed to distinguish a phase from all others in the survey, is used so that comparable phases in other areas have the same name.

Phases are groupings created to serve specific purposes in individual soil surveys. They can be defined for any class or classes of any category. Table 4-3 lists some commonly used phase terms. Other terms can be developed as necessary. The phase classes are helpful in describing the soil phases that are important for the survey. Differences in soil or environmental features that are significant to use and management or soil behavior are the basis for designating soil phases.

Any property or combination of properties that does not duplicate class limits for a taxon can be used to differentiate phases, and any value of a property can be set to divide phases. The choice of properties and limits are determined by the purpose of the survey and by how consistently the phase criteria can be applied. Because objectives differ from one soil survey to another, limits and ranges of a property or attribute may also differ from one survey to another. In general, phase criteria are given a smaller range where soil use is intensive (as for irrigated farming or urban development) and a larger range where soil use is extensive (as for forestry or grazing).

For detailed surveys, decisions must be made about what criteria to use to recognize phases of soil components, how broadly or narrowly to define the phases, and whether similar phases of different components have interpretations similar enough that they can be combined. Phases are used to convey important information about a map unit and to differentiate it from other map units in the legend. For less-detailed surveys, decisions must be made about how the complexities of soil in large areas can be best identified and represented for purposes of the survey, what combinations of soils characterize useful and mappable units, what taxonomic level should be used in naming map unit components, and which phases contribute to the usefulness of the map units.

The names of soil taxa, along with one or more modifying terms, are used to identify the soils in map units. For example, the name "Tama silt loam, 2 to 5 percent slopes" indicates that soils of the Tama series (an Udoll) are dominant in that map unit. The names of taxa of higher categories are also used in map unit names, especially on small-scale maps. For example, "Udolls, rolling" identifies a map unit consisting dominantly of soils of the Udoll suborder, which includes Tama and other series.

As methods of measuring soil properties are refined, as experience in the field increases, and as use and management requirements are

Table 4-3

Phases Most Commonly Used in Naming Soil Map Units

[Terms are listed in preferred order of occurrence if more than one phase term is used.]

Phase group	Phase usage
Surface texture	USDA surface texture name
Deposits on the surface	*Overblown, wind hummocky,* and *overwash*
Fragments	Size and quantity classes, including *gravelly, cobbly, stony,* and *rocky*, or *artifactual* (anthropogenic) and appropriate modifier of *non, very,* or *extremely*
Slope	Expressed as percent or a descriptive slope class, such as *nearly level, gently sloping (undulating), strongly sloping (rolling), moderately steep (hilly), steep,* and *very steep*
Depth	*Shallow* or *deep*, and appropriate modifier (such as *moderately* or *very)*
Substratum	Contrasting material as base of named soil (e.g., *sandy substratum, gravelly substratum, saline substratum*)
Soil water state	Reference to water table, drainage classes, wetness, flooding, or ponding or to artificial drainage (*drained)*
Salinity	*Nonsaline* through *strongly saline*
Sodicity	*Sodic*, with modifier as needed (e.g., *strongly sodic*)
Physiography	Landscape or physiographic term, as appropriate
Erosion	Degree of erosion, from *slightly eroded* through *severely eroded,* and *gullied*
Thickness	Thick or thin surface horizon or subsoil (e.g., *thick surface, thin solum*)
Climate	Precipitation and temperature variation (e.g., *high precipitation, cool*)

intensified, progressively narrower ranges in soil properties can be recognized or established. Narrow ranges of properties should not be established just because methods permit it. Unnecessary separations take time to delineate consistently, and they make the survey difficult to use. However, not separating two significantly different, mappable units makes a survey less useful. The significance of each map unit in meeting the objectives of the survey must be constantly evaluated during the mapping process.

Orders of Soil Surveys

All soil surveys are made by examining, describing, and classifying soils in the field and delineating their areas on maps. Some surveys are made to serve users who need precise information about the soil resources of areas a few hectares or less in size. These surveys require refined distinctions among small, homogeneous areas of soil. Others are made for users who need a broad perspective of heterogeneous, but distinctive, areas thousands of hectares in size. A soil survey made for one group of users may not be useful for another group.

The elements of a soil survey can be adjusted to provide the most useful product for the intended purposes. Different intensities of field study, different degrees of detail in mapping, different phases or levels of abstraction in defining and naming map units, and different map unit designs produce a wide range of soil surveys. Adjustments in these elements form the basis for differentiating five orders of soil surveys. Table 4-4 is a key for identifying orders of soil surveys.

Recognition of these different levels of detail is helpful in communicating information about soil surveys and maps, even though the levels cannot be sharply separated from each other. The orders are intended to convey the level of detail used in making a survey, the scale used to delineate map units, and how general the map units are. They also indicate the general levels of quality control that are applied during surveys. These levels affect the kind and precision of subsequent interpretations and predictions. The orders differ in the following elements:

- The soil survey legend, including:
    - the kinds of map units (consociations, complexes, associations, and undifferentiated groups) and
    - the kinds of soil taxa used in identifying the map unit components (soil series, families, subgroups, great groups, suborders, orders, and phases of them);
- The standard for purity (in composition or probability) of delineated soil areas, including:

    - the minimum area of a limiting dissimilar soil that must be delineated separately and thus excluded from areas identified as another kind of soil, and
    - the maximum percentage of limiting dissimilar minor components that is permissible in a map unit;
- The field operations necessary to identify and delineate areas of the map units within prescribed standards; and
- The minimum map scale required to accommodate the map units of the legend, the standards of minimum composition, and the map detail justified by field methods.

