CHAPTER 3

Examination and Description of Soil Profiles

Revised by Soil Science Division Staff.

Introduction

A description of the soils is essential in any soil survey. This chapter provides standards and guidelines for describing the soil. It contains standard technical terms and their definitions for most soil properties and features and provides information for describing the necessary related facts. For some soils, standard terms are not adequate and must be supplemented by a narrative. Some soil properties change through time. Many properties must be observed over time and summarized if one is to fully understand the soil being described and its response to short-term environmental changes. Examples are the length of time that cracks remain open, the patterns of soil temperature and moisture, and the variations in size, shape, and hardness of clods in the surface layer of tilled soils.

This chapter does not discuss every possible soil property. For some soils, other properties need to be described. Good judgment is needed to decide what properties merit detailed attention for any given pedon (sampling unit). Observations must not be limited by preconceived ideas about what is important.

Although the format of the description and the order in which individual properties are described are less important than the content of the description, a standard format has distinct advantages. The reader can find information more rapidly, and the writer is less likely to omit important features. Furthermore, a standard format makes data entry into a computer database more efficient. Any standardized forms need to allow enough space for all possible information.

Each investigation of the internal properties of a soil is made on a soil body with certain dimensions. The body may be larger than a pedon (e.g., a backhoe pit) or represent only a portion of a pedon (e.g., a sample from a hand auger). During field operations, many soils are investigated by examining the soil material removed by a sampling tube or auger. For rapid investigations of thin soils, a small pit can be dug and a section of soil removed with a spade. All of these are samples of pedons. Knowledge of the internal properties of a soil is derived mainly from studies of such samples. Samples can be studied more rapidly than entire pedons; consequently, a much larger number can be studied and for several more places. For many soils, the information obtained from a small sample amply describes the pedon from which it is taken. For other soils, however, important properties of a pedon are not observable in a smaller sample and detailed studies of the entire pedon are needed. Complete study of an entire pedon requires the exposure of a vertical section and the removal of horizontal sections layer by layer. Horizons are studied in both horizontal and vertical dimensions. The kind of exposure (e.g., bucket auger, push tube, small hand-dug pit, backhoe pit, road cut, etc.) should be identified in the soil description.

The information in this chapter, which focuses on the standards and guidelines for describing a soil profile in the field, is complemented by that provided in chapters 2, 6, 10, and 11. Chapter 2 provides information related to describing the site surrounding the soil profile. Chapter 6 discusses the use of proximal sensors to measure some soil properties quickly and efficiently at field and larger scales by using field-based electronic technology. Chapter 10 provides information specific to describing subaqueous soils. Chapter 11 discusses soils heavily impacted by human activity.

General Terms Used to Describe Soils

This section describes several of the general terms for internal elements of the soil. Other more specific terms are described or defined in the following sections.

Pedon

A pedon is a three-dimensional body of soil that has sufficient area (roughly 1 to 10 m^2) and depth (up to 200 cm) to be used in describing the internal arrangement of horizons and in collecting representative samples for laboratory analysis (see chapter 4). The pedon is the individual classified with Soil Taxonomy. Multiple pedons that have the same classification and occur together in landscapes are used in defining soil series. Conceptually, these contiguous pedons are called polypedons (see chapter 4).

Soil Profile

A soil profile is smaller than a pedon. It is exposed by a two-dimensional vertical cut through the soil. It is commonly conceived as a plane at right angles to the soil surface. In practice, a description of a soil profile includes soil properties that can be determined only by inspecting volumes of soil. However, the volume of soil described from a profile is almost always less than the volume of soil defined by a full pedon because observations of the soil profile are generally made to only a few decimeters behind the face of the exposed profile. A pedon description is commonly based on examination of a profile, and the properties of the pedon are inferred from the properties of the profile. The width of a profile ranges from a few decimeters to several meters or more. The size of the profile should be sufficient to include the largest structural units.

Soil Horizon

A soil horizon is a layer, approximately parallel to the surface of the soil, that is distinguishable from adjacent layers by a distinctive set of properties produced by the soil-forming processes (i.e., pedogenesis). The term “layer” is used instead of “horizon” if the properties are inherited from the parent material, such as sedimentary strata. Horizons, in contrast, display the effects of pedogenesis, such as the obliteration of sedimentary strata and accumulation of illuvial clay.

Solum

The solum (plural, sola) of a soil consists of a set of horizons that are related through the same period of pedogenesis. It includes all horizons now forming. It may also include a bisequum (discussed below). It does not include a buried soil or layer unless it has acquired some of its properties by currently active soil-forming processes. The solum of a soil is not necessarily confined to the zone of major biological activity. Its genetic horizons may be expressed faintly to prominently. A solum does not have a maximum or minimum thickness.

Solum and soils are not synonymous. Some soils include layers that are not affected by soil formation. These layers are not part of the solum. The number of genetic horizons ranges from one to many. An A horizon that is 10 cm thick overlying bedrock is by itself the solum. A soil that consists only of recently deposited new soil material or recently exposed soft sediment generally does not have a solum.

In terms of soil horizons as described in this chapter, a solum consists of O, V, A, E, and B horizons and their transitional horizons. Included are horizons with an accumulation of carbonates or more soluble salts if these horizons are either within, or contiguous to, other genetic horizons and are judged to be at least partly produced during the same period of soil formation.

The lower limit of the solum, in a general sense, in many soils should be related to the depth of rooting for perennial plants, assuming that water state and chemistry are not limiting. In some soils, the lower limit can be set only arbitrarily and is defined in relation to the particular soil. For example, horizons of carbonate accumulation are easily visualized as part of the solum in many soils in arid and semiarid environments. However, to conceive of cemented horizons of carbonates that may extend for 5 meters or more below the surface as part of the modern solum is more difficult. Such massive carbonate horizons represent pedogenesis over hundreds of thousands of years and are referred to as relict paleosols. Gleyed soil material begins in some soils a few centimeters below the surface and continues practically unchanged to a depth of many meters. Gleying immediately below the A horizon is likely to be related to the processes of soil formation in the modern soil. At great depth, gleying is likely to be relict or related to processes that are more geological than pedological. The same kind of problem exists for some deeply weathered soils—the deepest material penetrated by roots is very similar to the weathered material at much greater depth.

For some soils, digging deep enough to reveal all of the relationships between soils and plants is not practical. Plant roots, for example, may derive much of their moisture from fractured bedrock. Descriptions should indicate the nature of the soil-rock contact and determinations about the upper part of the underlying rock.

Not everyone will agree about the exact extent of the solum in some soils. For example, a certain level of subjectivity is involved in differentiating transitional BC or CB horizons from C horizons or in determining which properties observed in the soil are the product of active pedogenic processes. The concept of the solum remains useful for discussions about the nature of soils and soil profiles but is generally not used as a part of any technical definitions.

Sequum

A sequum (plural, sequa) consists of a B horizon and any overlying eluvial horizons. A single sequum is considered to be the product of a specific combination of soil-forming processes.

Most soils have only one sequum, but some have two or more. For example, a new sequence of horizons that meet the criteria for a Spodosol can form in the upper part of a previously existing Alfisol, producing an eluviated zone and a spodic horizon underlain by another eluviated zone overlying an argillic horizon. Such a soil has two sequa. Soils in which two sequa have formed, one above the other in the same deposit, are said to be *bisequal*.

If two sequa formed in different deposits at different times, the soil is not bisequal. For example, a soil having an A-E-B horizon sequence may form in material that was deposited over another soil that already had an A-E-B horizon sequence. Each set of A-E-B horizons is a sequum, but the combination is not a bisequum; the lower set is a buried soil. If the horizons of the upper sequum extend into the underlying sequum, the affected layer is considered part of the upper sequum. For example, the A horizon of the lower soil may retain some of its original characteristics and also have some characteristics of the overlying soil. In this case, the soils are also not considered bisequal; the upper part of the lower soil is the parent material of the lower part of the currently forming soil. In many soils the distinction cannot be made with certainty. If some of the C material of the upper sequum remains, the distinction is clear.

Studying Pedons

Site Selection

Pedons representative of an extensive mappable area are generally more useful than pedons that represent a transitional area to another soil. For detailed study of a soil, a pedon is tentatively selected and then examined preliminarily to determine whether or not it represents the desired segment of the soil's range. This is a critical step. Typically, only a few pedons can be studied in detail due to the time and expense involved in exposing, describing, photographing, and sampling soil profiles and performing necessary laboratory analysis. It is very important that the site selected for study is a representative sample of the overall soil body in the landscape because data from the site will be used to classify the soil pedon and correlate it with other similar pedons.

Information Recorded

For a soil description to be of greatest value, detailed information about its setting should be recorded (see chapter 2). Important items include location (identified by latitude and longitude, including datum, or another acceptable geographic location system), the part of the landscape that the pedon represents (i.e., landform, position on landform, any applicable microfeature), elevation, aspect, parent material, vegetation, land use, and erosion or other disturbance affecting the soil profile. The level of detail will depend on the objectives. A complete setting description should include information about the pedon and other soils conterminous with the pedon. It also may include information on any features that differ from the central concept of the soil series for which the described pedon is named (if a series has been defined).

The description of a body of soil in the field, whether an entire pedon or a soil profile within it, should record the kinds of horizons or layers, their depth and thickness, and the properties of each. Generally, external features, such as slope, surface stoniness, erosion, and vegetation, are observed for the area around the pedon, which is considered to be part of the same soil body. Internal features, such as color, texture, and structure, are observed from the study of the pedon.

Observing Pedons

In order to observe a pedon fully, including soil structure (size and kind), horizon boundary topography, and short-range variability in horizon thickness, a pit exposing a vertical face approximately 1 meter across to an appropriate depth (fig. 3-1) is adequate for most soils. Excavations associated with roads, railways, gravel pits, and other soil disturbances provide easy access for studying soils. Old exposures, however, must be used cautiously. In these areas, the soils can dry out or freeze and thaw from both the surface and the sides. In addition, the soil structure may be more pronounced than is typical, salts may have accumulated near the edges of exposures or been removed by seepage, plinthite may have irreversibly hardened to ironstone, or other changes may have taken place.

For hand- or backhoe-dug pits, care must be taken to ensure that the pit conforms to safety regulations. Loose sandy soils and wet soils are particularly susceptible to cave-ins.

After the sides of the pit are cleaned of all loose material disturbed by digging, the exposed vertical faces are examined, typically starting at the top and working downward, to identify significant changes in properties. Boundaries between layers are marked on the face of the pit, and the layers are identified and described.

Photographs should be taken after the layers have been identified but before the vertical section is disturbed in the description-writing process. An estimation of the volume of stones or other features also is done before the layers are disturbed.

Figure 3-1

A shallow soil pit with a face that has been cleaned and prepared for describing the soil profile. This soil (a Fibristel in Alaska) has been dug to the depth of permafrost (about 40 cm).

If bulk samples are to be collected for laboratory analysis, it generally is best to begin with the bottom layer and work upward. This prevents material from the upper layers falling onto the face of lower layers before they have been sampled.

A horizontal view of each horizon is useful. This exposes structural units that otherwise may not be readily observable from the vertical pit face. Patterns of color within structural units, variations of particle size from the outside to the inside of structural units, and the pattern in which roots penetrate structural units are commonly seen more clearly in a horizontal section (fig. 3-2).

Measuring Depth to and Thickness of Horizons and Layers

Soil Surface

When describing soil profiles, depth is measured from the soil surface. Generally, the soil surface is the top of the mineral soil. For soils with an O horizon (Oi, Oe, or Oa), it is the top of the O horizon. Fresh leaf or needle fall that has not undergone observable decomposition is excluded

Figure 3-2

A horizontal view (looking down) of a fragipan from a soil (a Fragiudalf) in Tennessee. The horizon has prismatic structure with gray seams between prisms and reddish redoximorphic features, mostly within the prisms. This view allows the structure and color patterns of the horizon to be easily observed. The exposed area is approximately 30 by 40 cm.

from the concept of an O horizon and may be described separately as a surface feature. Profile measurements begin below any fresh leaf or needle fall.

For soils that have a cover of 80 percent or more rock or pararock fragments (as in some areas of rubbly colluvial materials), the top of the soil is considered the mean height of the tops of the rock or pararock fragments. Depth measurements are taken from this height.

It is important to note that, when measuring depth and thickness for *taxonomic purposes,* the "mineral soil surface" is commonly specified as the datum to use in measurements. This essentially excludes any overlying O horizon and is therefore not synonymous with the soil surface as defined here for making soil descriptions. See *Keys to Soil Taxonomy* (Soil Survey Staff, 2014b or later version) for further information.

Depth Measurements

The depth to a horizon or layer boundary commonly differs within short distances, even within a pedon. The part of the pedon that is typical or most common is described. In the soil description, the horizon or layer designation is listed, followed by the values that represent the depths from the soil surface to the upper and lower boundaries (e.g., Bt1 - 8 to 20 cm). The depth to the lower boundary of a horizon or layer is the depth to the upper boundary of the horizon or layer beneath it. Variation in the depths of the boundaries is recorded in the description of the horizon or layer. The depth limits of the deepest horizon or layer described include only that part actually seen.

In some soils, the variations in depths to boundaries are so complex that the usual terms used to describe the boundary topography are inadequate. These variations are described separately, e.g., "depth to the lower boundary is mainly 30 to 40 cm, but tongues extend to depths of 60 to 80 cm." The lower boundary of a horizon or layer and the upper boundary of the horizon or layer below share a common irregularity.

Thickness Measurements

The thickness of each horizon or layer is the vertical distance between the upper and lower boundaries. Overall thickness may vary within a pedon, and this variation should be noted in the description. A range in thickness may be given, e.g., "thickness ranges from 20 to 30 cm." This range is not calculated from the range of upper and lower boundary depths. Instead, the range is calculated from evaluations across the exposure at different lateral points. For example, the upper boundary of a horizon may range in depth from 25 to 45 cm and the lower boundary from 50 to 75 cm. Taking the extremes of these two ranges, it is incorrect to conclude that the horizon thickness ranges from as little as 5 cm to as much as 50 cm when in fact it may be 20 to 30 cm in the field.

Designations for Horizons and Layers

Soils vary widely in the degree to which horizons are expressed. Relatively fresh parent materials, such as recent deposits of alluvium, eolian sands, or mantles of volcanic ash, may have no recognizable genetic horizons but may have distinct layers that reflect different modes of deposition. As soil formation proceeds, horizons in their early stages may be detected only by very careful examination. As horizons increase in age, they generally are more easily identified in the field. However, only one or two different horizons may be readily apparent in some very old, deeply weathered soils in tropical areas where annual precipitation is high. This section provides the standard nomenclature and definitions for a system used to assign symbols to soil horizons and layers.

Background and Concepts for Use of Designations

Different kinds of layers are identified by different symbols. Designations are provided for layers that have been changed by soil formation and for those that have not. Each horizon designation indicates either that the original material has been changed in certain ways or that there has been little or no change. The designation is assigned after comparison of the observed properties of the layer with properties inferred for the material before it was affected by soil formation. The processes that have caused the change need not be known; properties of soils relative to those of an estimated parent material are the criteria for judgment. The parent material inferred for the horizon in question, not the material below the solum, is used as the basis of comparison. The inferred parent material commonly is very similar to, or the same as, the soil material below the solum.

Designations show the describer's interpretations of genetic relationships among the layers within a soil. Layers do not need to be identified by symbols in order to make a good description, but the usefulness of soil descriptions is greatly enhanced by the proper use of designations. The designations provide a sort of shorthand nomenclature conveying the important properties observed by the person describing the soil as well as the genetic inferences made by that person regarding the formation of the soil. The definitions of the symbols provided below are generally more qualitative than quantitative. There is a small degree of subjectivity that allows some freedom for the describer to convey their theory of how the soil formed. There may be a certain level of inconsistency in the way different describers label the horizons of the same profile. For example, one describer may label a horizon "C" while another may label it "CB" or one may record a subtle lithologic discontinuity that another person does not observe.

Designations are not substitutes for descriptions. If both designations and adequate descriptions of a soil are provided, the reader has the interpretation made by the person who described the soil and also the evidence on which the interpretation was based.

Genetic horizons are not equivalent to the diagnostic horizons of Soil Taxonomy. Designations of genetic horizons express a qualitative judgment about the kind of changes that are believed to have taken place. Diagnostic horizons are quantitatively defined features used to differentiate taxa. Changes implied by genetic horizon designations may not be large enough to justify recognition of diagnostic criteria. For example, the designation "Bt" does not always indicate an argillic horizon. Furthermore, the diagnostic horizons may not be coextensive with genetic horizons.

Basic System of Horizon and Layer Designations

Four kinds of symbols are used in various combinations to designate horizons and layers:

Capital letters.—Used to designate the master horizons and layers.

Lowercase letters.—Used as suffixes to indicate specific characteristics of master horizons and layers.

Numbers.—Used both as suffixes to indicate vertical subdivisions within a horizon or layer and as prefixes to indicate discontinuities.

Special symbols.—Used to indicate layers formed in human-transported material or sequences of horizons having otherwise identical designations.

Master Horizons and Layers

The capital letters O, L, V, A, E, B, C, R, M, and W represent the master horizons and layers of soils. These letters are the base symbols to which other characters are added to complete the designations. Most horizons and layers have a designation using one capital letter symbol; some have two.

O Horizons or Layers

O horizons or layers are dominated by organic soil materials. Some are saturated with water for long periods; some were once saturated but are now artificially drained; and others have never been saturated.

Some O horizons or layers consist of slightly decomposed to highly decomposed litter (such as leaves, needles, twigs, moss, and lichens) that was deposited on the surface of either mineral or organic soils. Others consist of organic materials that were deposited under saturated conditions and have decomposed to varying stages. The mineral fraction of such material constitutes only a small percentage of the volume of the material and generally much less than half of its weight. Some soils consist entirely of materials designated as O horizons or layers.

An O horizon or layer may be at the surface of a mineral soil or, if buried, at any depth below the surface. A horizon formed by illuviation of organic material into a mineral subsoil is not an O horizon, although some horizons that formed in this manner contain a large amount of organic matter. Horizons or layers composed of limnic materials are not designated as O horizons.

L Horizons or Layers

L horizons or layers include both organic and mineral limnic materials that were either:

1. Deposited in water by precipitation or through the actions of aquatic organisms, such as algae and diatoms; or
2. Derived from underwater and floating aquatic plants and subsequently modified by aquatic animals.

L horizons or layers include coprogenous earth (sedimentary peat), diatomaceous earth, and marl. They are described only for Histosols (decomposed plant material) and not for mineral soils. They have only the following suffixes: *co, di,* or *ma* (described below). They do not have the subordinate distinctions of the other master horizons and layers.

V Horizons

V horizons are mineral horizons that formed at the soil surface or below a layer of rock fragments (e.g., desert pavement), a physical or biological crust, or recently deposited eolian material. They are characterized by the predominance of vesicular pores and have platy, prismatic, or columnar structure.

Porosity in a V horizon may include vughs and collapsed vesicles in addition to the spherical vesicular pores. V horizons formed in eolian material but may be underlain by soil horizons that formed in residuum, alluvium, or other transported materials. Because of their eolian origin, they are typically enriched in particle-size fractions ranging from silt through fine sand. Rarely, the V horizon is massive rather than structured. The structural arrangement of particles and vesicular porosity differentiates this horizon from the loose, unaltered eolian deposits that may occur above it. Underlying B horizons commonly have redder hues than the V horizon and lack vesicular pores (Turk et al., 2011).

Transitional and combination horizons with V horizon material occur in certain circumstances. Although uncommon, an AV or VA horizon may occur. It is both enriched in organic matter and contains vesicular pores. BV or VB horizons may indicate vesicular horizons that contain clay or carbonate coatings, or other properties of the underlying B horizon. EV or VE transitional horizons may also occur, especially in sodic soils.

Combination horizons of the V horizon with A, B, or E horizons may occur in bioturbated zones, such as shrub islands or areas where surface cover associated with the vesicular horizon (e.g., desert pavement) is patchy. Vesicular pores have been observed to reform quickly after physical disruption (Yonovitz and Drohan, 2009).

A Horizons

A horizons are mineral horizons that formed at the soil surface or below an O horizon. They exhibit obliteration of all or much of any original rock structure and show one or both of the following:

1. An accumulation of humified organic matter closely mixed with the mineral fraction and not dominated by properties characteristic of V, E, or B horizons; and/or
2. Properties resulting from cultivation, pasturing, or similar kinds of disturbance.

If a surface horizon has properties of both A and E horizons but the feature emphasized is an accumulation of humified organic matter, it is designated as an A horizon. Recent alluvial or eolian deposits that retain most of the original rock structure are not considered to be A horizons unless they are cultivated.

E Horizons

E horizons are mineral horizons in which the main feature is the eluvial loss of silicate clay, iron, aluminum, or some combination of these that leaves a concentration of sand and silt particles. They exhibit obliteration of all or much of the original rock structure.

An E horizon is commonly differentiated from an underlying B horizon in the same sequum by a color of higher value or lower chroma (or both), by coarser texture, or by a combination of these properties. In some soils the color of the E horizon is that of the sand and silt particles, but in many soils coatings of iron oxides or other compounds mask the color of the primary particles. An E horizon is most commonly differentiated from an overlying A horizon by its lighter color. It generally contains less organic matter than the A horizon. It is commonly near the soil surface, below an O, V, or A horizon, and above a B horizon. However, the symbol E can be used for eluvial horizons that are at the soil surface, are within or between parts of the B horizon, or extend to depths greater than those of normal observation, if the horizons have resulted from pedogenic processes.

B Horizons

B horizons are mineral horizons that typically formed below an A, V, E, or O horizon. They exhibit obliteration of all or much of the original rock structure and show one or more of the following as evidence of pedogenesis:

1. Illuvial concentration of silicate clay, iron, aluminum, humus, sesquioxides, carbonates, gypsum, salts more soluble than gypsum, or silica, alone or in combination;
2. Evidence of the removal, addition, or transformation of carbonates, anhydrite, and/or gypsum;
3. Residual concentration of oxides, sesquioxides, and silicate clay, alone or in combination;
4. Coatings of sesquioxides that make the horizon color conspicuously lower in value, higher in chroma, or redder in hue than overlying and underlying horizons, without apparent illuviation of iron;
5. Alteration that forms silicate clay or liberates oxides, or both, and that forms pedogenic structure if volume changes accompany changes in moisture content;
6. Brittleness; or
7. Strong gleying when accompanied by other evidence of pedogenic change.

All of the different kinds of B horizons are, or originally were, subsurface horizons. B horizons include horizons (cemented or not cemented) with illuvial concentrations of carbonates, gypsum, or silica that are the result of pedogenic processes. They are contiguous to other genetic horizons and brittle layers that show other evidence of alteration, such as prismatic structure or illuvial accumulation of clay.

B horizons do not include layers in which clay films coat rock fragments or cover finely stratified unconsolidated sediments, regardless of whether the films formed in place or by illuviation; layers into which carbonates have been illuviated but that are not contiguous to an overlying genetic horizon; and layers with strong gleying but no other pedogenic changes.

C Horizons or Layers

C horizons or layers are mineral horizons or layers, excluding strongly cemented and harder bedrock, that are little affected by pedogenic processes and lack properties of O, A, V, E, B, and L horizons. Their material may be either like or unlike that from which the solum presumably formed. The C horizon may have been modified, even if there is no evidence of pedogenesis.

Included as C layers (and typically designated Cr) are sediment, saprolite, bedrock, and other geologic materials that are moderately cemented or less cemented (see table 3-7). The excavation difficulty of these materials commonly is low or moderate (see table 3-14). In descriptions of soils that formed in material that is already highly weathered, if this material does not meet the requirements of an A, V, E, or B horizon, it is designated by the letter C. Changes are not considered pedogenic if they are not related to the overlying horizons. Some layers that have accumulations of silica, carbonates, gypsum, or more soluble salts are included in C horizons, even if cemented. However, if a cemented layer formed through pedogenic processes, rather than geologic processes (e.g., lithification), it is considered a B horizon.

R Layers

R layers consist of strongly cemented to indurated bedrock. Granite, basalt, quartzite, limestone, and sandstone are examples of bedrock that commonly is cemented enough to be designated by the letter R. The excavation difficulty of these layers commonly exceeds high. The R layer is sufficiently coherent when moist to make hand-digging with a spade impractical, although it may be chipped or scraped. Some R layers can be ripped with heavy power equipment. The bedrock may have fractures, but these are generally too few or too widely spaced to allow root penetration. The fractures may be coated or filled with clay or other material.

M Layers

M layers are root-limiting layers beneath the soil surface consisting of nearly continuous, horizontally oriented, human-manufactured materials. Examples of materials designated by the letter M include geotextile liners, asphalt, concrete, rubber, and plastic, if they occur as continuous, horizontal layers.

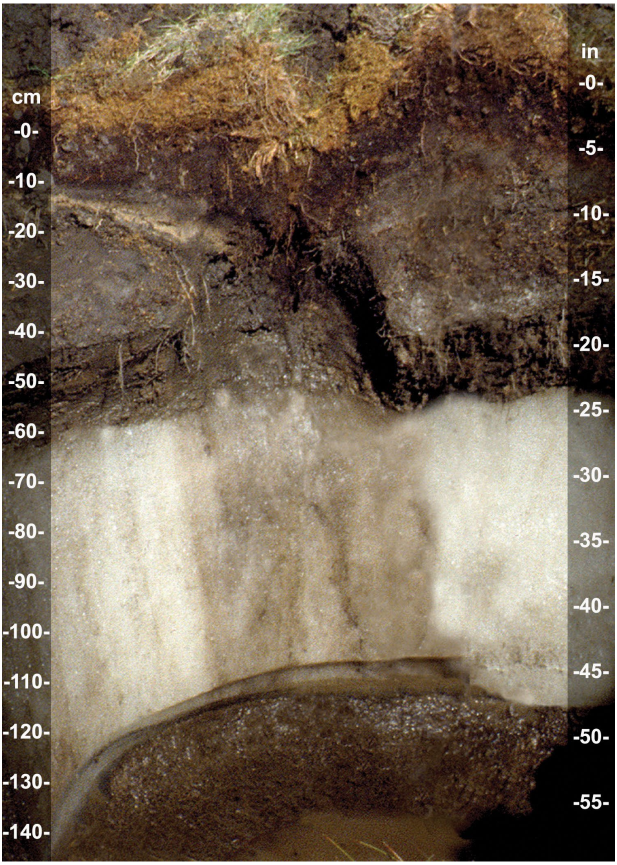
W Layers

W layers are used to identify water layers within or beneath the soil (fig. 3-3). They are not merely layers of saturated soil material but rather zones of water between soil layers. The water layer is designated “Wf” if it is permanently frozen (as in a glacic horizon) and “W” if it is not permanently frozen (as in a floating bog). The designations W and Wf are not used for shallow water, ice, or snow above the soil surface.

Transitional and Combination Horizons

In some cases a single master horizon designation does not adequately convey information about the layer, such as where the horizon transitions

Figure 3-3



A soil (a Glacistel in Alaska) with a permanently frozen ice layer (designated "Wf") between depths of 60 and 130 cm. (Photo courtesy of John Kelley)

to another layer or where it contains distinct parts from two kinds of master horizons.

Transitional Horizons

Transitional horizons are dominated by properties of one master horizon but have subordinate properties of another. They are designated by two capital-letter symbols, e.g., AB, EB, BE, or BC. The first letter indicates the horizon whose properties dominate the transitional horizon. An AB horizon, for example, has characteristics of both an overlying A horizon and an underlying B horizon, but it is more like the A horizon than the B.

In some cases, a horizon can be designated as transitional even if one of the master horizons to which it transitions is not present. For example, a BE horizon recognized in a truncated soil has properties similar to those of a BE horizon in a soil from which the overlying E horizon has not been removed by erosion. A BC horizon may be recognized even if no underlying C horizon is present: it transitions to assumed parent materials.

Combination Horizons

Combination horizons have two distinct parts that have recognizable properties of the two kinds of master horizons. They are designated by two capital-letter symbols (master horizons) separated by a virgule (/), e.g., E/B, B/E, or B/C. Most of the individual parts of one horizon component are surrounded by the other. The designation may be used even when horizons similar to one or both of the components are not present, provided that the separate components can be recognized in the combination horizon. The first letter indicates the horizon with the greater volume.

Because single sets of designators do not cover all situations, some improvising may be necessary. For example, Lamellic Udipsamments have lamellae that are separated from each other by eluvial layers. It is generally not practical to describe each lamella and eluvial layer as a separate horizon, so the horizons can be combined and the components described separately. The horizon with several lamellae and eluvial layers can be designated as an "E and Bt" horizon. The complete horizon sequence for these soils could be: Ap-Bw-E and Bt1-E and Bt2-C.

Suffix Symbols

Lowercase letters are used as suffixes to designate specific subordinate distinctions within master horizons and layers. The term "accumulation," which is used in many of the suffix definitions, indicates that the horizon has more of the material in question than is presumed to have been present in the parent material. The use of a suffix symbol is not restricted only to those horizons that meet certain criteria for diagnostic horizons and other criteria as defined in *Soil Taxonomy*. If there is any evidence of accumulation, a suffix (or suffixes) can be used. The suffix symbols and their meanings follow:

a *Highly decomposed organic material*
This symbol is used with O horizons to indicate the most highly decomposed organic materials, which have a fiber content of less than 17 percent (by volume) after rubbing.

b *Buried genetic horizon*
This symbol indicates identifiable buried horizons with major genetic features that developed before burial. Genetic horizons may or may not have formed in the overlying material, which may be either like or unlike the assumed parent material of the buried horizon. This symbol is not used to separate horizons composed of organic soil material (that are forming at the soil surface) from underlying horizons composed of mineral soil material. It may be used in organic soils, but only if they are buried by mineral soil materials.

c *Concretions or nodules*
This symbol indicates a significant accumulation of concretions or nodules. Cementation is required. The cementing agent commonly is iron, aluminum, manganese, or titanium. It cannot be silica, dolomite, calcite, gypsum, anhydrite, or soluble salts.

co *Coprogenous earth*
This symbol, used only with L horizons, indicates a limnic layer of coprogenous earth (sedimentary peat).

d *Physical root restriction*
This symbol indicates non-cemented, root-restricting layers in naturally occurring or human-made sediments or materials. Examples of natural layers are dense till and some non-cemented shales and siltstones. Examples of human-made dense layers are plowpans and mechanically compacted zones in human-transported material.

di *Diatomaceous earth*
This symbol, used only with L horizons, indicates a limnic layer of diatomaceous earth.

e *Organic material of intermediate decomposition*
This symbol is used with O horizons to indicate organic materials of intermediate decomposition. The fiber content of these materials is 17 to less than 40 percent (by volume) after rubbing.

f *Frozen soil or water*
This symbol indicates that a horizon or layer contains permanent ice. It is not used for seasonally frozen layers or for dry permafrost.

ff *Dry permafrost*
This symbol indicates a horizon or layer that is continually colder than 0 °C and does not contain enough ice to be cemented by ice. It is not used for horizons or layers that have a temperature warmer than 0 °C at some time during the year.

g *Strong gleying*
This symbol indicates either that iron has been reduced and removed during soil formation or that saturation with stagnant water has preserved iron in a reduced state. Most of the affected layers have chroma of 2 or less, and many have redox concentrations. The low chroma can represent either the color of reduced iron or the color of the uncoated sand and silt particles from which iron has been removed. The symbol is not used for soil materials of low chroma that have no history of wetness, such as some shales or E horizons. If it is used with B horizons, pedogenic change (e.g., soil structure) in addition to gleying is implied. If no other pedogenic change besides gleying has taken place, the horizon is designated "Cg."

h *Illuvial accumulation of organic matter*
This symbol is used with B horizons to indicate the accumulation of illuvial, amorphous, dispersible complexes of organic matter and sesquioxides. The sesquioxide component is dominated by aluminum and is present only in very small quantities. The organo-sesquioxide material coats sand and silt particles. In some horizons these coatings have coalesced, filled pores, and cemented the horizon. The symbol *h* is also used in combination with the symbol *s* (e.g., Bhs) if the amount of the sesquioxide component is significant but the value and chroma, moist, of the horizon are 3 or less.

i *Slightly decomposed organic material*
This symbol is used with O horizons to indicate the least decomposed of the organic materials. The fiber content of these materials is 40 percent or more (by volume) after rubbing.

j *Accumulation of jarosite*
This symbol indicates an accumulation of jarosite, which is a potassium (ferric) iron hydroxy sulfate mineral,

$KFe_3(SO_4)_2(OH)_6$. Jarosite is commonly the product of pyrite that has been exposed to an oxidizing environment. It has hue of 2.5Y or yellower and normally has chroma of 6 or more, although chroma as low as 3 or 4 has been reported. It forms in preference to iron (hydr)oxides in active acid sulfate soils at pH of 3.5 or less and can be stable for long periods of time in post-active acid sulfate soils with higher pH.

jj *Evidence of cryoturbation*
This symbol indicates evidence of cryoturbation, which includes irregular and broken horizon boundaries, sorted rock fragments, and organic soil materials occurring as bodies and broken layers within and/or between mineral soil layers. The organic bodies and layers are most commonly at the contact between an active layer and the permafrost.

k *Accumulation of secondary carbonates*
This symbol indicates an accumulation of visible pedogenic calcium carbonate (less than 50 percent, by volume). Carbonate accumulations occur as carbonate filaments, coatings, masses, nodules, disseminated carbonate, or other forms.