Mapping legends are designed to provide the degree of refinement of map units required by the objectives of the survey. A map unit can be identified as a consociation (an area dominated by a soil component of a single taxon, such as a series or suborder) or as a group (geographic mixture) of taxa, such as an association or complex. A group may be more heterogeneous, and less refined, than a consociation at the same level of classification. A soil series has a much more narrowly defined set of soil properties than a suborder and, therefore, is a more refined distinction. Thus, phases of soil series are used as map unit components if users need more precise information about small areas of soils. Phases of any category in Soil Taxonomy might be used as soil map unit components if only a very broad perspective of the soil resources of very large areas is needed.

Scale and Order of Mapping

The order of a survey is commonly reflected in the scale of mapping, but not determined by it. Rather, the order of a survey is determined by the field procedures used to identify soil components and place map unit boundaries, the minimum permissible size of map unit delineation, and the kind of map unit to which soil components are aggregated. Where soil maps are available in digital form, computer software allows users to change the map scale for display purposes. The ability to enlarge a map in this way can lead to misunderstanding the accuracy and level of detail on the soil map. The scale used to make the survey is the scale that must be used to display the mapping. See the 1993 *Soil Survey Manual* (Soil Survey Division Staff, 1993) for a discussion on scale and map legibility.

Digital soil mapping techniques (discussed in chapter 5) augment field procedures and remote sensing in identifying soil map components and placement of map unit boundaries. The benefits of digital soil mapping increase with increasing order of soil mapping.

Table 4-4

Key for Identifying Orders of Soil Surveys

Order and level of data needed	Field procedures	Min. size of map units *(ha)*[1]	Typical components of map units	Kind of map units[2]	Appropriate scales for field mapping and publications
Order 1 —Very intensive (e.g., experimental plots, individual building sites, required reviews and permits from regulatory agencies)	The soils in each delineation are identified by transecting or traversing or even grid mapping. Soil boundaries are observed throughout their length. Remotely sensed data are used as an aid in boundary delineation.	1 or less	Phases of soil series; misc. areas	Mostly consociations; some complexes; misc. areas	1:15,840 or larger
Order 2 —Intensive (e.g., general agriculture, urban planning)	The soils in each delineation are identified by field observations and by remotely sensed data. Boundaries are verified at closely spaced intervals.	0.6 to 4	Phases of soil series; misc. areas; few components named at a level above the series	Consociations, complexes; few associations and undifferentiated groups	1:12,000 to 1:31,680
Order 3 —Extensive (e.g., range, community planning)	Soil boundaries are plotted by observation and interpretation of remotely sensed data. They are verified by traversing representative areas and by some transects.	1.6 to 16	Phases of soil series or taxa above the series; misc. areas	Mostly associations or complexes; some consociations and undifferentiated groups	1:20,000 to 1:63,360

Table 4-4.—continued

Order and level of data needed	Field procedures	Min. size of map units *(ha)*[1]	Typical components of map units	Kind of map units[2]	Appropriate scales for field mapping and publications
Order 4 —Extensive (e.g., general soil information for broad statements concerning land use potential and general land management)	Soil boundaries are plotted by interpretation of remotely sensed data. They are verified by traversing representative areas and by some transects.	16 to 252	Phases of soil series or taxa above the series; misc. areas	Mostly associations; some complexes, consociations, and undifferentiated groups	1:63,360 to 1:250,000
Order 5 —Very extensive (e.g., regional planning, selection of areas for more intensive study)	The soil patterns and composition of map units are determined by mapping representative ideas and like areas by interpretation of remotely sensed data. Soils are verified by some onsite investigation or by traversing.	252 to 4,000	Phases of levels above the series; misc. areas	Associations; some consociations and undifferentiated groups	1:250,000 to 1:1,000,000 or smaller

[1] This is about the smallest delineation allowable for readable soil maps. In practice, the minimum size of delineations is generally larger than that shown in table.

[2] Where applicable, all kinds of map units (consociations, complexes, associations, and undifferentiated groups) can be used in any order of soil survey.

Order 1 Surveys

Order 1 (or first order) surveys are made if very detailed information about soils, generally in small areas, is needed for very intensive land uses. These land uses commonly require reviews and permits from regulatory agencies, engineers, and other professionals. Order 1 surveys are also conducted for specialized information, such as for critical habitat or cultural resources. The information can be used to plan for irrigation, drainage, truck crops, citrus or other specialty crops, and experimental plots; to site individual building lots; to locate disturbed areas or anthropogenic landforms (see chapter 11); to delineate wetlands and special habitat; and for other uses that require a detailed and very precise knowledge of the soils and their variability. Order 1 surveys are also referred to as high-intensity soil surveys.

Transecting, traversing, and, in some cases, grid mapping are used for accurate placement of soil boundary lines over small distances. Soil boundaries can be marked in the field with flagging for accurate location by GPS or standard land surveying methods and later transferred to a base map using mapping software. Remotely sensed data and digital techniques using LiDAR and ground-penetrating radar (chapter 6) can aid in soil boundary delineation. Typically, soil pits are used to determine parent material, bedrock, and drainage classes. They are mechanically dug with small excavators or backhoes.

Order 1 surveys have high map unit purity. Map units are typically consociations, containing no more than 15 percent dissimilar minor components. Complexes are seldom used. Map unit components can be phases of soil series, taxonomic categories above the soil series, or miscellaneous areas. Some map units may be named at a categorical level above the series or named for the type of material (e.g., "excavated," "regraded"). Soil mapping legends may use taxonomic categories or connotative terms that are customized for users. Delineation size is designed to meet the detailed needs of the survey. Many order 1 surveys use a minimum size of about 1 hectare (2.5 acres). Depending on scale, environmental concerns, and needs of the survey, as small as 2,000 square feet may be used. Base map scale is generally 1:15,840 or larger and may be as large as 1 cm = 15 m (1 inch = 20 feet). Order 1 base maps may also have perimeter surveys determined by a professional land surveyor and show detailed topography with less than 2-foot interval contour lines. Order 1 surveys may employ significantly different methodologies than traditional order 2 and 3 surveys, such as a connotative legend. A connotative legend has map unit symbols that notate specific interpretive or inherent properties of the taxonomic component (e.g., drainage class, texture, hydrologic soil group) or any aspect of a component that is of interest to the user. Typical end users of a high-intensity soil survey, such as engineers, regulatory agency staff (Federal, State, and local), land developers, wetland scientists, site evaluators (e.g., septic system designers), and other professionals, generally are not familiar with the named soil series on a map.

Due to the deviations from normal soil survey standards to accommodate unique user needs and the lack of a formal soil correlation process, order 1 surveys in the U.S. are treated as special types of onsite investigations and are not part of the official soil survey for the National Cooperative Soil Survey. Order 1 surveys can differ from order 2 and 3 surveys in the landscape models used to explain soil and landform distribution. It is useful to view order 1 components at an order 2 or 3 level to better understand landscape patterns.

Order 2 Surveys

Order 2 (or second order) surveys are made if detailed information about soil resources is needed to make predictions of soil suitability and treatment needs for intensive land uses. The information can be used in planning for general agriculture, construction, urban development, and similar uses that require precise knowledge of the soils and their variability.

Field procedures allow plotting of soil boundaries by observation and by interpretation of remotely sensed data. The soils in each delineation are identified primarily by traversing and transecting. Observations and remotely sensed data are secondary types of documentation. Boundaries are verified at closely spaced intervals. Map units are mostly consociations and complexes but may also include undifferentiated groups or associations. Map unit components are phases of soil series or phases of miscellaneous areas. Map units may also be named for a taxonomic category above the series. Delineations are variable in size, with a minimum of 0.6 hectare to 4 hectares (1.5 to 10 acres), depending on landscape complexity and survey objectives. Contrasting minor components vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:12,000 to 1:31,680, depending on the complexity of the soil pattern within the area.

Order 3 Surveys

Order 3 (or third order) surveys are made where land uses do not require precise knowledge of small areas or detailed soil information. The survey areas are commonly dominated by a single land use and have few subordinate uses. The soil information can be used in planning for range, forest, and recreational areas and in community planning.

Field procedures allow plotting of most soil boundaries by observation and by interpretation of remotely sensed data. Boundaries are verified primarily by field observations, transecting, and remotely sensed data. Secondary types of documentation include traversing representative areas and applying the information to like areas. Map units include associations, complexes, consociations, and undifferentiated groups. Components of map units are phases of soil series, taxa above the series, or miscellaneous areas. Delineations have a minimum size of about 1.6 to 16 hectares (4 to 40 acres), depending on the survey objectives and complexity of the landscapes. Contrasting minor components vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:20,000 to 1:63,360, depending on the complexity of the soil pattern and intended use of the maps.

Order 4 Surveys

Order 4 (or fourth order) surveys are made if general soil information is needed about the potential and general management of land for extensive uses. The information can be used in locating, comparing, and selecting suitable areas for major kinds of land use, in regional land use planning, and in selecting areas for more intensive study and investigation.

Field procedures permit plotting of soil boundaries primarily by interpretation of remotely sensed data and transecting. Secondary documentation types are field observations. Traverses are made in representative areas to determine soil patterns, and the information is applied to like areas. Transects are made in selected delineations to estimate map unit composition. Most map units are associations, but some surveys have consociations and undifferentiated groups. Map unit components are phases of soil series, taxa above the series, or miscellaneous areas. Minimum size of delineations is about 16 to 252 hectares (40 to 640 acres). Contrasting minor components vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:63,360 to 1:250,000.

Order 5 Surveys

Order 5 (or fifth order) surveys are made to collect soil information in very large areas at a level of detail suitable for planning regional land use and interpreting information at a high level of generalization. The primary use of this information is selection of areas for more intensive study.

Field procedures consist of mapping representative areas 39 to 65 square kilometers (15 to 25 square miles) in size to determine soil patterns and composition of map units. This information is then applied to like areas by interpretation of remotely sensed data. Soils are identified by a few onsite observations or by traversing. Map units are typically associations but may include some consociations and undifferentiated groups. Map unit components are phases of taxa above the series level and miscellaneous areas. Minimum size of delineations is about 252 to 4,000 hectares (640 to 10,000 acres). Contrasting minor components vary in size and amount within the limits permitted by the kind of map unit used. Base map scale ranges from about 1:250,000 to 1:1,000,000 or smaller.

Two Orders of Soil Survey in the Same Project

Some soil survey areas have two or more separate and distinct parts with different needs. For example, one part may be mapped to make predictions related to irrigation and the other may be mapped to make predictions related to range management. For the irrigated part, areas are mapped at the intensity required for an order 2 soil survey and map unit components are mostly consociations of narrowly defined phases of soil series. For the rangeland part, areas are mapped as an order 3 survey and map units are associations, complexes, and some consociations of more broadly defined phases of soil series or of taxa above the series. Some map units of the two parts will consist of the same kinds of soil, but it is essential that map units for the two different orders of soil survey maps do not have the same names or symbols.

Large, separate, and distinct areas that are within the same project but are surveyed by different methods need to be distinguished clearly by boundaries on the published soil map or on a small-scale inset map. Each part should be identified by a note printed parallel to the line separating the areas of each survey order. The two parts need separate legends. The parts are considered as distinctly different orders of soil survey, but the results are reported in the same publication. The same or different map scales may be used for the different survey orders, depending on the intended uses.

Many order 2 surveys delineate some map units by methods that are less intensive, even though the areas mapped at different intensities are intermingled on the map. For example, within an otherwise detailed soil map, the delineations of very steep or very stony soils are commonly investigated at the intensity normally used for an order 3 survey.