kk *Engulfment of horizon by secondary carbonates*
This symbol indicates major accumulations of pedogenic calcium carbonate. It is used when the soil fabric is plugged with fine grained pedogenic carbonate (50 percent or more, by volume) that occurs as an essentially continuous medium. It corresponds to the Stage III (or higher) plugged horizon of the carbonate morphogenetic stages (Gile et al., 1966).

m *Pedogenic cementation*
This symbol indicates continuous or nearly continuous pedogenic cementation. It is used only for horizons that are more than 90 percent cemented but may be fractured. The cemented layer is physically root-restrictive. The predominant cementing agent (or the two dominant ones) can be indicated by letter suffixes, singly or in pairs. The horizon suffix *kkm* (and the less commonly used *km*) indicates cementation by carbonates; *qm*, cementation by silica; *sm*, cementation by iron; *yym*, cementation by gypsum; *kqm*, cementation by carbonates and silica; and *zm*, cementation

by salts more soluble than gypsum. The symbol *m* is not used for permanently frozen layers impregnated by ice.

ma *Marl*
This symbol, used only with L horizons, indicates a limnic layer of marl.

n *Accumulation of sodium*
This symbol indicates an accumulation of exchangeable sodium.

o *Residual accumulation of sesquioxides*
This symbol indicates a residual accumulation of sesquioxides.

p *Tillage or other disturbance*
This symbol indicates disturbance of a horizon by mechanical means, pasturing, or similar uses. A disturbed organic horizon is designated "Op." A disturbed mineral horizon is designated "Ap" even if it is clearly a former E, B, or C horizon.

q *Accumulation of silica*
This symbol indicates an accumulation of secondary silica.

r *Weathered or soft bedrock*
This symbol is used with C horizons to indicate layers of bedrock that are moderately cemented or less cemented. Examples are weathered igneous rock and partly consolidated sandstone, siltstone, or shale. The excavation difficulty is low to high.

s *Illuvial accumulation of sesquioxides and organic matter*
This symbol is used with B horizons to indicate an accumulation of illuvial, amorphous, dispersible complexes of organic matter and sesquioxides, if both the organic matter and sesquioxide components are significant and if either the value or chroma, moist, of the horizon is 4 or more. The symbol is also used in combination with *h* (e.g., Bhs) if both the organic matter and sesquioxide components are significant and if the value and chroma, moist, are 3 or less.

se *Presence of sulfides*
This symbol indicates the presence of sulfides in mineral or organic horizons. Horizons with sulfides typically have dark

colors (e.g., value of 4 or less, chroma of 2 or less). These horizons typically form in soils associated with coastal environments that are permanently saturated or submerged (i.e., tidal marshes or estuaries). Soil materials which have sulfidization actively occurring emanate hydrogen sulfide gas, which is detectable by its odor (Fanning and Fanning, 1989; Fanning et al., 2002). Sulfides may also occur in upland environments that have a source of sulfur. Soils in such environments are commonly of geologic origin and may not have a hydrogen sulfide odor. Examples include soils that formed in parent materials derived from coal deposits, such as lignite, or soils that formed in coastal plain deposits, such as glauconite, that have not been oxidized because of thick layers of overburden.

ss *Presence of slickensides*
This symbol indicates the presence of pedogenic slickensides. Slickensides result directly from the swelling of clay minerals and shear failure, commonly at angles of 20 to 60 degrees above horizontal. They are indicators that other vertic characteristics, such as wedge-shaped peds and surface cracks, may be present.

t *Accumulation of silicate clay*
This symbol indicates an accumulation of silicate clay that either has formed within a horizon and subsequently has been translocated within the horizon or that has been moved into the horizon by illuviation, or both. At least some part of the horizon shows evidence of clay accumulation, either as coatings on surfaces of peds or in pores, as lamellae, or as bridges between mineral grains.

u *Presence of human-manufactured materials (artifacts)*
This symbol indicates the presence of objects or materials that have been created or modified by humans, typically for a practical purpose in habitation, manufacturing, excavation, or construction activities. Examples of artifacts are bitumen (asphalt), boiler slag, bottom ash, brick, cardboard, carpet, cloth, coal combustion by-products, concrete (detached pieces), debitage (i.e., stone tool flakes), fly ash, glass, metal, paper, plasterboard, plastic, potsherd, rubber, treated wood, and untreated wood products.

v *Plinthite*
This symbol is used to indicate the presence of iron-rich, humus-poor, reddish material that is firm or very firm when moist and is less than strongly cemented. Plinthite hardens irreversibly when exposed to the atmosphere and to repeated wetting and drying.

w *Development of color or structure*
This symbol is used only with B horizons to indicate the development of color or structure, or both, with little or no apparent illuvial accumulation of material. Note: It is not used to indicate a transitional horizon.

x *Fragipan character*
This symbol indicates a genetically developed layer that has a combination of firmness and brittleness and commonly a higher bulk density than adjacent layers. Some part of the layer is physically root-restrictive.

y *Accumulation of gypsum*
This symbol indicates an accumulation of gypsum. It is used when the horizon fabric is dominated by soil particles or minerals other than gypsum. Gypsum is present in amounts that do not significantly obscure or disrupt other features of the horizon. This symbol is also used to indicate the presence of anhydrite.

yy *Dominance of horizon by gypsum*
This symbol indicates a horizon that is dominated by the presence of gypsum. The gypsum content may be due to an accumulation of secondary gypsum, the transformation of primary gypsum inherited from parent material, or other processes. This symbol is used when the horizon fabric has such an abundance of gypsum (generally 50 percent or more, by volume) that pedogenic and/or lithologic features are obscured or disrupted by growth of gypsum crystals. Horizons that have this suffix typically are highly whitened (e.g., value of 7 through 9.5 and chroma of 4 or less). This symbol is also used to connote the presence of anhydrite.

z *Accumulation of salts more soluble than gypsum*
This symbol indicates an accumulation of salts that are more soluble than gypsum.

Conventions for Using Horizon Designation Symbols

The following guidelines can be used in assigning horizon designation symbols to soil horizons and layers.

Letter Suffixes

Many master horizons and layers that are symbolized by a single capital letter can have one or more lowercase-letter suffixes. The following rules apply:

1. Letter suffixes directly follow the capital letter of the master horizon or layer, or the prime symbol, if used.
2. More than three suffixes are rarely used.
3. If more than one suffix is needed, the following letters (if used) are written first: *a, d, e, h, i, r, s, t,* and *w*. None of these letters are used in combination for a single horizon, except to designate a Bhs horizon or Crt layer.
4. If more than one suffix is needed and the horizon is not buried, the following symbols, if used, are written last: *c, f, g, m, v,* and *x*. Examples are Bjc and Bkkm. If any of these suffixes are used together in the same horizon, symbols *c* and *g* are written last (e.g., Btvg), with one exception. If the symbol *f* (frozen soil or water) is used together with any of the other symbols in this rule, it is written last, e.g., Cdgf.
5. If a genetic horizon is buried, the suffix *b* is written last, e.g., Oab.
6. Suffix symbols *h, s,* and *w* are not used with *g, k, kk, n, o, q, y, yy,* or *z*.
7. If the above rules do not apply to certain suffixes, such as *k, kk, q, y,* or *yy,* the suffixes may be listed together in order of assumed dominance or alphabetically if dominance is not a concern.

A B horizon that has a significant accumulation of clay and also shows development of color or structure, or both, is designated "Bt" (suffix symbol *t* has precedence over symbols *w, s,* and *h*). A B horizon that is gleyed or that has accumulations of carbonates, sodium, silica, gypsum, salts more soluble than gypsum, or residual accumulations of sesquioxides carries the appropriate symbol: *g, k, kk, n, q, y, yy, z,* or *o*. If illuvial clay is also present, the symbol *t* precedes the other symbol, e.g., Bto.

Vertical Subdivisions

Commonly, a horizon or layer designated by a single letter or a combination of letters has to be subdivided. For this purpose, numbers are added to the letters of the horizon designation. These numbers follow all the letters. Within a sequence of C horizons, for example, successive layers may be designated C1, C2, C3, etc. If the lower horizons are strongly gleyed and the upper horizons are not strongly gleyed, they may be designated C1-C2-Cg1-Cg2 or C-Cg1-Cg2-R.

These conventions apply regardless of the purpose of the subdivision. In many soils a horizon that could be identified by a single set of letters is subdivided to recognize differences in morphological features, such as structure, color, or texture. These divisions are numbered consecutively, but the numbering starts again at 1 when any letter of the horizon symbol changes, e.g., Bt1-Bt2-Btk1-Btk2 (not Bt1-Bt2-Btk3-Btk4). The numbering of vertical subdivisions within consecutive horizons is not interrupted at a discontinuity (indicated by a numerical prefix) if the same letter combination is used in both materials, e.g., Bs1-Bs2-2Bs3-2Bs4 (not Bs1-Bs2-2Bs1-2Bs2).

During sampling for laboratory analyses, thick soil horizons are sometimes subdivided even though differences in morphology are not evident in the field. These subdivisions are identified by numbers that follow the respective horizon designations. For example, four subdivisions of a Bt horizon sampled by 10-cm increments are designated Bt1, Bt2, Bt3, and Bt4. If the horizon has already been subdivided because of differences in morphological features, the set of numbers that identifies the additional sampling subdivisions follows the first number. For example, three subdivisions of a Bt2 horizon sampled by 10-cm increments are designated Bt21, Bt22, and Bt23. The descriptions for each of these sampling subdivisions can be the same, and a statement indicating that the horizon has been subdivided only for sampling purposes can be added.

Discontinuities

Numbers are used as prefixes to horizon designations (specifically, A, V, E, B, C, and R) to indicate discontinuities in mineral soils. These prefixes are distinct from the numbers that are used as suffixes denoting vertical subdivisions.

A discontinuity that can be identified by a number prefix is a significant change in particle-size distribution or mineralogy that indicates a difference in the parent material from which the horizons have formed and/or a significant difference in age, unless the difference in age is indicated by the suffix *b*. Symbols that identify discontinuities are used only when they can contribute substantially to an understanding of the relationships among horizons. The stratification common to soils that formed in alluvium is not designated as a discontinuity, unless particle-size distribution differs markedly from layer to layer (i.e., particle-size classes are strongly contrasting) even though genetic horizons may have formed in the contrasting layers.

If a soil formed entirely in one kind of material, the whole profile is understood to be material 1 and the number prefix is omitted from the symbol. Similarly, the uppermost material in a profile consisting of two or more contrasting materials is understood to be material 1 and the number is omitted. Numbering starts with the second layer of contrasting material, which is designated 2. Underlying contrasting layers are numbered consecutively. Even when the material of a layer below material 2 is similar to material 1, it is designated 3 in the sequence; the numbers indicate a change in materials, not types of material. Where two or more consecutive horizons have formed in the same kind of material, the same prefix number indicating the discontinuity is applied to all the designations of horizons in that material, for example, Ap-E-Bt1-2Bt2-2Bt3-2BC. The suffix numbers designating vertical subdivisions of the Bt horizon continue in consecutive order across the discontinuity. However, vertical subdivisions do not continue across lithologic discontinuities if the horizons are not consecutive or contiguous to each other. If other horizons intervene, another vertical numbering sequence begins for the lower horizons, for example, A-C1-C2-2Bw1-2Bw2-2C1-2C2.

If an R layer is below a soil that formed in residuum and if it is similar to the material from which the soil developed, the number prefix is not used. The prefix is used, however, if it is thought that the R layer would weather to material unlike that in the solum, e.g., A-Bt-C-2R or A-Bt-2R. If part of the solum has formed in residuum, the symbol R is given the appropriate prefix, for example, Ap-Bt1-2Bt2-2Bt3-2C1-2C2-2R.

A buried genetic horizon (designated by the suffix *b*) requires special consideration. It is obviously not in the same deposit as the overlying horizons. Some buried horizons, however, formed in material that is lithologically like the overlying deposit. In this case, a prefix is not used to distinguish material of the buried horizon. If the material in which a horizon of a buried soil formed is lithologically unlike the overlying material, the discontinuity is indicated by a number prefix and the symbol for the buried horizon also is used, for example, Ap-Bt1-Bt2-BC-C-2ABb-2Btb1-2Btb2-2C.

Discontinuities between different kinds of layers in organic soils are not identified. In most cases, such differences are identified by letter suffixes if the different layers are organic materials (e.g., Oe vs. Oa) or by the master horizon symbol if the different layers are mineral or limnic materials (e.g., Oa vs. Ldi).

The Prime Symbol

If two or more horizons with identical number prefixes and letter combinations are separated by one or more horizons with a different horizon designation, identical letter and number symbols can be used for those horizons with the same characteristics. For example, the sequence A-E-Bt-E-Btx-C identifies a soil that has two E horizons. To emphasize this characteristic, the prime symbol (´) is added after the symbol of the lower of the two horizons that have identical designations, e.g., A-E-Bt-E´-Btx-C. The prime symbol is placed after the master horizon symbol and before the suffix letter symbol or symbols (if used), for example, B´t.

The prime symbol is not used unless all letter and number prefixes are completely identical. The sequence A-Bt1-Bt2-2E-2Bt1-2Bt2 is an example. Because it has two Bt master horizons of different lithologies, the Bt horizons are not identical and the prime symbol is not needed. The prime symbol is used for soils with lithologic discontinuities if horizons have identical designations. For example, a soil with the sequence A-C-2Bw-2Bc-2B´w-3Bc has two identical 2Bw horizons but two different Bc horizons (2Bc and 3Bc); the prime symbol is used only with the lower 2Bw horizon (2B´w). In the rare cases where three layers have identical letter symbols, double prime symbols can be used for the lowest of these horizons, for example, E´´.

Vertical subdivisions of horizons or layers (number suffixes) are not taken into account when the prime symbol is assigned. The sequence A-E-Bt-E´-B´t1-B´t2-B´t3-C is an example.

These same principles apply in designating layers of organic soils. The prime symbol is used only to distinguish two or more horizons that have identical symbols. For example, Oi-C-O´i-C´ indicates a soil with two identical Oi and C layers and Oi-C-Oe-C´ indicates a soil with two identical C layers. The prime symbol is added to the lower layers to differentiate them from the upper layers.

The Caret Symbol

The caret symbol (^) is used as a prefix to indicate horizons and layers that formed in human-transported material. This material has been moved horizontally onto a pedon from a source area outside of that pedon by purposeful human activity, usually with the aid of machinery or hand tools. Number prefixes may be used before the caret symbol to indicate the presence of discontinuities within the human-transported material (e.g., ^Au-^Bwu-^BCu-2^Cu1-2^Cu2) or between the human-transported material and underlying horizons formed in other parent materials (e.g., ^A-^C1-2^C2-3Bwb).

Sample Horizons and Sequences

The following examples illustrate some common horizon and layer sequences of important soils (subgroup taxa) and the use of numbers to identify vertical subdivisions and discontinuities. Transitional horizons, combination horizons, and the use of the prime and caret symbols are also illustrated.

Mineral Soils

Typic Hapludoll: A1-A2-Bw-BC-C
Typic Haplustoll: Ap-A-Bw-Bk-Bky1-Bky2-C
Cumulic Haploxeroll: Ap-A-Ab-C-2C-3C
Typic Argialboll: Ap-A-E-Bt1-Bt2-BC-C
Typic Argiaquoll: A-AB-BA-Btg-BCg-Cg
Alfic Udivitrand: Oi-A-Bw1-Bw2-2E/Bt-2Bt/E1-2Bt/E2-2Btx1-2Btx2
Entic Haplorthod: Oi-Oa-E-Bs1-Bs2-BC-C
Typic Haplorthod: Ap-E-Bhs-Bs-BC-C1-C2
Typic Fragiudalf: Oi-A-E-BE-Bt1-Bt2-B/E-Btx1-Btx2-C
Typic Haploxeralf: A1-A2-BAt-2Bt1-2Bt2-2Bt3-2BC-2C
Glossic Hapludalf: Ap-E-B/E-Bt1-Bt2-C
Typic Paleudult: A-E-Bt1-Bt2-B/E-B´t1-B´t2-B´t3
Typic Hapludult: Oi-A1-A2-BA-Bt1-Bt2-BC-C
Arenic Plinthic Paleudult: Ap-E-Bt-Btc-Btv1-Btv2-BC-C
Xeric Haplodurid: A-Bw-Bkq-2Bkqm
Vertic Natrigypsid: A-Btn-Btkn-Bky-2By-2BCy-2Cr
Typic Calciargid: A-Bt-Btk1-Btk2-C
Typic Dystrudept: Ap-Bw1-Bw2-C-R
Typic Fragiudept: Ap-Bw-E-Bx1-Bx2-C
Typic Endoaquept: Ap-AB-Bg1-Bg2-BCg-Cg
Typic Haplustert: Ap-A-Bss-BCss-C
Typic Hapludox: Ap-A/B-Bo1-Bo2-Bo3-Bo4-Bo5
Typic Udifluvent: Ap-C-Ab-C´
Glacic Histoturbel: Oi-OA-Bjjg-Wf-Cgf

Organic Soils

Typic Haplosaprist: Oap-Oa1-Oa2-Oa3-C
Typic Sphagnofibrist: Oi1-Oi2-Oi3-Oe
Limnic Haplofibrist: Oi-Lco-O´i1-O´i2-L´co-Oe-C
Lithic Cryofolist: Oi-Oa-R
Typic Hemistel: Oi-Oe-Oef

Human-Altered Soils

Anthrodensic Ustorthent: ^Ap-^C/B-^Cd-2C
Anthroportic Udorthent: ^Ap-^Cu-Ab-Btb-C

Subaqueous Soils

Psammentic Frasiwassents: A1-A2-CA-Cg1-Cg2-Cg3-Cg4
Thapto-Histic Sulfiwassents: Ase-Cse1-Cse2-Oase1-Oa1-Oa2
Sulfic Psammowassents: A-Cg1-Cg2-Aseb-C´g-A´seb-C´´g1-C´´g2-C´´g3

Cyclic and Intermittent Horizons and Layers

Soils with cyclic or intermittent horizons pose special challenges in describing soil profiles. The profile of a soil having cyclic horizons exposes layers whose boundaries are near the surface at one point and extend deep into the soil at another. The aggregate horizon thickness may be only 50 cm at one place but more than 125 cm at a place 2 meters away. The cycle repeats. It commonly has considerable variation in both depth and horizontal interval but still has some degree of regularity. When the soil is visualized in three dimensions instead of two, some cyclic horizons extend downward in inverted cones. The cone of the lower horizon fits around the cone of the horizon above. Other cyclic horizons appear wedge-shaped.