Other soil surveys include areas consisting of two or more distinctive soils that could be mapped separately by detailed soil survey methods but are not, because the cost of making the separation cannot be justified. For example, a survey area that is mostly productive soils suitable for general farming may contain large areas of unproductive sandy soils covered with thick brush. Although the sandy areas contain contrasting kinds of soil that could be delineated separately, the cost of detailed mapping to separate the kinds of soils may outweigh the expected benefit. The outer boundaries of the sandy areas are plotted in as much detail and with as careful investigation as any other boundaries of the soil survey, but the sandy areas themselves are mapped using order 3 or order 4 methods. Traverses are made, and the composition of the areas is defined in terms of the kinds, proportions, and patterns of the individual soils. The delineations are described in the text of the published soil survey as soil associations mapped by methods of the appropriate survey order.

It is important to note that many soil survey areas in the U.S. were recompiled from their original mapping and publication base scale during soil survey digitizing in the 1990s. Surveys containing intensively managed or populated areas and also vast remote areas or wild lands were mapped using multiple map scales that were recompiled and digitized as a single base layer at a scale of 1:24,000. Original mapping and publication scales can be determined by referencing the original printed maps and correlation data.

Correlation Steps

Soil correlation is a multi-step quality assessment process (fig. 4-6) that ensures accuracy and consistency both within and between soil surveys on both local and regional bases. It involves classifying soils, naming map units, and providing accurate interpretations. The purpose of correlation is to provide consistency in designing and naming map units, provide effective transfer of information to and between users, and allow flexibility between the standards used in soil survey and the variability scientists observe and document geographically. Correlation is a continuous process, from the initial descriptions at the start of mapping through the final manuscript, tables, map development, and certification. It is the responsibility of all survey team members, and the decisions are based primarily on the standards used to create the survey (see table 4-5).

The correlation process is an integral part of soil survey. It is carried out on a continuing basis throughout the course of the project. Soil correlation can be described by the following steps: (1) design of map units, (2) characterization of map unts, (3) classification of map unit components, (4) correlation of map units, and (5) certification.

Figure 4-6

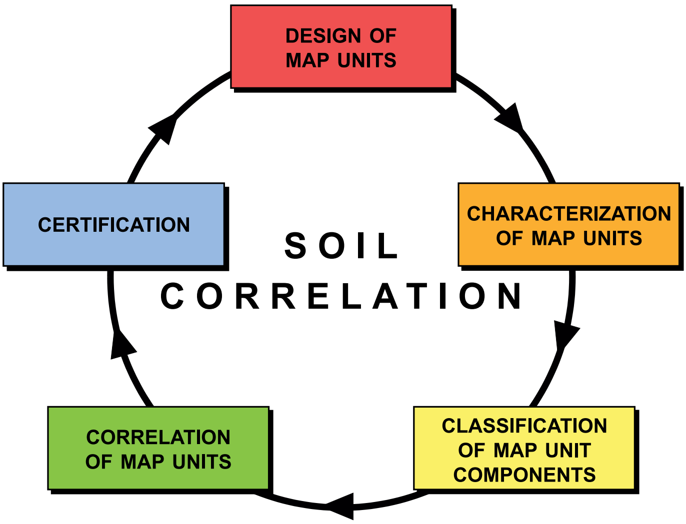


Diagram that illustrates soil correlation is a continuous process, not a single event. The process is used to facilitate consistent collection, identification, grouping, and transfer of soil information.

Design of Map Units

Every soil survey must begin with a clear understanding of the purpose and needs for the project. At a minimum, a project plan must be developed to outline the needs of a soil survey. Preferably, all partners in a survey create a memorandum of understanding and agree to it. These documents outline the scale to be used in making the survey, minimum delineation size for map units, kinds of map units, documentation requirements, and interpretation needs of the soil survey users. Commonly, there is agreement on soil-landscape models to be used and the important soil-forming factors and soil orders known in a project area. These documents are essential to balancing survey detail, survey costs, and time frames for a project.

A map unit can be tentatively correlated as soon as it has been accurately described and mapped. Map units in a survey are correlated to ensure consistency in design and level or order of mapping in a survey area.

Characterization of Map Units

Map unit characterization includes identifying the kind of components (see table 4-1 in the "Soil Map Units" section) and the kind of map units to use and what data to collect for the soil database. Surveys in high-value, heavily used areas may require that most map units be consociations with components identified to the series level. Surveys in remote areas used primarily for watershed protection or wildlife habitat may only require that map units be complexes and associations with components named for taxonomic categories above the series.

Classification of Map Unit Components

Soil pedons representing the components of the map unit are described and classified to the appropriate taxonomic level (series or higher). In addition to pedon description and classification, laboratory characterization data are collected, and interpretive features (such as ecological site descriptions; see appendix 4) may be developed. The importance of this information cannot be overemphasized. The descriptions and data provide the basic information needed for complete and accurate interpretation. Working from the soil descriptions, supervisory soil scientists can give maximum help to the survey team.

Soil taxa (series or higher category) are used to name the components making up the map unit. Soil map unit components are correlated internally to ensure that classification is consistent and that the recorded properties coincide with established taxonomic limits. Property ranges documented for the component that extend slightly beyond the taxonomic ranges are used to document and interpret the map unit component. Laboratory data supports the aggregation or grouping of pedons as well as soil database population. Pedons described in U.S. surveys use the Soil Taxonomy system of classification.

There are four main purposes of Soil Taxonomy. The first is to facilitate communication among soil scientists. Soil Taxonomy allows scientists to group and sort thousands of soil series in a meaningful way. Groupings can be made at various map scales by using different levels of the classification hierarchy. For the most detailed surveys, soils are grouped into the series level of components. Some order 4 surveys may use families or phases of higher taxa. Small-scale surveys may use the order or suborder level in Soil Taxonomy.

The second purpose of Soil Taxonomy is to provide names for taxa that are based on formative elements. For example, soil orders (such as Aridisols) begin with a formative element and end in "sol," the Latin word for soil. The taxa names quickly convey information about soil, including diagnostic horizons and features, moisture and temperature regimes, and natural fertility. Use of the formative elements helps organize knowledge about soils.

The third purpose is to provide a link between the conceptual classes in Soil Taxonomy and actual natural bodies of soils. The conceptual classes embody current understanding of soil genesis and geographic distribution of soils worldwide. Through the correlation process, the specific natural soil bodies (components) making up the map units depicted in soil survey maps are assigned names using the taxonomic system.

Lastly, Soil Taxonomy provides a way to transfer information and technology. It allows the transfer of information about soil properties and performance gathered at one location to other locations where the same soil occurs.

Correlation of Map Units

The correlation of map units impacts many subparts of a soil survey. Similar and dissimilar soils should be consistently and objectively evaluated and listed in map unit descriptions and databases to properly account for the complexity in a survey. A system of analyzing this information should be developed and followed. Analysis methods might include the use of spatial analysis software or tabular information in databases to identify correct groupings.

Taxonomic unit descriptions represent the range in characteristics of the dominant soils in a survey area. Each map unit should reference a typical pedon that describes the range of characteristics for that taxa within the survey. The typical pedon, and commonly the taxonomic unit description, represent only a portion of the full range in characteristics for a given soil series.

Soil interpretations and ratings are correlated to ensure that soil suitabilities or limitations are evaluated equitably across the survey. Correlation ensures consistency within the map unit descriptions, including consistent wording to describe important features and consistent use of performance data among map units having the same use and management.

Map unit correlation also includes the proper documentation of the map unit history. This includes conceptual changes that may occur over the course of a survey project as new areas are identified for use of the same map unit. Current surveys maintain and track this history in a soil database.

Certification

Soil surveys typically have a formal, final correlation document that summarizes all correlation decisions within a survey project. This document lists the final versions of map unit and taxonomic legends and explains the reasons for combining soils into map units, any classification anomalies, and any geographical exceptions. An explanation of the correlation of map units and components between adjoining survey areas ensures consistency between surveys. Both initial and update surveys use a similar process to explain correlation decisions and to present new information and data collected to support those decisions.

Correlation documents certify that a soil survey product has followed and met the standards used to make a survey. This certification is essential for product delivery. Current delivery of U.S. soil surveys uses the publicly available Web Soil Survey (Soil Survey Staff, 2016b).

Quality Control and Quality Assurance

Quality control and quality assurance provide consistency in a survey, for mapping, classifying, and naming soils. They also include joining maps, database population, and developing interpretations. Survey activities that ensure consistency include field visits, field reviews, and survey team communication. Quality control is the process of evaluating, prioritizing, and coordinating survey activities to ensure that products meet the agreed-upon standards and user needs. It is carried out on a daily basis by each member of the soil survey team. It requires that each member be aware of the standards used in making the soil survey and adhere to those standards in their daily activities. Quality assurance is a review and assessment process, commonly led by senior soil scientists and carried out on a periodic basis. This process provides review of completed work and training of staff members to support and ensure soil survey quality for users. Progressive reviews of completed work are performed to discover and correct errors or inconsistencies within the survey and ensure consistent use of standards throughout a soil survey project. Problems identified during reviews are corrected and can be used to provide training to the survey team.

It is essential that everyone involved in making a soil survey has a thorough understanding of the standards used to conduct it. Table 4-5 lists ways standards are used in creating soil surveys. Standards are dynamic, changing to meet current needs of users and keep pace with technology. It is important to know what the standards were when a soil survey was initially made because they will impact soil survey maintenance and update.

Table 4-5

Major Applications of Soil Survey Standards

- Designing and controlling map legends
- Identifying, describing, and classifying soils in the field
- Delineating soil boundaries on a map
- Determining map unit composition
- Populating soil databases
- Preparing map unit descriptions
- Selecting and classifying representative pedons
- Naming map units
- Conducting special studies
- Preparing or testing interpretations
- Preparing soil survey manuscript and database
- Preparing correlation documentation
- Making documentation requirements
- Evaluating data
- Developing analytical procedures

Records and Documentation

Keeping definitions and names of soil taxa up to date is essential for identification of map units, for correlation of soils nationwide, and for transfer of information about soils at one place to similar kinds of soil elsewhere. Different methods can be used and periodically modified. Some kind of centralized system is needed to obtain a nationwide perspective, to maintain standards for defining soil taxa, to assemble field and laboratory data, and to disseminate information to the field. See chapter 7 for more information.

Soil Series Definitions

Soil series are used for naming most map units in U.S. soil surveys. There are currently more than 22,000 series defined and named. Soil series definitions are the framework within which most of the detailed information about U.S. soils is identified with soils at specific places. They also provide the principal medium through which detailed information about the soil and its behavior at one place is projected to similar soils at other places. The concepts of the series category and of individual series have changed over time.

Rigorous standards for definitions of soil series ensure that names and descriptions for the same kinds of soils are consistent from survey to survey. Consistency is a major objective of the correlation process. The classes of the soil series category are not static. As new knowledge is acquired, definitions of some established series must be modified. New series are defined for newly recognized kinds of soils. Changes in criteria or limits of taxa in higher categories commonly require modification of definitions of member series.

Keeping records of series names and updating definitions of series is a continuous process. Changes should be made in ways that detract the least from the predictive value associated with the earlier definitions and names. A centralized system for keeping records of soil series names and definitions ensures that names and definitions of soil series meet the rigorous standards needed in a national soil survey program.

Official Soil Series Descriptions

Each soil series must be defined as fully and accurately as existing knowledge permits. This applies to proposed soil series used in an individual survey as well as to established series. To ensure the inclusion of essential information and to permit comparison of series definitions, a standard format for recording specific kinds of information is used.