The profile of a soil having an intermittent horizon shows that the horizon extends horizontally for some distance, ends, and reappears again some distance away. For example, the horizons of Turbels, which by definition are subject to cryoturbation, are irregular, intermittent, and distorted. A B horizon interrupted at intervals by upward extensions of bedrock into the A horizon is another example. The distance between places where the horizon is absent is commonly variable but has some degree of regularity. It ranges from less than 1 meter to several meters.

For soils with cyclic or intermittent horizons or layers, a soil profile at one place may be unlike a profile only a few meters away. Standardized horizon nomenclature and pedon description forms are not well suited to soil profiles with such variability. When describing these types of soils, it is important to make notes on the individual horizons to record the nature of the variations. Photographs and diagrams can also be used to convey the information. Descriptions of the order of horizontal variation as well as vertical variation within a pedon include the kind of variation, the spacing of cycles or interruptions, and the amplitude of depth variation of cyclic horizons.

Boundaries of Horizons and Layers

A boundary is a relatively sharp plane-like division or a more gradual transitional layer between two adjoining horizons or layers. Most boundaries are zones of transition rather than sharp lines of division. Boundaries vary in distinctness and topography.

Distinctness

Distinctness refers to the thickness of the zone within which the boundary can be located. The distinctness of a boundary depends partly on the degree of contrast between the adjacent layers and partly on the thickness of the transitional zone between them. Distinctness is defined in terms of thickness of the transitional zone as follows:

Very abrupt .... less than 0.5 cm
Abrupt..................... 0.5 to less than 2 cm
Clear .... 2 to less than 5 cm
Gradual .... 5 to less than 15 cm
Diffuse .... 15 cm or more

Very abrupt boundaries occur at some lithologic discontinuities, such as geogenic deposits or strata (tephras, alluvial strata, etc.). They can also occur at the contacts of root-limiting layers. Examples are duripans; fragipans; petrocalcic, petrogypsic, and placic horizons; continuous ortstein; and densic, lithic, paralithic, and petroferric contacts. See *Soil Taxonomy* (Soil Survey Staff, 1999) for more information and definitions.

Abrupt soil boundaries, such as those between the E and Bt horizons of many soils, are easily determined. Some boundaries are not readily seen but can be located by testing the soil above and below the boundary. Diffuse boundaries, such as those in many old soils in tropical areas, are very difficult to locate. They require time-consuming comparisons of small specimens of soil from various parts of the profile to determine the midpoint of the transitional zone. For soils that have nearly uniform properties or that change very gradually as depth increases, horizon boundaries are imposed more or less arbitrarily without clear evidence of differences.

Topography

Topography refers to the irregularities of the surface that divides the horizons (fig. 3-4). Terms for topography describe the shape of the contact between horizons as seen in a vertical cross-section. Even though soil layers are commonly seen in vertical section, they are three-dimensional. Terms describing topography of boundaries are:

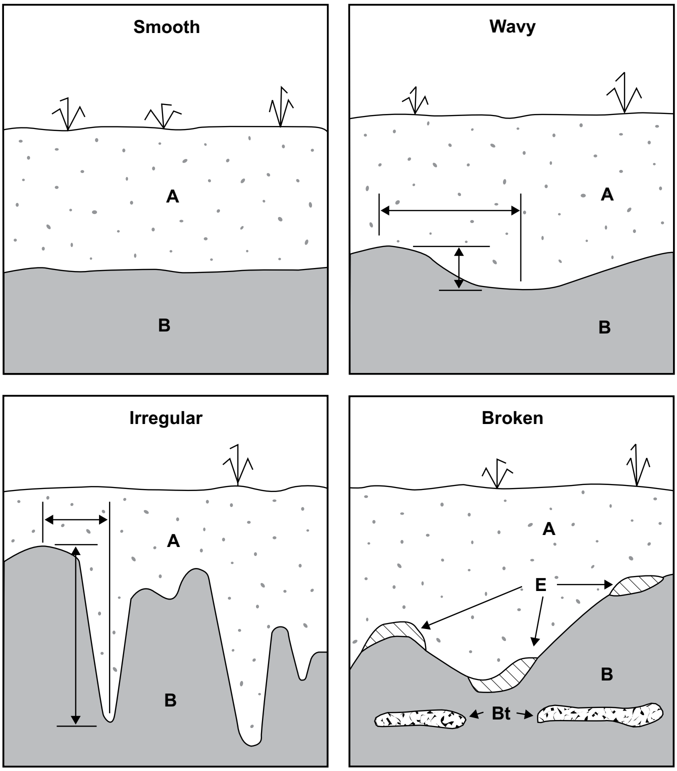
Smooth.—The boundary is a plane with few or no irregularities.

Wavy.—The boundary has undulations in which depressions are wider than they are deep.

Irregular.—The boundary has pockets that are deeper than they are wide.

Broken.—One or both of the horizons or layers separated by the boundary are discontinuous and the boundary is interrupted.

Figure 3-4



Examples of topography classes for horizon boundaries (adapted from Schoeneberger et al., 2012).

Thickness

The thickness of the horizon or layer is recorded by entering depths for the upper and lower boundaries. For horizons or layers with significant lateral variation in thickness, the average horizon thickness may also be noted.

Near Surface Subzones

Background Information

In many soils, the morphology of the uppermost few centimeters (generally from less than 1 to about 18 cm) is strongly controlled by antecedent weather and by soil use. A soil may be freshly tilled and have a loose surface one day and have a strong crust because of a heavy rain the next day. A soil may be highly compacted by livestock and have a firm near surface in one place but have little disturbance to the uppermost few centimeters and be very friable in most other places. These affected soils properties are referred to as "use-dependent" or "dynamic." See chapter 9 for information about studying dynamic soil properties in the field.

The following discussion provides a set of terms for describing subzones of the near surface and, in particular, the near surface of tilled soils. The horizon designations or symbols for describing these near surface subzones are limited. The suffix *d* is used for root-restrictive compacted layers; master horizon symbol *V* may be used to designate some layers with a dominance of vesicular pores. Surface horizons can be subdivided using standard horizon designations to record the subzones. An example horizon sequence could include Ap1 (a mechanically bulked subzone), Ap2 (a water-compacted subzone), and Bd (a mechanically compacted subzone). Descriptions of these separations should also identify the kind of subzone described. Very thin surface crusts (less than about 1 cm thick) are generally described as a special surface feature rather than as a separate layer.

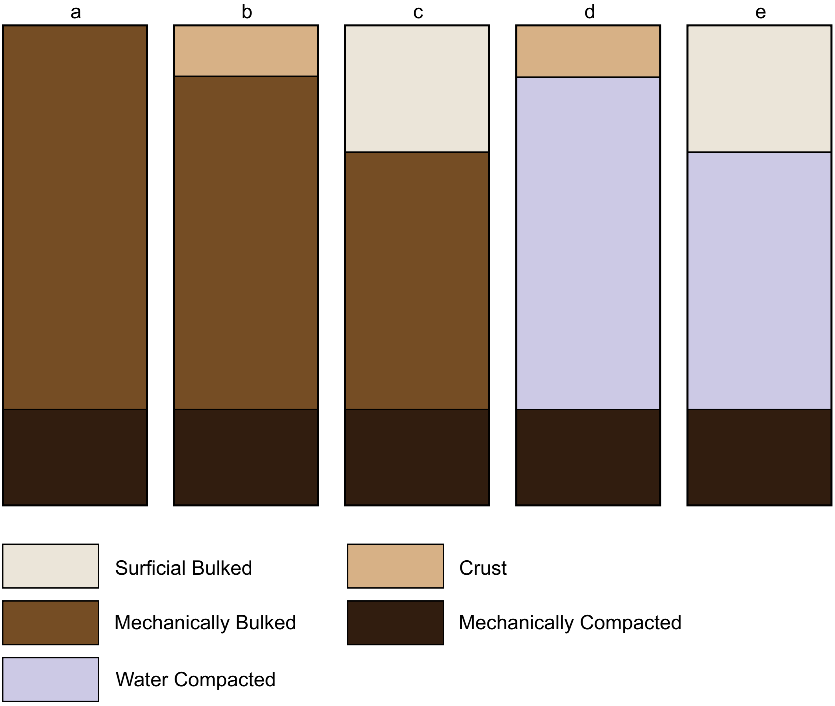
Kinds of Near Surface Subzones

In this section, five kinds of near surface subzones are presented and the general processes leading to their formation are described. The five kinds of subzones are: *mechanically bulked*, *mechanically compacted*, *water compacted*, *surficial bulked*, and *crust* (either biological or chemical). Figure 3-5 shows stylized profiles depicting various combinations of these subzones.

Identification of subzones is not clear cut. Morphological expression of bulking and compaction may be quite different among soils depending on particle-size distribution, organic matter content, clay mineralogy, water regime, or other factors.

The distinction between a bulked and compacted state for soil material with appreciable shrink-swell potential is partly based on the

Figure 3-5



Five kinds of near surface subzones (scale is approximately 18 cm).

potential for the transmission of strain on drying over distances greater than the horizontal dimensions of the larger structural units. In a bulked subzone, little or no strain is propagated; in a compacted subzone, the strain is propagated over distances greater than the horizontal dimensions of the larger structural units. Many soils have low shrink-swell potential because of texture, clay mineralogy, or both. For these soils, the expression of cracks cannot be used to distinguish between a bulked state and a compacted state.

The distinction between compaction and bulking is subjective. It is useful to establish a concept of a normal degree of compaction of the near surface and then compare the actual degree of compaction to this. The concept for tilled soils should be the compaction of soil material on level or convex parts of the tillage-determined relief. The soil should have been subject to the bulking action of conventional tillage without the subsequent mechanical compaction. The subzone in question should have been brought to a *wet* or *very moist* water state from an appreciably drier condition and then dried to *slightly moist* or drier at least once. It should not have been subject, however, to a large number of wetting and drying cycles where the maximum wetness involved the presence of free water. If the soil material has a degree of compaction similar to what would be expected, then the term *normal compaction* is used.

Mechanically Bulked Subzone

The mechanically bulked subzone has undergone, through mechanical manipulation, a reduction in bulk density and an increase in discreteness of structural units, if present. The mechanical manipulation is commonly due to tillage operations. Rupture resistance of the mass overall, inclusive of a number of structural units, is typically *loose* or *very friable* and is occasionally *friable*. Individual structural units may be *friable* or even *firm*. Mechanical continuity among structural units is low. Structure grade, if the soil material exhibits structural units less than 20 mm across, is moderate or strong. Strain that results from contraction on drying of individual structural units may not extend across the structural units. Hence, internally initiated desiccation cracks may be weak or absent even though the soil material in a consolidated condition has considerable shrink-swell potential. Cracks may be present, however, if they initiate deeper in the soil. The mechanically bulked subzone is depicted in figure 3-5 as the first layer in profile a and the second layer in profiles b and c.

Mechanically Compacted Subzone

The mechanically compacted subzone has been subject to compaction, usually due to tillage operations but also by animals. Commonly, mechanical continuity of the fabric and bulk density are increased. Rupture resistance depends on texture and degree of compaction. Generally, *friable* is the minimum class. Mechanical continuity of the fabric permits propagation of strain (that results on drying) only over several centimeters. Internally initiated cracks appear if the soil material has appreciable shrink-swell potential and drying was sufficient. In some soils this subzone restricts root growth. The suffix *d* may be used if compaction results in a strong plow pan. The mechanically compacted subzone is the lowest layer of all profiles shown in figure 3-5.

Water-Compacted Subzone

The water-compacted subzone has been compacted by repetitive large changes in water state without mechanical load, except for the weight of the soil. Repetitive occurrence of free water is particularly conducive to compaction. Depending on texture, moist rupture resistance ranges from *very friable* through *firm*. Structural units, if present, are less discrete than those in the same soil material if mechanically bulked. The subzone generally has weak structure or is massive. Mechanical continuity of the fabric is sufficient for strain that originates on drying to propagate appreciable distances. As a consequence, if shrink-swell potential is sufficient, cracks develop on drying. In many soils, the water-compacted subzone replaces the mechanically bulked subzone over time. The replacement can occur in a single year if the subzone is subject to periodic occurrence of free water with intervening periods of being *slightly moist* or *dry*. The presence of a water-compacted subzone and the absence of a mechanically bulked subzone is an important consequence of no-till farming systems. The water-compacted subzone is depicted in figure 3-5 as the second layer of profiles d and e.

Surficial Bulked Subzone

The surficial bulked subzone occurs in the very near surface. Continuity of the fabric is low. Cracks are not initiated in this subzone but may be present (they may initiate in underlying, more compacted soil). The subzone forms by various processes. Frost action under conditions where the soil is drier than *wet* is one process. Pronounced shrinking and swelling in response to drying and wetting (which is characteristic of Vertisols) is another process. The surficial bulked subzone is depicted in figure 3-5 as the first layer of profiles c and e.

Crust

A crust is a surficial subzone, typically less than 50 mm thick but ranging to as much as 100 mm thick, that exhibits markedly more mechanical continuity of the soil fabric than the zone immediately beneath. Commonly, the original soil fabric has been reconstituted by water action and the original structure has been replaced by a massive condition. While the material is *wet*, raindrop impact (including sprinkler irrigation) and freeze-thaw cycles can lead to reconstitution. The crust is depicted in figure 3-5 as the first layer of profiles b and d.

Crusts may be described in terms of thickness in millimeters, structure and other aspects of the fabric, and consistence, including rupture resistance while dry and micropenetration resistance while wet. Thickness pertains to the zone where reconstitution of the fabric has been pronounced. The distance between surface-initiated cracks (described later in this chapter) may be a useful observation for seedling emergence considerations. If the distance is short, the weight of the crust slabs is low.

Soil material with little apparent reconstitution commonly adheres beneath the crust and is removed with the crust. This soil material, which shows little or no reconstitution, is not part of the crust and does not contribute to the thickness.

Recognized types of soil crusts include biological, chemical and structural.

Biological crusts, which consist of algae, lichens, or mosses, occur on the surface of some soils, especially in some relatively undisturbed settings, such as rangelands. These crusts are easily diminished or destroyed by disturbance.

Chemical crusts commonly occur in arid environments where salty evaporites accumulate at the surface. They include crusts consisting of mineral grains cemented by salts.

Structural crusts form from local transport and deposition of soil material, commonly in tilled fields. They have weaker mechanical continuity than other crusts. The rupture resistance is lower, and the reduction in infiltration may be less than that of crusts with similar texture. Raindrop impact and freeze-thaw cycles contribute to the formation of structural crusts.

Root-Restricting Depth

The root-restricting depth is the depth at which physical (including soil temperature) and/or chemical characteristics strongly inhibit root penetration. Restriction means the incapability to support more than a few *fine* or *very fine* roots if the depth from the soil surface and the water state (other than the occurrence of frozen water) are not limiting. For cotton, soybeans, and other crops that have less abundant roots than grasses have, the *very few* class is used instead of the *few* class. The restriction may be below where plant roots normally occur because of limitations in water state, temperatures, or depth from the surface. The root-restricting depth should be evaluated for the specific plants important to the use of the soil. These plants are indicated in the soil description. The root-restriction depth may differ depending on the plant.