Official soil series descriptions (OSD) record definitions and other relevant information about each series. The format and the kind and amount of detail may change from time to time, but a detailed definition is essential. Generally, descriptive information is also needed to aid the reader in identifying the soil in the landscape and relating it to other kinds of soil.

Since soil series are not listed and described in *Soil Taxonomy*, a system is required to record and store this information in an easily accessible format. In the United States, soil series are maintained in the Official Soil Series Descriptions database (Soil Survey Staff, 2016a). An official soil series description in the U.S. includes the features and sections listed below, in the order shown. Some items (such as 1, 2, 4, 16, and 17) are partly or wholly applicable only in the U.S. system designed to store series descriptions. This list can be modified for other systems. See appendix 1 for an example of an official soil series description.

Features and sections of an OSD:

1. Location line with first instance of series name and the States using it (FIPS code)

2. Status of soil series (tentative, established, or inactive)
3. Initials of authors (up to three sets of initials; those of the original author are listed first)
4. Date of latest revision in mm/yyyy format (auto-generated if using the SC-OSD maintenance tool)
5. Name of soil series
6. Introductory paragraph. It includes information on the general nature of the soil (including soil depth, drainage, and parent material and its probable sources); landscape information (including position on landform and slope ranges); and climatic information (such as average annual air temperature, annual precipitation, frost-free season, and elevation). It may also include specific information important to the pedogenic processes and landscape evolution for the series.
7. Taxonomic class. The full taxonomic name of the family taxon is given. It indicates the classes that provide limits of properties that are diagnostic for the series at all categorical levels, except for those between series of the same family.
8. Typical pedon. A typical pedon and its horizons are described in as much detail as necessary to recognize taxonomic class. Horizons and features that are diagnostic for the pedon are described.
9. Type location. The location at which the pedon was described is specified. It is given in geographic unit coordinates and is descriptively accurate enough that it can be identified in the field.
10. Range in characteristics. The ranges of properties of the series are described. This section also contains statements about the relationship of the series control section and diagnostic horizons to vertical subdivisions of the typical pedon.
11. Competing series. The series is distinguished from the other series within the same or similar class with which it might be confused. Competing series commonly share limits with the series described or are members of the same family.
12. Geographic setting. The physiography and landscape in which the soil occurs are described.
13. Geographically associated soils. Other soils with which the series is closely associated geographically are identified.
14. Drainage and saturated hydraulic conductivity ("permeability" in older series). Drainage of the soil is described by drainage class or other means of description relative to soil moisture regimes and the rate of water movement through the soil. Seasonal wetness or dryness, if important, is also described.

15. Use and vegetation. Major uses of the soil and dominant kinds of vegetation that grow on it are described. Native plants, if known, are identified.
16. Distribution and extent. The known geographic distribution (generally physiographic areas, States, and MLRAs) is given along with whether the soil occupies a small, intermediate, or large aggregate area.
17. Soil survey regional office (SSRO) responsible. This is the NRCS soil survey regional office that provides quality assurance review and maintenance of soil series records.
18. Series proposed or series established. Date and location of the soil survey project in which the series was established are given.
19. Remarks on diagnostic horizons and features recognized in the pedon. All of the diagnostic horizons and features, including thickness, depth, and horizons needed in determining the taxonomic class, are listed.
20. Additional data as needed. This section is generally used to document sampling and laboratory analysis associated with the series and information specific to the survey or investigation project.

Other items that may enhance the official soil series descriptions for a broader audience include:

- Pictures of the profile and landscape setting for individual series, and
- Ability to search archived series descriptions for diagnostic features, horizon thicknesses, and other soil characteristics that need to be interpreted.

Soil Handbook

The descriptive legend is the main document governing field operations, but it is only part of the information compiled during a survey. The descriptive legend—the basic document of a soil survey—consists of four parts: (1) description and classification of the soils, (2) identification legend, (3) conventional and special symbols legend, and (4) general soil map and legend. The descriptive legend and the other information about the soils in the survey area are organized into a soil handbook (not to be confused with the *National Soil Survey Handbook,* which is the repository of NCSS policy and guidance). The soil handbook is used by the field team and by engineers, agronomists, planners, and others who need information about the soils of the area before the survey is completed.

The soil handbook contains everything needed for the published soil survey, plus material that is important to the soil scientists making the survey. A detailed outline for the text of the published soil survey should guide development of the handbook. The descriptive legend and soil handbook should follow the same format that will be used for the published soil survey. A soil handbook that is kept up to date as mapping progresses will require a minimum amount of editing after the mapping has been completed.

In addition to the mapping legend, a soil handbook includes interpretations and general sections covering topics related to the kinds of soil in the area, such as climate, physiography, relief, drainage, geology, and vegetation. This information improves the understanding of the properties, distribution, use, and management of the soils.

A record of the extent of each map unit is also maintained. In some surveys, the map unit extent is recorded progressively as the field sheets are completed. In other surveys, progressive extent records of each map unit are kept only until the unit is deemed extensive enough to keep in the legend. The final tally is made after the survey has been completed.

Some items prepared for the mapping legend or handbook may be incorporated into different sections of the publication. For example, the genetic key and classification table could become part of the section on how the soils formed and how they are classified. Some diagrams could be used in that section as well as in the section on the general soil map.

Description and Classification of the Soils

The descriptive legend includes descriptions of the soil taxa as they occur in the survey area and descriptions of map units delineated on field sheets. These descriptions form the primary reference document for identifying kinds of soils and miscellaneous areas and provide the information needed for proper classification, correlation, and interpretation. They also provide the information needed to recognize the map units in the survey area. Descriptions of the taxa and the map units, including the ranges in characteristics within the survey area, ensure that all members of the field team classify and map the soils consistently. Creating a clear, concise, accurate, and complete set of descriptions of the soils is a difficult and important job.

An up-to-date record of what has been learned about the soils is especially important when members of a survey team change. If the project leader leaves before completion of the survey area, an up-to-date descriptive legend of how the soils have been classified and mapped ensures continuity in survey operations.

The project leader organizes the information that has been gathered about the soils in an area. While preparing the descriptions, the project leader may discover items that need clarification or supporting field data. Field studies can then be planned to clarify concepts and improve knowledge of the soils.

Guidelines for describing soils presented earlier in this chapter emphasize individual pedons and polypedons used to define soil map unit components. The soil descriptions in the descriptive legend give the properties of pedons and polypedons plus the extent of the components in each map unit, the variations in properties and in extent of components from one delineation to another throughout the survey area, and the geographic relationships of components within each map unit and of map units to each other. Compete descriptions of the soils in the survey are made from detailed field descriptions of pedons and polypedons, laboratory data, brief notes about internal properties and surface features, and summaries of transects. Appendix 2 gives an example of a map unit description.

As the descriptions of the soils are prepared, each map unit description is compared with the standard definition of the soil for which it is named and with the descriptions of closely related soils. The classification of the soils must be consistent with the descriptions of the components in the map units and also with the standard definition of series or other taxa.

A table of classification is included in the descriptive legend and shows how soils in the survey area fit into the national system of soil classification as presented in *Soil Taxonomy*. If soil series are used in naming map unit components, the table can list the series alphabetically, followed by the classification. Otherwise, the soils can be arranged according to the appropriate families, subgroups, etc.

The nature, kind, position, and amount of minor components are also described for every map unit. The extent, position, and significant differentiating characteristics of soils that are dissimilar to the named components of the map unit are particularly important. The extent and nature of minor components that have interpretative or management characteristics similar to those of the major components should also be determined.

Written descriptive records of the soils are references for an ongoing soil survey. The properties of a soil commonly vary from one part of a survey area to another and may be evaluated differently as a result of increased experience in the area. The soil descriptions are continually revised and updated as mapping progresses. During mapping, new map units and taxonomic units are commonly added and units determined to be of limited extent are discontinued.

As mapping progresses, kinds of soils that do not fit any map units in the legend commonly are discovered. If the kind of soil is extensive and uniquely different from the soils in other map units, it is added to the legend after it has been defined by a project member and approved by supervisory soil scientists of the cooperating agencies. Some new kinds of soil can be treated by redefinition of existing map units, and others can be treated as minor components. New, approved map units must be promptly listed in the legend and defined so that all members of the project team can use them correctly.

Some soils are so limited in extent that they should be included in other map units. It may be best to combine two or more soils that have similar use and management in one map unit. Soils that are so closely intermingled that they cannot be delineated separately should be mapped as complexes. Deletions and other changes are not made formally until the supervisory soil scientists have reviewed the proposed legend changes and deemed them acceptable. If proposed changes are not acceptable, the agency representatives and the project leader resolve any issues. A complete record is kept concerning changes in map units and the disposition of any discontinued map unit. Any changes made between field reviews are recorded in the report of the next field review.

Distinctions between map units must be larger than the ranges that normally occur in measuring diagnostic properties and locating soil boundaries. The soil descriptions must be tested to ensure that the map units are recognized and delineated consistently.

Progressive mapping by the field team is a continuing test of the legend. Inadequacies are evaluated, and any necessary changes are made in the legend. Changes are recorded on all copies of the legend, and each soil scientist in the team must clearly understand the new concepts.

Field notes are summarized periodically, and the summary is recorded in the revisions of the soil descriptive legend. If observations are not summarized and recorded promptly, they may be lost or not used by other members of the survey project.

Field reviews also test the legend and its use in mapping to determine whether survey objectives and requirements are being met. Such reviews typically involve supervisory soil scientists and representatives of cooperating agencies.

Identification Legend

A symbol is placed in each delineation on the map for identification. The identification legend is a list of these symbols and the names of the map units they represent. In some legends, the names of the map units are listed alphabetically, followed by their symbols. This list of names is used by soil scientists as they map. In other legends, the symbols are listed numerically or alphabetically, followed by their names. This list is used by everyone who reads the maps. Typically, both lists are prepared.

The identification legend links names of map units to delineations on the soil maps through the map unit symbols. Many conventions and systems are used for selecting symbols. The choice of symbols is unimportant provided that the symbols are short, that each symbol is unique, and that the map unit that each symbol represents is named and described.

All symbols must be legible on the maps when viewed on a computer screen or in hard-copy printouts. Long symbols are problematic. If they are made small enough to place on the map they may be illegible. They commonly must be placed outside small delineations and arrowed to them. This increases the chance of error. Experience and tests have shown that map users have difficulty reading field sheets that have many symbols placed outside the areas to which they correspond. If the symbol is arrowed from a large delineation to a small one, many users assume that it represents the large delineation. In addition, potentially confusing combinations in symbols should be avoided. They include the lowercase letter l with the number 1 and the capital letter O with the number 0 (zero). While map unit symbols consisting of numbers are simplest to manage, care is needed to ensure that they are distinguished from other numbers, such as coordinates, grid numbers, and other numeric attribution that may appear on finished maps.

The map symbols are primarily used to identify map units delineated within the polygons. Annotation using soil map symbols connotative with a particular soil or property should be avoided. Connotative symbols typically result in a legend that fails to achieve its primary purpose. Any connotative value of symbols may be offset by decreased legibility of the map. Use of connotative map symbols can lead to confusion and mistaken association of map symbols to soil component names, especially when map legends from adjoining survey areas are viewed together. Map users must not assume that connotative symbols or even the map unit names describe all of the important soil properties. The set of soil descriptions (map unit and taxon descriptions) is essential to the purpose of the soil survey and should be used by mappers and by those who need the information while the survey is in progress.