Morphology and Root Restriction

Root-depth observations should be used to make the generalization of root-restricting depth. If these are not available (commonly because roots do not extend to the depth of concern) then inferences may be made from morphology. A change in particle-size distribution alone (e.g., loamy sand over gravel) is not typically a basis for physical root restriction. Some guidelines for inferring physical restriction are given below. Chemical restrictions, such as high levels of extractable aluminum and/or low levels of extractable calcium, are not considered; these are generally not determinable by field examination alone.

Physical root restriction is assumed:

1. At the contact with bedrock and other continuously cemented materials, regardless of the rupture resistance class or thickness;
2. For certain horizons or layers, such as *fragipans* or those consisting of *densic materials*, that, although non-cemented, are root restrictive by definition; and
3. For layers with a combination of structure, consistence, and/or penetration resistance that suggests that the resistance of the soil fabric to root entry is high and that vertical cracks and planes of weakness for root entry are absent or widely spaced (i.e., more than 10 cm apart) as follows:
    a. For a zone more than 10 cm thick that when *very moist* or *wet* is *very firm* (*firm*, if sandy) or firmer or that has a penetration resistance class of *large* (i.e., *high* or higher), and is *massive* or *platy* or has *weak* structure of any type.
    b. For a zone that has structural units of any grade with a vertical repeat distance of more than 10 cm and while *very moist* or *wet* is *very firm* (*firm*, if sandy) or *extremely firm*, or has a *large* (i.e., *high* or higher) penetration resistance.

Classes of Root-Restricting Depth

Terms describing depth to physical restriction for roots are:

Very shallow .... less than 25 cm
Shallow.................. 25 to less than 50 cm
Moderately deep .... 50 to less than 100 cm
Deep....................... 100 to less than 150 cm
Very deep............... 150 cm or more

Particle-Size Distribution

This section discusses particle-size distribution of mineral soil separates. *Fine earth* indicates particles smaller than 2 mm in diameter. Fragments 2 mm or larger consist of *rock fragments,* pieces of geologic or pedogenic material with a strongly cemented or more cemented rupture-resistance class; *pararock fragments,* pieces of geologic or pedogenic material with an extremely weakly cemented to moderately cemented rupture-resistance class; and *discrete artifacts,* pieces of human-manufactured material. Particle-size distribution of fine earth is determined in the field mainly by feel. The content of rock fragments, pararock fragments, and discrete artifacts is an estimate of the proportion of the soil volume that they occupy.

Soil Separates

After pretreatment to remove organic matter, carbonates, soluble salts, and other cementing agents and after dispersion to physically separate individual soil particles, the U.S. Department of Agriculture uses the following size separates for fine-earth fraction:

Very coarse sand.... < 2.0 to > 1.0 mm
Coarse sand............ 1.0 to > 0.5 mm
Medium sand......... 0.5 to > 0.25 mm
Fine sand................ 0.25 to > 0.10 mm
Very fine sand........ 0.10 to > 0.05 mm
Coarse silt.............. 0.05 to > 0.02 mm
Fine silt.................. 0.02 to > 0.002 mm
Coarse clay............ 0.002 to > 0.0002 mm
Fine clay................ less than or equal to 0.0002 mm

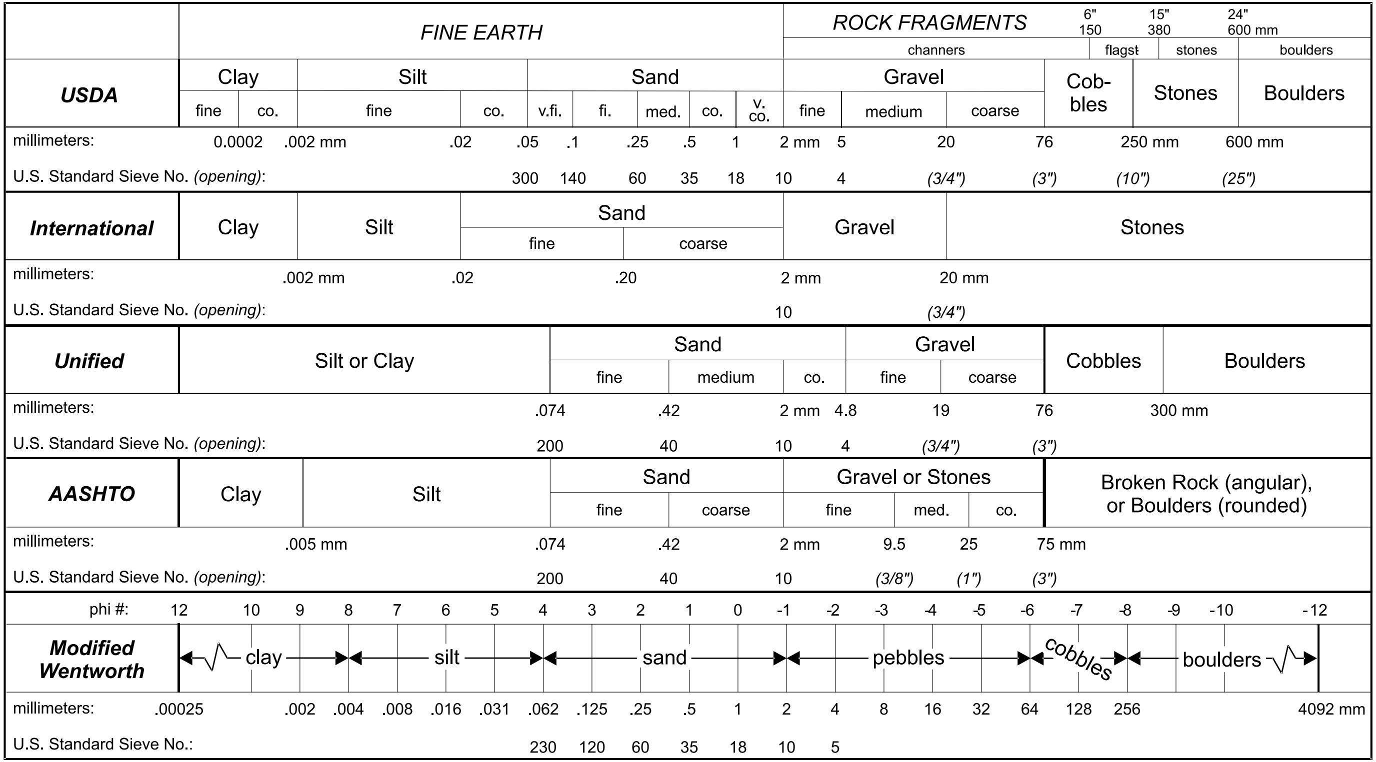
Figure 3-6 compares the USDA system for naming various sizes of soil separates with four other systems: International (Soil Survey Staff, 1951); Unified (ASTM, 2011); AASHTO (AASHTO, 1997a, 1997b); and Modified Wentworth (Ingram, 1982).

Soil Texture

Soil texture refers to the weight proportion of the separates for particles less than 2 mm in diameter as determined from a laboratory particle-size distribution. The pipette method is the preferred standard, but the hydrometer method also is used in field labs (Soil Survey Staff, 2009). If used, the hydrometer method should be noted with the results.

Field estimates of soil texture class are based on qualitative criteria, such as how the soil feels (gritty, smooth, sticky) and how it responds to rubbing between the fingers to form a ribbon. Estimated field texture class should be checked against laboratory determinations, and the field criteria used to estimate texture class should be adjusted as necessary to reflect local conditions. Sand particles feel gritty and can be seen individually with the naked eye. Silt particles have a smooth feel to the fingers when

Figure 3-6



Relationships among particle-size classes of the USDA system and four other systems.

dry or wet and cannot be seen individually without magnification. Clay soils are sticky in some areas and not sticky in others. For example, soils dominated by smectitic clays feel different from soils that contain similar amounts of micaceous or kaolinitic clay. The relationships that are useful for judging texture of one kind of soil may not apply as well to another kind.

Some soils are not dispersed completely in the standard laboratory particle-size analysis. Examples include soils with andic soil properties (high amounts of poorly crystalline, amorphous minerals) and soils with high contents of gypsum (more than about 25 percent). For soils like these, for which the estimated field texture class and the laboratory measured particle-size distribution differ markedly, the field texture is referred to as *apparent* because it is not an estimate that correlates well with the results of a laboratory test. Apparent field texture is only a tactile evaluation and does not infer laboratory test results. The twelve texture classes (fig. 3-7) are sands, loamy sands, sandy loams, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. Subclasses of sand are coarse sand, sand, fine sand, and very fine sand. Subclasses of loamy sands and sandy loams that are based on sand size are named similarly.

Definitions of Soil Texture Classes and Subclasses

Sands.—Material has more than 85 percent sand, and the percentage of silt plus 1.5 times the percentage of clay is less than 15.

Coarse sand.—Material has a total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sand.—Material has a total of 25 percent or more very coarse, coarse, and medium sand, a total of less than 25 percent very coarse and coarse sand, and less than 50 percent fine sand and less than 50 percent very fine sand; OR material has 25 percent or more very coarse and coarse sand and 50 percent or more medium sand.

Fine sand.—Material has 50 percent or more fine sand, and fine sand exceeds very fine sand; OR material has a total of less than 25 percent very coarse, coarse, and medium sand and less than 50 percent very fine sand.

Very fine sand.—Material has 50 percent or more very fine sand.

Loamy sands.—Material has between 70 and 90 percent sand, the percentage of silt plus 1.5 times the percentage of clay is 15 or more, and the percentage of silt plus twice the percentage of clay is less than 30.

Loamy coarse sand.—Material has a total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Loamy sand.—Material has a total of 25 percent or more very coarse, coarse, and medium sand, a total of less than 25 percent very coarse and coarse sand, and less than 50 percent fine sand and less than 50 percent very fine sand; OR material has a total of 25 percent or more very coarse and coarse sand and 50 percent or more medium sand.

Loamy fine sand.—Material has 50 percent or more fine sand or less than 50 percent very fine sand and a total of less than 25 percent very coarse, coarse, and medium sand.

Loamy very fine sand.—Material has 50 percent or more very fine sand.

Sandy loams.—Material has 7 to less than 20 percent clay and more than 52 percent sand, and the percentage of silt plus twice the percentage of clay is 30 or more; OR material has less than 7 percent clay and less than 50 percent silt, and the percentage of silt plus twice the percentage of clay is 30 or more.

Coarse sandy loam.—Material has a total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand; OR material has a total of 30 percent or more very coarse, coarse, and medium sand, and very fine sand is 30 to less than 50 percent.

Sandy loam.—Material has a total of 30 percent or more very coarse, coarse, and medium sand but a total of less than 25 percent very coarse and coarse sand, less than 30 percent fine sand, and less than 30 percent very fine sand; OR material has a total of 15 percent or less very coarse, coarse, and medium sand, less than 30 percent fine sand, and less than 30 percent very fine sand with a total of 40 percent or less fine and very fine sand; OR material has a total of 25 percent or more very coarse and coarse sand and 50 percent or more medium sand.

Fine sandy loam.—Material has 30 percent or more fine sand, less than 30 percent very fine sand, and a total of less than 25 percent very coarse and coarse sand; OR material has a total of 15 to less than 30 percent very coarse, coarse, and medium sand and a total of less than 25 percent very coarse and coarse sand; OR material has a total of 40 percent or more fine and very fine sand (and fine sand equals or exceeds very fine sand) and a total of 15 percent or less very coarse, coarse, and medium sand; OR material has a total of 25 percent or more very coarse and coarse sand and 50 percent or more fine sand.

Very fine sandy loam.—Material has 30 percent or more very fine sand and a total of less than 15 percent very coarse, coarse, and medium sand, and very fine sand exceeds fine sand; OR material has 40 percent or more fine and very fine sand (and very fine sand exceeds fine sand) and a total of less than 15 percent very coarse, coarse, and medium sand; OR material has 50 percent or more very fine sand and a total of 25 percent or more very coarse and coarse sand; OR material has a total of 30 percent or more very coarse, coarse, and medium sand and 50 percent or more very fine sand.

Loam.—Material has 7 to less than 27 percent clay, 28 to less than 50 percent silt, and 52 percent or less sand.

Silt loam.—Material has 50 percent or more silt and 12 to less than 27 percent clay; OR material has 50 to less than 80 percent silt and less than 12 percent clay.

Silt.—Material has 80 percent or more silt and less than 12 percent clay.

Sandy clay loam.—Material has 20 to less than 35 percent clay, less than 28 percent silt, and more than 45 percent sand.

Clay loam.—Material has 27 to less than 40 percent clay and more than 20 to 45 percent sand.

Silty clay loam.—Material has 27 to less than 40 percent clay and 20 percent or less sand.

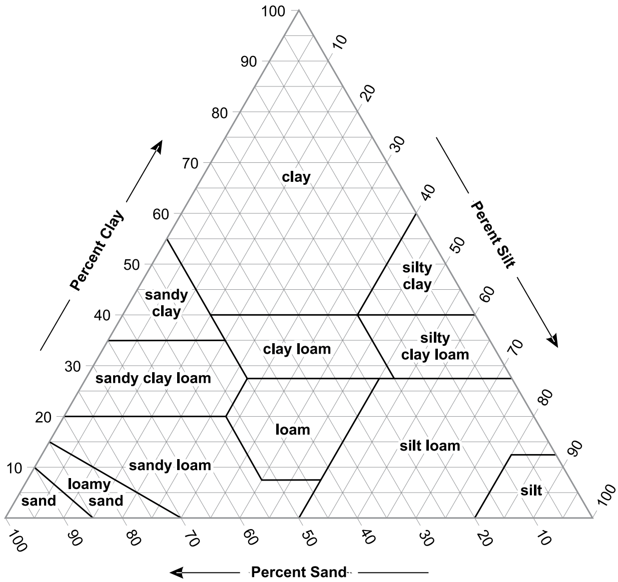
Sandy clay.—Material has 35 percent or more clay and more than 45 percent sand.

Silty clay.—Material has 40 percent or more clay and 40 percent or more silt.

Clay.—Material has 40 percent or more clay, 45 percent or less sand, and less than 40 percent silt.

The USDA textural triangle is shown in figure 3-7. A soil sample is assigned to one of the twelve soil texture classes according to the values for the proportions of sand, silt, and clay, which are located along each of the three axes. The eight subclasses in the sand and loamy sand groups provide refinement that in some cases may be greater than can be consistently determined by field techniques. Only those distinctions that are significant to use and management and that can be consistently made in the field should be applied when determinations of texture are based on field estimates alone.

Figure 3-7



USDA textural triangle showing the percentages of clay, silt, and sand in the 12 basic texture classes.

Groupings of Soil Texture Classes

The need for fine distinctions in the texture of the soil layers results in a large number of classes and subclasses of soil texture. It commonly is convenient to speak generally of broad groups or classes of texture. Table 3-1 provides an outline of three general soil texture groups and five subgroups. In some areas where soils have a high content of silt, a fourth general class, silty soil materials, may be used for silt and silt loam.

Terms Used *in Lieu* of Soil Texture

There are some horizons or layers for which soil texture class terms are not applicable. These include bedrock and other cemented horizons (such as petrocalcic horizons, duripans, etc.), those composed of organic soil materials, and those composed of water, either liquid or frozen, below a mineral or organic soil surface layer. Other exceptions include layers composed of more than 90 percent rock fragments or artifacts and horizons or layers composed of 40 percent or more gypsum in the fine-earth fraction (and that are not cemented). These exceptions are discussed below.

Table 3-1

General Soil Texture Groups

General texture groups and subgroups*	Texture classes
Sandy soil materials	
Coarse textured	Sands (coarse sand, sand, fine sand, very fine sand); loamy sands (loamy coarse sand, loamy sand, loamy fine sand, loamy very fine sand)
Loamy soil materials	
Moderately coarse textured	Coarse sandy loam, sandy loam, fine sandy loam
Medium textured	Very fine sandy loam, loam, silt loam, silt
Moderately fine textured	Clay loam, sandy clay loam, silty clay loam
Clayey soil materials	
Fine textured	Sandy clay, silty clay, clay

* Note: These are not the sandy, loamy, and clayey family particle-size classes defined in *Soil Taxonomy*.

Soil Materials with a High Content of Gypsum

For soil materials with 40 percent or more, by weight, gypsum in the fine-earth fraction, gypsum dominates the physical and chemical properties of the soil to the extent that particle-size classes are not meaningful. Two terms *in lieu* of texture are used:

Coarse gypsum material.—50 percent or more of the fine-earth fraction is comprised of particles ranging from 0.1 to 2.0 mm in diameter.

Fine gypsum material.—Less than 50 percent of the fine-earth fraction is comprised of particles ranging from 0.1 to 2.0 mm in diameter.

Bedrock and Cemented Horizons

These horizons or layers are described as *bedrock* or *cemented material*. Additional information about the kind of rock, degree of cementation, and kind of cementing agent can also be provided.