Using the same or similar symbols during the mapping process and on published maps accelerates map compilation because it reduces the amount of time compilers spend converting one set of symbols to another. It also reduces the amount of errors. It is most practical in areas where soils are well known. It is less practical if soils are not well known at the start of the survey, because symbols can change during mapping and correlation.

Taxonomic Legend

Taxonomic legends list all soil component names appearing in map unit names for a survey area followed by their full taxonomic classification. The names of series that are proposed are typically followed by "(P)." The names of series used for a soil taxadjunct are followed by "(T)." The taxonomic classification as observed and described in the survey area is used for the taxadjuncts.

Conventional and Special Symbols Legend

Conventional symbols on soil maps show many natural and cultural features other than map units and their boundaries. They help users locate delineations. Special symbols identify some areas of soils or miscellaneous areas that are too small to be delineated at the scale of mapping. All symbols must be defined. Definitions of special symbols should specify the size of area that each represents.

General Soil Map and Legend

The general soil map helps the field team in mapping and organizing fieldwork. It also provides, for any user of the soil survey, a general overview and introduction to the major soils and their pattern of occurrence in the survey area. The draft of the general soil map prepared during preliminary field studies is refined as more is learned about the soils. The properties, distribution, and extent of the soils in each general area and their suitabilities, limitations, and potentials are described. Significant differences in soil moisture or soil temperature between areas can also be shown on the general soil map.

Soil Maps Made by Other Methods

Although most soil maps published in the U.S. by the National Cooperative Soil Survey are made from field investigations, some are compiled from other sources. These kinds of soil maps are described below.

Generalized Soil Maps

Some users need soil information about areas larger than individual fields or tracts, perhaps as large as several square kilometers. A detailed map tends to obscure the broad relationships. Generalized soil maps are made to reveal geographic relationships that cannot be seen readily on detailed maps. Most soil survey reports include a general soil map for the area. The scale of these maps depends on the intended uses.

Generalized soil maps are made by combining the delineations of existing soil survey maps to form broader map units. A detailed map is generalized by enclosing those larger areas within which a few kinds of soil predominate in relatively consistent proportions and patterns. On the generalized soil map, detailed map units are commonly grouped based on repeating landscape segments and broader physiographic areas. The larger areas are described in terms of the dominant soils. The map is interpreted to show the combined effects of the constituent soils of each map unit.

Generalized soil maps are commonly used to appraise the basic soil resources of whole counties, to guide commercial interests, and to assist farm advisors. They serve as a basis for targeting and implementing agricultural and conservation programs. These maps are increasingly becoming the base maps for county and regional land use planning and for predicting the general suitability of large areas of soils for residential, recreational, wildlife, and other nonfarm uses.

The Digital General Soil Map of the United States (STATSGO2) is the nationally coordinated State-level general soil map of the U.S. It is produced at a scale of 1:250,000 for most of the U.S. and its territories and at a scale of 1:1,000,000 for Alaska. The level of mapping is designed for broad planning and management uses covering State, regional, and multi-State areas. STATSGO2 is comprised of general soil map units and is maintained and distributed as a spatial and tabular dataset.

Schematic Maps

Schematic maps (also called reconnaissance maps) differ from generalized soil maps in being compiled from information other than pre-existing soil maps. Scale is commonly 1:1,000,000 or smaller, although maps made at larger scales can be useful in some cases. Schematic soil maps are commonly made as a preliminary step in locating areas where further investigation is justified. For many areas, especially in undeveloped regions, a schematic soil map is useful in advance of an organized field survey. Some maps serve as the only source of soil information in areas where more intensive studies are not feasible.

Schematic soil maps are made by using many sources of information to predict the geographic distribution of different kinds of soil. Information about climate, vegetation, geology, landforms, and other factors related to soil are gathered and studied. Data obtained by remote sensing techniques, including aerial photography and satellite multispectral band imagery, may be useful. Any available information about the soil is used to the extent justified by its quality. Some soil information is available for most parts of the world, but the information for remote areas may be mainly notes by travelers and rough maps interpreted from aerial photographs and never verified on the ground.

Thematic Maps

Thematic maps are created by combining delineations of soil maps based upon a singular property theme, including soil features (e.g., surface texture, depth to water table, or salinity). They commonly represent interpretative qualities, such as suitability for septic tank absorption fields, land capability classification for farming, or hazards to use (such as flooding). Thematic maps provide a geographic comparison of a singular soil quality or feature across broad land areas. The use of digital soil map products and GIS systems together with soil attribute databases enables rapid creation and manipulation of thematic soil maps that can be easily understood by land managers and policy makers.

GIS technologies and digital mapping techniques (see chapter 5) are extremely valuable in developing generalized, schematic, and thematic maps. Combining digital data drawn from other sources with known soil information can increase the precision of map line placement as well as improve the purity of the composition or consistency in identification of soil components.

Supporting Data

Data collected during the course of a soil survey is recorded and analyzed, and then integrated in mapping, interpretation, and correlation decisions. The most notable types of supporting data and information developed are transects, field notes, photographs, laboratory analyses, investigations, special interpretations, climatic data, geology maps, vegetation maps, and research reports.

Notes are indispensable parts of the mapping legend. Some notes are used in revising the descriptive legend, which becomes incorporated into the manuscript for publication. Notes help make mapping faster and more accurate. They may record tonal patterns on aerial photographs that are peculiar to a certain map unit, the relationship between minor but key indicator plants, or surface configurations that have little bearing on use or management but help the mapper locate significant soil areas. Notes and other information needed in mapping, but not intended for publication, can be kept on separate sheets after each taxon or map unit description in the descriptive legend.

Photographs of soil profiles can be very effective in illustrating some soil features. Photographs or diagrams of soil systems and landscapes show the relationships of soils to various landscapes. Cross-sectional and three-dimensional diagrams of parts of the survey area are also helpful.

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