Water Layers

These layers are described as *water* or *ice*. They only refer to subsurface layers, such as in a floating bog. Figure 3-3 shows a subsoil layer of ice.

Soil Materials with a High Content of Rock or Pararock Fragments

For soil materials with more than 90 percent rock or pararock fragments, there is not enough fine earth to determine the texture class. In these cases, the terms *gravel*, *cobbles*, *stones*, *boulders*, *channers*, and *flagstones* or their pararock fragment equivalents are used. Size range and shape for these terms are described under "Rock Fragments and Pararock Fragments" and are summarized in table 3-2.

Soil Materials with a High Content of Artifacts

For soil materials with more than 90 percent artifacts, the term *artifacts* is used.

Organic Soils

Layers that are not saturated with water for more than a few days at a time are organic if they have 20 percent or more organic carbon. Layers that are saturated for longer periods, or were saturated before being drained, are organic if they have 12 percent or more organic carbon and no clay, 18 percent or more organic carbon, and 60 percent or more clay or have a proportional amount of organic carbon, between 12 and 18 percent, if the clay content is between 0 and 60 percent. The required organic carbon content for saturated soils having between 0 and 60 percent clay can be calculated as: $OC_{required} = 12 + (0.1 * \text{percent clay})$. Soils with more than 60 percent clay need an organic carbon content of at least 18 percent.

The kind and amount of the mineral fraction, the kind of organisms from which the organic material was derived, and the state of decomposition affect the properties of the soil material. Descriptions include the percentage of undecomposed fibers and the solubility in sodium pyrophosphate of the humified material. Attention should be given to identifying and estimating the volume occupied by *sphagnum* fibers, which have extraordinary high water retention. When squeezed firmly in the hand to remove as much water as possible, *sphagnum* fibers are lighter in color than fibers of *hypnum* and most other mosses.

Fragments of wood more than 20 mm across and so undecomposed that they cannot be crushed by the fingers when moist or wet are called *wood fragments*. They are comparable to rock fragments in mineral soils and are described in a comparable manner.

Saturated organic soil materials.—The types of organic soil materials that are described in saturated organic soil materials are:

Muck.—Well decomposed organic soil material with a low content of fibers (plant tissue excluding live roots).
Peat.—Slightly decomposed organic soil material with a high content of original fibers.
Mucky peat.—Organic soil material that is intermediate in degree of decomposition, fiber content, bulk density, and water content between muck and peat.

Muck, peat, and mucky peat may be described in both organic and mineral soils provided the soils are saturated with water for 30 or more cumulative days in normal years or are artificially drained. These materials only qualify for the diagnostic sapric, fibric, and hemic soil material of Soil Taxonomy when they occur in organic soils (i.e., the soil of the order Histosols and the suborder Histels).

Non-saturated organic soil materials.—The types of organic soil materials that are described in layers not saturated for 30 or more cumulative days are:

Highly decomposed plant material.—Well decomposed, organic soil material with a low content of fibers (plant tissue excluding live roots).
Moderately decomposed plant material.—Material intermediate in degree of decomposition, fiber content, bulk density, and water content between highly decomposed and slightly decomposed plant material.
Slightly decomposed plant material.—Slightly decomposed organic soil material with a high content of original fibers.

Modifiers for Terms Used *in Lieu* of Texture

Modifiers may be needed to better describe the soil material making up the horizon or layer. These include terms for significant amounts of particles 2.0 mm or larger (rock fragments, pararock fragments, or artifacts) and terms that indicate the composition of the soil material.

Soil Materials with Rock Fragments, Pararock Fragments, or Artifacts

To describe soils with 15 percent or more, by volume, rock fragments, pararock fragments, or artifacts, the texture terms are modified with terms indicating the amount and kind of fragments. Examples include very gravelly loam, extremely paracobbly sand, and very artifactual sand. The conventions for use of these terms and the definitions of class terms are discussed in the following sections on rock fragments, pararock fragments, and artifacts.

Class Modifiers Indicating Soil Material Composition

Soil composition modifiers are used for some soils that have andic properties or formed in volcanic materials, soils that have a high content of gypsum, some organic soil materials, and mineral soil materials with a high content of organic matter. Terms are also provided for limnic soil materials and permanently frozen layers (permafrost).

Soil Materials with Andic Properties or Volcanic Origin

Hydrous.—Material that has andic soil properties and an undried 15 bar (1500 kPa) water content of 100 percent or more of the dry weight (e.g., hydrous clay).

Medial.—Material that has andic soil properties and has a 15 bar (1500 kPa) water content of less than 100 percent on undried samples and of 12 percent or more on air-dried samples (e.g., medial silt loam).

Ashy.—Material that has andic soil properties and is neither hydrous nor medial, or material that does not have andic soil properties and the chemistry and physical makeup of its fine-earth fraction reflects the weathering processes of volcanic materials (e.g., ashy loam). The weathering processes of volcanic materials are evidenced by 30 percent or more particles 0.02 to 2.0 mm in diameter, of which 5 percent or more is composed of volcanic glass and the [(aluminum plus ½ iron percent by ammonium oxalate) times 60] plus the volcanic glass percent is equal to or more than 30.

Soil Materials with Gypsum

Gypsiferous.—Material that contains 15 to less than 40 percent, by weight, gypsum (e.g., gypsiferous fine sandy loam).

For material that has 40 percent or more gypsum, a term *in lieu* of texture is used (e.g., *fine gypsum material* or *coarse gypsum material,* defined above).

Organic Soil Materials

Modifiers are only used with the "*in lieu* of texture" terms *muck*, *peat*, or *mucky peat*. The following modifiers are used only for organic soil materials that are saturated with water for 30 or more cumulative days in normal years or are artificially drained.

Woody.—Material contains 15 percent or more wood fragments larger than 20 mm in size or contains 15 percent or more fibers that can be identified as wood origin and has more wood fibers than any other kind of fiber (e.g., woody muck).

Grassy.—Material contains more than 15 percent fibers that can be identified as grass, sedges, cattails, and other grasslike plants and contains more grassy fibers than any other kind of fiber (e.g., grassy mucky peat).

Mossy.—Material contains more than 15 percent fibers that can be identified as moss and contains more moss fibers than any other kind of fiber (e.g., mossy peat).

Herbaceous.—Material contains more than 15 percent fibers that can be identified as herbaceous plants other than moss and grass or grasslike plants and has more of these fibers than any other kind of fiber (e.g., herbaceous muck).

Mineral Soil Materials with a High Content of Organic Matter

Highly organic.—Term indicates near surface horizons of mineral soils that are saturated with water for less than 30 cumulative days in normal years and are not artificially drained (e.g., highly organic loam). Excluding live roots, the horizon has organic carbon content (by weight) of one of the following:

- 5 to < 20 percent if the mineral fraction contains no clay,
- 12 to < 20 percent if the mineral fraction contains 60 percent or more clay, or
- [5 + (clay percentage multiplied by 0.12)] to < 20 percent if the mineral fraction contains less than 60 percent clay.

Mucky.—Term indicates near surface horizons of mineral soils that are saturated with water for 30 or more cumulative days in normal years or are artificially drained (e.g., mucky silt loam). Excluding live roots, the horizon has more than 10 percent organic matter and less than 17 percent fibers.

Peaty.—Term indicates near surface horizons of mineral soils that are saturated with water for 30 or more cumulative days in normal years or are artificially drained (e.g., peaty clay loam). Excluding live roots, the horizon has more than 10 percent organic matter and 17 percent or more fibers.

Limnic Soil Materials

Limnic soil materials occur in layers underlying some soils of the soil order Histosols. By definition (see *Soil Taxonomy*) they are not recognized in mineral soils. They are mineral or organic soil materials originating from aquatic organisms or from aquatic plants that were later altered by aquatic organisms. The following terms are used to describe the origin of the limnic materials:

Coprogenous.—Material contains many very small (0.1 to 0.001 mm) fecal pellets (e.g., coprogenous sandy loam).
Diatomaceous.—Material is composed dominantly of diatoms (e.g., diatomaceous silt loam).
Marly.—Material is composed dominantly of calcium carbonate "mud" (e.g., marly silty clay).

Layers for which these terms are used may or may not also meet the definition for coprogenous earth, diatomaceous earth, or marl as defined in *Soil Taxonomy*.

Permafrost

Layers of permafrost are described as *permanently frozen* (e.g., permanently frozen loamy sand).

Rock Fragments and Pararock Fragments

Rock fragments are unattached pieces of geologic or pedogenic material 2 mm in diameter or larger that have a *strongly cemented* or more cemented rupture-resistance class. Pararock fragments are unattached pieces of geologic or pedogenic material 2 mm in diameter or larger that are *extremely weakly cemented* through *moderately cemented*. Pararock fragments are not retained on sieves because they are crushed by grinding during the preparation of samples for particle-size analysis in the laboratory. Rock fragments and pararock fragments include all sizes between 2.0 mm and horizontal dimensions smaller than the size of a pedon. The words "rock" and "pararock" are used here in the broad sense and connote more than just natural fragments of geologic material. Thus, rock and pararock fragments may be discrete, cemented pieces of bedrock, bedrock-like material, durinodes, concretions, nodules, or pedogenic horizons (e.g., petrocalcic fragments). Artifacts, however, are not included as rock or pararock fragments. They are described separately.

Rock fragments and pararock fragments are described by size, shape, hardness, roundness, and kind of fragment. The classes are *gravel,* *cobbles, channers, flagstones, stones,* and *boulders* and their pararock counterparts (i.e., *paragravel, paracobbles*, etc.) (table 3-2). If a size or range of sizes predominates, the class is modified (e.g., "fine gravel," "cobbles 100 to 150 mm in diameter," "channers 25 to 50 mm in length").

Gravel and *paragravel* are a collection of fragments that have diameters ranging from 2 to 76 mm. Individual fragments in this size range are properly referred to as "pebbles," not "gravels." The term gravel as used here indicates the collection of pebbles in a soil horizon and does not imply a geological formation. The terms "pebble" and "cobble" are typically restricted to rounded or subrounded fragments; however, they can be used to describe angular fragments that are not flat. Words such as "chert," "limestone," and "shale" refer to a kind or lithology of rock, not a piece of rock. The composition of the fragments can be given, for example: "chert gravel," "limestone channers," "siltstone parachanners."

The upper size limit of gravel and paragravel is 76 mm (3 inches). This coincides with the upper limit used by many engineers for grain-size distribution computations. The 5-mm and 20-mm divisions for the separation of fine, medium, and coarse gravel coincide with the sizes of openings in the number 4 screen (4.76-mm) and the ¾-inch (19.05-mm) screen used in engineering.

The 76-mm (3-inch) limit separates gravel from cobbles, the 250-mm (10-inch) limit separates cobbles from stones, and the 600-mm (24-inch) limit separates stones from boulders. The 150-mm (6-inch) and 380-mm (15-inch) limits for thin, flat channers and flagstones, respectively, follow conventions used for many years to provide class limits for plate-shaped and crudely spherical rock fragments that have about the same soil use implications as the 250-mm limit for spherical shapes.

Estimating Rock Fragments in the Soil

Rock fragments in the soil can greatly influence use and management. It is important to not only consider the total amount of rock fragments, but also the proportions of the various size classes (gravel, cobbles, stones, etc.). A soil with 10 percent stones is quite different from one with 10 percent gravel. When developing interpretive criteria, a distinction must be made between volume and weight percent of rock fragments. Field descriptions generally record estimates of volume, while laboratory measurements of rock fragments are given as weight for the various size classes.

The National Cooperative Soil Survey in the United States uses interpretive algorithms based on weight percent of the > 250, > 76-250, > 5-76, and 2-5 mm fractions when rating soils for various potential uses.

The first two size ranges are on a whole soil basis, and the latter two are on a < 76 mm basis. For the > 250 and > 76-250 mm fractions, weighing is generally impracticable and volume percentage estimates are made from areal percentage measurements by point-count or line-intersect methods. Length of the transect or area of the exposure should be at least 50 times, and preferably 100 times, the area or dimensions of the rock fragment size that encompasses about 90 percent of the rock fragment volume. For the < 76 mm weight, measurements are feasible but may require 50 to 60 kg of sample if appreciable rock fragments near 76 mm are present. An alternative is to obtain volume estimates for the 20-76 mm fraction and weight estimates for the < 20 mm fraction. This method is preferred because of the difficulty in visual evaluation of the 2 to 5 mm size separations. The weight percentages of > 5-20 mm and 2-5 mm fractions may be converted to volume estimates and placed on a < 76 mm base by computation.

Terms for Rock Fragments and Their Use in Modifying Texture Classes

The adjectival form of a class name of rock fragments or pararock fragments (table 3-2) is used as a modifier of the texture class name, e.g., paragravelly loam, very cobbly sandy loam. Table 3-3 provides rules for determining the proper texture modifier term for material with a mixture of rock fragment sizes. This section also provides rules for assigning terms for soils with a mixture of rock and pararock fragments.

The following classes, based on volume percentages, are used:

Less than 15 percent.—No texture modifier terms are used with soils having less than 15 percent gravel, paragravel, cobbles, paracobbles, channers, parachanners, flagstones, or paraflagstones.

15 to less than 35 percent.—The adjectival term of the dominant kind of fragment is used as a modifier of the texture class, e.g., gravelly loam, parachannery silt loam, cobbly sandy loam.

35 to less than 60 percent.—The adjectival term of the dominant kind of rock fragment is used with the word “very” as a modifier of the texture class, e.g., very gravelly loam, very parachannery silt loam, very cobbly loamy sand (fig. 3-8).

60 to less than 90 percent.—The adjectival term of the dominant kind of rock fragment is used with the word “extremely” as a modifier of the texture class, e.g., extremely gravelly loam, extremely parachannery silt loam, extremely cobbly sandy loam.

Table 3-2

Terms for Rock Fragments and Pararock Fragments

Shape and size	Noun*	Adjective*
Nonflat fragments (spherical or cubelike):		
2–76 mm diameter	Gravel	Gravelly
2–5 mm diameter	Fine gravel	Fine gravelly
> 5–20 mm diameter	Medium gravel	Medium gravelly
> 20–76 mm diameter	Coarse gravel	Coarse gravelly
> 76–250 mm diameter	Cobbles	Cobbly
> 250–600 mm diameter	Stones	Stony
> 600 mm diameter	Boulders	Bouldery
Flat fragments:		
2–150 mm long	Channers	Channery
> 150–380 mm long	Flagstones	Flaggy
> 380–600 mm long	Stones	Stony
> 600 mm long	Boulders	Bouldery

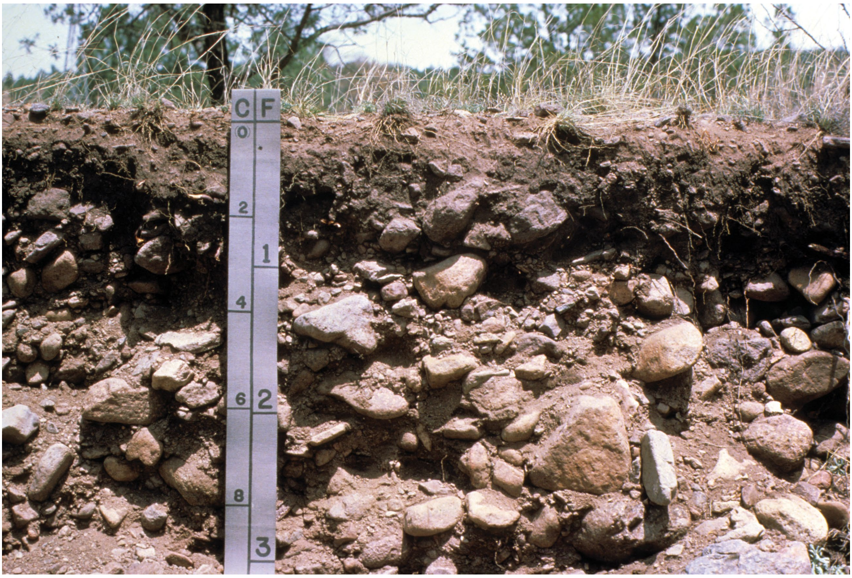
* For fragments that are less than strongly cemented, the prefix "para" is added to the terms in this table to form either a descriptive noun or the adjective for the texture modifier (e.g., paracobbles, paragravelly).

90 percent or more.—No texture modifier terms are used. If there is too little fine earth to determine the texture class (less than about 10 percent, by volume) a term *in lieu* of texture (i.e., gravel, cobbles, stones, boulders, channers, flagstones, or their pararock fragment equivalents) is used as appropriate.

The class limits apply to the volume of the layer occupied by all rock fragments 2 mm in diameter or larger. The soil generally contains fragments smaller or larger than those identified by the term. For example, very cobbly sandy loam typically contains gravel but "gravelly" is not in the name. The use of a term for larger pieces of rock, such as boulders, does not imply that the pieces are entirely within a given soil layer. A single boulder may extend through several layers.

Table 3-3 can be used to determine the proper modifier if there is a mixture of rock fragment sizes. To use the table, first choose the row with the appropriate total rock fragments. Then read the criteria in the columns under "Gravel, cobbles, stones, and boulders," starting from the

Figure 3-8



A soil in which the layers below a depth of about 20 cm are very cobbly loamy sand. Left side of scale is in 20-cm increments.

Table 3-3

Guide for Determining Rock Fragment Modifier of Texture for Soils with a Mixture of Rock Fragment Sizes

Total rock fragments *(Vol. %)*	Gravel (GR), cobbles (CB), stones (ST), and boulders (BY) (Substitute channers for gravel and flagstones for cobbles, where applicable)			
	If GR ≥ 1.5 CB + 2 ST + 2.5 BY	If CB ≥ 1.5 ST + 2 BY	If ST ≥ 1.5 BY	If ST < 1.5 BY
≥ 15 < 35	Gravelly	Cobbly	Stony	Bouldery
≥ 35 < 60	Very gravelly	Very cobbly	Very stony	Very bouldery
≥ 60 < 90	Extremely gravelly	Extremely cobbly	Extremely stony	Extremely bouldery
≥ 90	Gravel	Cobbles	Stones	Boulders

left-most column and proceeding to the right. Stop in the first column in which a criterion is met.

More precise estimates of the amounts of rock fragments than are provided by the defined classes are needed for some purposes. For more precise information, estimates of percentages of each size class or a combination of size classes are included in the description, e.g., "very cobbly sandy loam," "30 percent cobbles and 15 percent gravel or silt loam," "about 10 percent gravel." If loose pieces of rock are significant to the use and management of a soil, they are the basis of phase distinctions among map units. Exposed bedrock is not soil and is identified separately in mapping as a kind of miscellaneous area (i.e., Rock outcrop).

The volume occupied by individual pieces of rock can be seen, and their aggregate volume percentage can be calculated. For some purposes, volume percentage must be converted to weight percentage.

The following rules are used to select texture modifiers if a horizon includes both rock and pararock fragments:

1. Describe the individual kinds and amounts of rock and pararock fragments.
2. Do not use a fragment texture modifier if the combined volume of rock and pararock fragments is less than 15 percent.
3. If the combined volume of rock and pararock fragments is more than 15 percent and the volume of rock fragments is less than 15 percent, assign pararock fragment modifiers based on the combined volume of fragments. For example, use "paragravelly" as a texture modifier for soils with 10 percent rock and 10 percent pararock gravel-sized fragments.
4. If the volume of rock fragments is 15 percent or more, use the appropriate texture modifier for rock fragments regardless of the volume of pararock fragments.

Rock Fragment Hardness, Roundness, and Kind

Fragment hardness is equivalent to the rupture resistance class for a cemented fragment of specified size that has been air dried and then submerged in water. The hardness of a fragment is significant where the rupture resistance class is strongly cemented or greater. See the section on rupture resistance later in this chapter for details describing the fragment hardness classes and their test descriptions.

Fragment roundness is an expression of the sharpness of the edges and corners of rock fragments and pararock fragments. The roundness of fragments impacts water infiltration, root penetration, and macropore space. The following roundness classes are used:

Very angular	Strongly developed faces and very sharp, broken edges
Angular	Strongly developed faces and sharp edges
Subangular	Detectable flat faces and slightly rounded corners
Subrounded	Detectable flat faces and well rounded corners
Rounded	Flat faces absent or nearly absent and all corners rounded
Well rounded	Flat faces absent and all corners rounded

Fragment kind is the lithology or composition of the 2 mm or larger fraction of the soil. Kinds of fragments are varied based on whether their origin is from a geologic source or a pedogenic source. Examples of kinds of fragments are basalt fragments, durinodes, iron-manganese concretions, limestone fragments, petrocalcic fragments, tuff fragments, and wood fragments.

Artifacts

Artifacts are discrete water-stable objects or materials created, modified, or transported from their source by humans, usually for a practical purpose in habitation, manufacturing, excavation, agriculture, or construction activities. Examples are processed wood products, coal combustion by-products, bitumen (asphalt), fibers and fabrics, bricks, cinder blocks, concrete, plastic, glass, rubber, paper, cardboard, iron and steel, altered metals and minerals, sanitary and medical waste, garbage, and landfill waste. Artifacts also include natural materials which were mechanically abraded by human activities (as evidenced by scrapes, gouges, tool marks, etc.), such as shaped or carved stone work, grindstones, and shaped stones and debitage (e.g., stone tool flakes).

Artifacts are generally categorized as either *particulate* or *discrete*. The distinction is based on size: particulate artifacts have a diameter of less than 2 mm and discrete artifacts have a diameter of 2 mm or more. Discrete artifacts are easier to identify and are essentially fragments of human origin. Particulate artifacts are sometimes difficult to discern from naturally occurring fine-earth soil material.

Describing Artifacts in Soil

Artifacts are described if they are judged to be durable enough to persist in the soil (resist weathering and leaching) for a few decades or more. Descriptions of artifacts generally include quantity, cohesion, persistence, size, and safety classes. They may also include shape, kind, penetrability by roots, and roundness. Additional attributes (such as those discussed below under the heading “Consistence”) may be described to help understand and interpret the soil. The conventions for describing artifacts are explained in the following paragraphs.

Quantity refers to the estimated volume percent of a horizon or other specified unit occupied by discrete artifacts. If classes (rather than quantitative estimates) are given, they are the same as those described in this chapter for mottles.

Cohesion refers to the relative ability of the artifact to remain intact after significant disturbance. The cohesion classes are:

Cohesive.—Artifacts adhere together sufficiently so that they cannot be easily broken into pieces < 2 mm either by hand or with a simple crushing device, such as a mortar and pestle.

Noncohesive.—Artifacts are easily broken into pieces < 2 mm either by hand or with a simple crushing device, such as a mortar and pestle. Noncohesive artifacts are similar to pararock fragments and will be incorporated into the fine-earth fraction of the soil during routine laboratory sample preparation.

Penetrability describes the relative ease with which roots can penetrate the artifact and potentially extract any stored moisture, nutrients, or toxic elements. The penetrability classes are:

Nonpenetrable.—Roots cannot penetrate through the solid parts of the artifact or between the component parts of the artifact.

Penetrable.—Roots can penetrate through the solid parts of the artifact or between the component parts of the artifact.

Persistence describes the relative ability of solid artifacts to withstand weathering and decay over time. Local conditions, such as temperature and moisture, significantly impact the persistence of artifacts in the soil. The persistence classes are:

Nonpersistent.—The artifact is susceptible to relatively rapid weathering or decay and is expected to be lost from the soil in less than a decade. Loss of soil mass and eventually subsidence result.

Persistent.—The artifact is expected to remain intact in the soil for a decade or more.

Roundness indicates the sharpness of edges and corners of natural objects, such as rock fragments, and human-manufactured objects, such as artifacts. The artifact roundness classes are the same as those used for fragment roundness (above).

Safety describes the degree of risk to humans from contact with soils that contain artifacts. Physical contact with soils containing dangerous or harmful artifacts should be avoided unless proper training is provided and protective clothing is available. The safety classes are:

Innocuous.—The artifacts are considered to be harmless to living beings. Examples include untreated wood products, iron, bricks, cinder blocks, concrete, plastic, glass, rubber, organic fibers, inorganic fibers, unprinted paper and cardboard, and some mineral and metal products. Sharp innocuous artifacts can cause injury, but the materials themselves are still considered innocuous.

Noxious.—The artifacts are potentially harmful or destructive to living beings unless dealt with carefully. The harm may be immediate or long-term and through direct or indirect contact. Examples include arsenic-treated wood products, batteries, waste and garbage, radioactive fallout, liquid petroleum products, asphalt, coal ash, paper printed with metallic ink, and some mineral and metal products.

Shape is variable among kinds of artifacts. The shape classes are:

Elongated.—One dimension is at least three times longer than both of the others.

Equidimensional.—Dimensions in length, width, and height are approximately similar.

Flat.—One dimension is less than one third that of both of the others, and one dimension is less than three times that of the intermediate dimension.

Irregular.—The form is branching and convoluted.

Size may be measured and reported directly or given as a class. The dimension to which size-class limits apply depends on the shape of the artifact described. If the shape is nearly uniform, size is measured in the shortest dimension, such as the effective diameter of a cylinder or the thickness of a plate. For elongated or irregular bodies, size generally refers to the longest dimension but direct measurements for 2 or 3 dimensions can be given for clarification. The size classes for discrete artifacts are:

Fine	2 to < 20 mm
Medium	20 to < 75 mm
Coarse	75 to < 250 mm
Very coarse	≥ 250 mm

Kinds of Artifacts

There are too many varieties of artifacts to provide a comprehensive list. The most common types include:

- Noxious and innocuous artifacts
- Treated and untreated wood products
- Liquid petroleum products
- Coal combustion by-products
- Paper (printed and unprinted) and cardboard
- Sanitary and medical waste
- Garbage and landfill waste
- Asphalt
- Organic and inorganic fibers
- Bricks
- Cinder blocks
- Concrete
- Plastic
- Glass
- Rubber products
- Iron and steel

Texture Modifier Terms for Soils with Artifacts

The texture of soils with artifacts is described according to the content of artifacts:

Less than 15 percent.—No texture modifier terms are used.

15 to less than 35 percent.—The term "artifactual" is used, e.g., artifactual loam.

35 to less than 60 percent.—The term "very artifactual" is used, e.g., very artifactual loam.

60 to less than 90 percent.—The term "extremely artifactual" is used, e.g., extremely artifactual loam.

90 percent or more.—No texture modifier terms are used. If there is not enough fine earth to determine the texture class (less than about 10 percent, by volume) the term "artifacts" is used.

Compound Texture Modifiers

In some cases, the mineral soil may contain a combination of fragment or composition types for which the use of compound texture modifiers is useful. For example, a soil horizon may contain both artifacts and other fragments, such as rock fragments and pararock fragments. In these cases, the rock fragments, pararock fragments, and artifacts are each described separately. Modifiers for both artifacts and rock or pararock fragments can be combined. The modifier for artifacts comes before the modifier for rock or pararock fragments, e.g., artifactual very gravelly sandy loam. Modifiers for composition and rock fragments can also be combined. For example, a horizon of channery mucky clay or one of gravelly gypsiferous sandy loam contains rock fragments and also a content of high organic matter or gypsum. There are many possible combinations.

Fragments on the Surface

This section discusses the description of rock fragments (especially stones and boulders) that are *on the soil* as opposed to *in the soil*. The description of gravel, cobbles, and channers (≥ 2 but < 250 mm in diameter) differs from that for stones and boulders (≥ 250 mm in diameter) because an important aspect of gravel, cobbles, and channers is their areal percent cover on the ground surface. This cover provides some protection from wind and water erosion. It may also interfere with seed placement and emergence after germination. For stones and boulders, the percent of cover is not of itself as important as the interference with mechanical manipulation of the soil. For example, a very small areal percentage of large fragments, insignificant for erosion protection, may interfere with tillage, tree harvesting, and other operations involving machinery.

The areal percentage of the ground surface is determined using point-count and/or line-intersect procedures. If the areal percentage equals or exceeds 80 percent, the top of the soil is considered to be the mean height of the top of the rock or pararock fragments. The volume proportions of the 2 to 5 mm, 5 to 75 mm, and 75 to 250 mm fragments should be recorded. This can be done from areal measurements in representative areas.

The number, size, and spacing of stones and boulders (≥ 250 mm in diameter) on the surface of a soil, including both those that lie on the surface and those that are partly within the soil, have important effects on soil use and management. The classes are given in terms of the approximate amount of rock fragments of stone and boulder size at the surface:

Class 1.—Stones or boulders cover 0.01 to less than 0.1 percent of the surface. The smallest stones are at least 8 meters apart; the smallest boulders are at least 20 meters apart (fig. 3-9).

Class 2.—Stones or boulders cover 0.1 to less than 3 percent of the surface. The smallest stones are not less than 1 meter apart; the smallest boulders are not less than 3 meters apart (fig. 3-10).

Class 3.—Stones or boulders cover 3 to less than 15 percent of the surface. The smallest stones are as little as 0.5 meter apart; the smallest boulders are as little as 1 meter apart (fig. 3-11).

Class 4.—Stones or boulders cover 15 to less than 50 percent of the surface. The smallest stones are as little as 0.3 meter apart; the smallest boulders are as little as 0.5 meter apart. In most places it is possible to step from stone to stone or jump from boulder to boulder without touching the soil (fig. 3-12).

Class 5.—Stones or boulders appear to be nearly continuous and cover 50 percent or more of the surface. The smallest stones are less than 0.03 meter apart; the smallest boulders are less than 0.05 meter apart. Classifiable soil is among the rock fragments, and plant growth is possible (fig. 3-13).

These limits are intended only as guides to amounts that may mark critical limitations for major kinds of land use. Table 3-4 is a summary of the classes.

Table 3-4

Classes of Surface Stones and Boulders in Terms of Cover and Spacing

Class	Percentage of surface covered	Distance in meters between stones or boulders if the diameter is:			Descriptive term
		0.25 m*	0.6 m	1.2 m	
1	0.01 to < 0.1	≥ 8	≥ 20	≥ 37	Stony or bouldery
2	0.1 to < 3.0	1–8	3–20	6–37	Very stony or very bouldery
3	3.0 to < 15	0.5–1	1–3	2–6	Extremely stony or extremely bouldery
4	15 to < 50	0.3–0.5	0.5–1	1–2	Rubbly
5	≥ 50	< 0.3	< 0.5	< 1	Very rubbly

* 0.38 m if the fragment is flat.

Figure 3-9

An area of bouldery soil (class 1).

Figure 3-10

An area of very bouldery soil (class 2).

Figure 3-11

An area of extremely bouldery soil (class 3).

Figure 3-12

An area of rubbly soil (class 4).

Figure 3-13

An area of very rubbly soil (class 5).

Soil Color

Most soil survey organizations, including the National Cooperative Soil Survey in the United States, have adopted the Munsell soil color system for describing soil color (using the elements of hue, value, and chroma). The names associated with each standard color chip (yellowish brown, light gray, etc.) are not strictly part of the Munsell color system. They were selected by the Soil Survey Staff to be used in conjunction with the Munsell color chips. The color chips included in the standard soil-color charts (a subset of all colors in the system) were selected so that soil scientists can describe the normal range of colors found in soils. These chips have enough contrast between them for different individuals to match a soil sample to the same color chip consistently. Interpolating between chips is not recommended in standard soil survey operations because such visual determinations cannot be repeated with a high level of precision. Although digital soil color meters that can provide precise color readings consistently are available, they are not widely used in field operations. Therefore, the standard procedure adopted for soil survey work is visual comparison to the standard soil-color charts.

Elements of Soil Color Descriptions

Elements of soil color descriptions are the color name, the Munsell notation, the water state (moist or dry), and the physical state. An example is "brown (10YR 5/3), dry, crushed and smoothed." Physical state is recorded as broken, rubbed, crushed, or crushed and smoothed. The term "crushed" typically applies to dry samples and "rubbed" to moist samples. If physical state is unspecified, a broken surface is implied. The color of the soil is normally recorded for a surface broken through a ped, if a ped can be broken as a unit. If ped surfaces are noticeably different in color from the ped interior, this should also be described.

The color value of most soil material is lower after moistening. Consequently, the water state of a sample is always given. The water state is either "moist" or "dry." The dry state for color determinations is air dry and should be made at the point where the color does not change with additional drying. Color in the moist state is determined on moderately moist or very moist soil material and should be made at the point where the color does not change with additional moistening. The soil should not be moistened to the extent that glistening takes place because the light reflection of water films may cause incorrect color determinations. In a humid region, the moist state generally is standard; in an arid region, the dry state is standard. In detailed descriptions, colors of both dry and moist soil are recorded if feasible. The color for the regionally standard moisture state is typically described first. Both moist and dry colors are valuable, particularly for the immediate surface and tilled horizons, in assessing reflectance.

A *Munsell notation* is obtained by comparison with a Munsell soil-color chart. The most commonly used charts include only about one fifth of the entire range of hues.[1] They consist of about 250 different colored papers, or chips, systematically arranged on hue cards according to their Munsell notations. Figure 3-14 illustrates the arrangements of color chips on a Munsell color card.

The Munsell color system uses three elements of color—*hue, value,* and *chroma*. The color notation is recorded as: hue, value/chroma (e.g., 5Y 6/3).

Hue is a measure of the chromatic composition of light that reaches the eye. The Munsell system is based on five principal hues: red (R), yellow (Y), green (G), blue (B), and purple (P). Five intermediate hues representing midpoints between each pair of principal hues complete the

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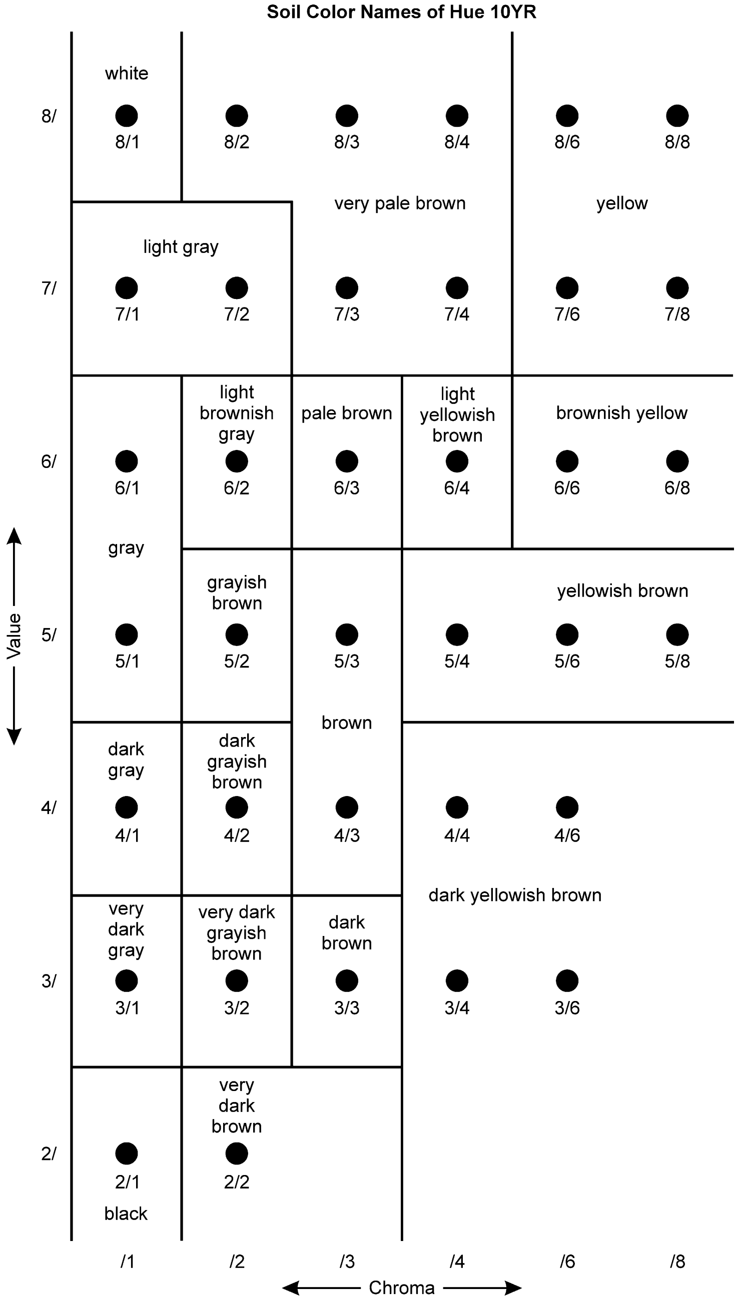
1 The appropriate color chips, separate or mounted by hue on special cards for a loose-leaf notebook, are available through several suppliers of scientific equipment.

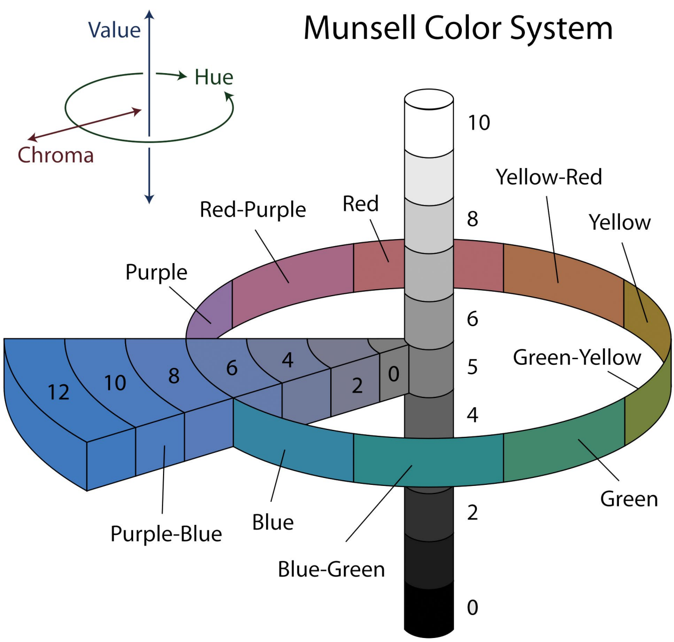
Figure 3-14



The arrangement of color chips according to value and chroma on the Munsell soil-color card of hue 10YR.

10 major hue names used to describe the notation. The intermediate hues are yellow-red (YR), green-yellow (GY), blue-green (BG), purple-blue (PB), and red-purple (RP). The relationships among the 10 hues are shown in figure 3-15. Each of the 10 major hues is divided into 4 segments of equal visual steps, which are designated by numerical values applied as prefixes to the symbol for the hue name.[2] For example, 10R marks a limit of red hue. Four equally spaced steps of the adjacent yellow-red (YR) hue are identified as 2.5YR, 5YR, 7.5YR, and 10YR, respectively. The standard chart for soil has separate hue cards, from 10R through 5Y. In addition, special charts for gley colors and for very light colors are available.

Figure 3-15



A schematic diagram showing relationships among hue, value, and chroma in the Munsell color system (Rus, 2007).

Value indicates the degree of lightness or darkness of a color in relation to a neutral gray scale. On a neutral gray (achromatic) scale, value extends from pure black (0) to pure white (10). The value notation

[2] The notation for hue, value, and chroma is a decimal number that can be refined to any degree. In practice, however, only the divisions on the color charts are used.

is a measure of the amount of light that reaches the eye under standard lighting conditions. Gray is perceived as about halfway between black and white and has a value notation of 5. The actual amount of light that reaches the eye is related logarithmically to color value. Lighter colors are indicated by numbers between 5 and 10; darker colors are indicated by numbers from 5 to 0. These values may be designated for either achromatic (i.e., having no hue and chroma of 0) or chromatic (i.e., having all three components—hue, value, and chroma) conditions. Thus, a card of the color chart for soil has a series of chips arranged vertically to show equal steps from the lightest to the darkest shades of that hue. Figure 3-14 shows this arrangement vertically on the card for the hue of 10YR. Note that the highest value shown on the standard color cards is 8. Color chips with value of 9 are included on special color cards for very light colors.

Chroma is the relative purity or strength of the spectral color. It indicates the degree of saturation of neutral gray by the spectral color. The scales of chroma for soils extend from 0 (for neutral colors) to 8 (for colors with the strongest expression). The color chips are arranged horizontally by increasing chroma from left to right on the soil-color chart (see fig. 3-14).

On the soil-color chart for a specific hue (e.g., 10YR), the darkest shades of that hue are at the bottom of the card and the lightest shades are at the top. The weakest expression of chroma (the grayest color) is at the left, and the strongest expression of chroma is at the right.

At the extreme left of some cards are symbols such as N 6/. These colors have zero chroma and are totally achromatic (neutral). They have no hue and no chroma but range in value from black (N 2.5/) to white (N 8/). An example of a notation for a neutral (achromatic) color is N 5/ (gray). The color 10YR 5/1 is also called gray because the hue is hardly perceptible at such low chroma.

Conditions for Measuring Color

The quality and intensity of the light source affect the amount and quality of the light reflected. The moisture content of the sample and the roughness of its surface affect the light reflected. The visual impression of color from the standard color chips is accurate only under standard conditions of light intensity and quality. Color determination may be inaccurate early in the morning or late in the evening. When the sun is low in the sky or the atmosphere is smoky, the light reaching the sample and the light reflected are redder. Even though the same kind of light reaches the color standard and the sample, the reading of sample color at these times is commonly one or more intervals of hue redder than at midday. Colors also appear different in the subdued light of a cloudy day than in bright sunlight. If artificial light is used, as for color determinations in an office, the light source must be as near the white light of midday as possible. With practice, compensation can be made for the differences. The intensity of incidental light is especially critical when matching soil to chips of low chroma and low value.

Roughness of the reflecting surface affects the amount of reflected light, especially if the incidental light falls at an acute angle. The incidental light should be as near as possible at a right angle. For crushed samples, the surface is smoothed and the state is recorded as “dry, crushed and smoothed.”

Guidelines for Recording Color

Uncertainty

Under field conditions, measurements of color are reproducible by different individuals within 2.5 units of hue (one Munsell soil-color chart) and 1 unit of value and chroma. Notations are made to match the chips included on the color charts, typically the nearest whole unit of value and chroma. Soil color should be recorded to the closest color chip provided but not interpolated between chips. For some hues, chips for value of 2.5 are included.

Determinations typically are not precise enough to justify interpolation between chromas of 4 and 6 or between chromas of 6 and 8. Color should never be extrapolated beyond the highest chip. The soil-color charts for individual hues do not show value greater than 8. However, chips with higher values are included on a special “white” chart and should be used for soils with very light colors (e.g., those with a high content of calcium carbonate). Observed colors are always rounded to the nearest chip.

For many purposes, the differences between colors of some adjacent color chips have little significance. For these, color notations have been grouped and named (see fig. 3-14).

Dominant Color

The dominant color is the one that occupies the greatest layer volume. It is always listed first among the colors of a multicolored layer. It is determined using the colors on ped faces or broken peds or on a matrix sample in structureless horizons. If two colors occur, the dominant color makes up more than 50 percent of the volume. If three or more colors are noted, the dominant color makes up more of the layer volume than any other color, although it may occupy less than 50 percent. The expression "brown with yellowish brown and grayish brown" signifies that brown is the dominant color and may, or may not, make up more than 50 percent of the layer.

In some layers, no single color is dominant and the first color listed is not more prevalent than others. The expression "brown and yellowish brown with grayish brown" indicates that brown and yellowish brown make up about equal amounts and are codominant. If the colors are described as "brown, yellowish brown, and grayish brown," the three colors make up nearly equal parts of the layer.

Other Non-Matrix Colors

In addition to either a single dominant matrix color or two or more codominant matrix colors, other non-matrix colors may be present. Non-matrix colors are generally related to one of the following four situations:

1. The additional colors are associated with a ped or void surface feature (such as clay films, silt coatings, slickensides, etc.).
2. The colors are associated with concentrations in the soil (such as plinthite, calcium carbonate, gypsum crystals, etc.).
3. The colors are due to oxidation and/or reduction processes in wet soil (i.e., redoximorphic features, such as iron masses, iron depletions, and manganese nodules).
4. The color is inherited from the parent material and is not the result of pedogenic processes. These colors are *lithochromic* or *lithomorphic* and described as *mottles*.

Protocols for describing redoximorphic features, surface features, and concentrations in the soil (including color) are presented later in this chapter.

Mottling

Mottling refers to repetitive color changes that cannot be associated with compositional properties of the soil. As described above, a color pattern related to a ped surface or other organizational or compositional feature is not mottling. In horizon description, mottle description follows dominant color. Mottles (and other non-matrix features) are described by quantity, size, contrast, color, and, if important, other attributes such as moisture state, shape, and location, in that order.

Quantity is indicated by three areal percentage classes of the observed surface:

Few............ less than 2 percent
Common.... 2 to less than 20 percent
Many.......... 20 percent or more

The notations must clearly indicate the colors to which the terms for quantity apply. For example, "common grayish brown and yellowish brown mottles" could mean that each color makes up 2 to 20 percent of the horizon. By convention, the example is interpreted to mean that the quantity of the two colors *together* is between 2 and 20 percent. If each color makes up between 2 and 20 percent, the description should be "common grayish brown (10YR 5/2) and common yellowish brown (10YR 5/4) mottles."

Size refers to dimensions as seen on a plane surface. If the length of a mottle is not more than two or three times the width, the dimension recorded is the greater of the two. If the mottle is long and narrow, as a band of color at the periphery of a ped, the dimension recorded is the smaller of the two and the shape and location are also described. Five size classes are used to describe mottles:

Fine........................ smaller than 2 mm
Medium .... 2 to less than 5 mm
Coarse.................... 5 to less than 20 mm
Very coarse .... 20 to less than 76 mm
Extremely coarse... 76 mm or more

Contrast refers to the degree of visual distinction that is evident between associated colors. The criteria for determining contrast class are given in table 3-5. The classes for color contrast are:

Faint.—Color is evident only on close examination.
Distinct.—Color is readily seen but contrasts only moderately with the color to which it is compared.
Prominent.—Color contrasts strongly with the color to which it is compared. Prominent colors are commonly the most obvious color feature of the section described.

Contrast is often not a simple comparison of one color with another but is a visual impression of the prominence of one color against a background of several colors.

Mottles and other features (if significant) are described using terms for shape, location, and boundary character.

Shape.—These terms are the same as those used for other concentrations in the soil (i.e., cylindrical, platy, reticulate, etc.).

Table 3-5

Color Contrast Class Terms and Their Criteria

Contrast class	Difference between compared colors			
	Hue	**Value**		**Chroma**
Faint*	0;	≤ 2	and	≤ 1
	1;	≤ 1	and	≤ 1
	2;	0	and	0
Distinct*	0;	≤ 2	and	> 1 to < 4
			or	
		> 2 to < 4	and	< 4
	1;	≤1	and	> 1 to < 3
			or	
		> 1 to < 3	and	< 3
	2;	0	and	> 0 to < 2
			or	
		0 to < 2	and	< 2
Prominent*	0;	≥ 4	or	≥ 4
	1;	≥ 3	or	≥ 3
	2;	≥ 2	or	≥ 2
	3			

* If the compared colors have both a value ≤ 3 and a chroma ≤ 2, the contrast is faint, regardless of hue differences.

Location.—The location of the mottles relative to structure of the soil is described.

Boundary classes.—Terms are as follows:

Sharp: Color grades over less than 0.1 mm. Gradation is barely discernable or not discernible by the naked eye, but visible under a 10X lens.

Clear: Color grades over more than 0.1 mm but less than 2 mm. Gradation can be obscure but visible to the naked eye. A 10X lens is not required.

Diffuse: Color grades over 2 mm or more. Gradation is easily discernable by the naked eye. A 10X lens is not required.

Moisture state and physical state of the dominant color are presumed to apply to the mottles unless the description states otherwise. For example, the description of a sample with a specified standard moist broken state may be “brown (10YR 4/3), brown (10YR 5/3) dry; many medium distinct yellowish brown (10YR 5/6) mottles, brownish yellow (10YR 6/6) dry.” Alternatively, the colors in the standard moisture state may be given together, followed by the colors in other moisture states. The color of mottles commonly is given only for the standard state unless colors in another state have special significance.

An example of a description of a sample with a nearly equal mixture of two colors for a moist broken standard state is “intermingled brown (10YR 4/3) and yellowish brown (10YR 5/6) in a medium distinct pattern; brown (10YR 5/3) and brownish yellow (10YR 6/6) dry.” If a third color is present, it can be added, for example, “common medium faint dark grayish brown (10YR 4/2) mottles, grayish brown (10YR 5/2) dry.”

If the mottles are fine and faint and cannot be compared easily with the color standards, the Munsell notation should be omitted. Other abbreviated descriptions are used for specific circumstances.

Color Patterns Within the Soil

Color may be recorded separately for features that merit a distinct description, especially for redoximorphic features but also for peds, concretions, nodules, cemented bodies, filled animal burrows, etc. Color patterns that exhibit a spatial relationship to composition changes or to features, such as nodules or surfaces of structural units, are useful in descriptions because they can infer genesis and soil behavior. Colors may be given for extensions of material from another soil layer. For example, the fine tubular color patterns that extend vertically below the A horizon of some wet soils were determined by the environment adjacent to roots that once occupied the tubules. The relationship of redoximorphic features to locations in the horizon (such as ped faces, ped interiors, pore linings, etc.) provides important clues about internal patterns of wetness. For example, a rim of bright color around an inner zone of lighter color at the surface of some peds relates to water movement into and out of the peds and to oxidation-reduction relationships.

Ground Surface Color

The ground surface color has an important effect on heat transmission into the soil. *Albedo* (the ratio of the reflected incident short-wave solar radiation to the total amount received) is related to soil color, especially *value*. It is an essential parameter for estimating evapotranspiration and for calculating water balance for hydrological models. The color value of the immediate ground surface may differ markedly from that of the surface horizon. For example, raindrop impact that removed clay-sized material from the surface of sand and silt particles may result in a thin surface crust about a millimeter thick with higher color value. Albedo for the fine-earth soil component of the surface cover (given the surface is smooth) can be estimated with the equation:

$$\text{albedo} = 0.069 * (\text{value dry}) - 0.114$$

Specialized studies involving model inputs that include albedo use color information for the total ground surface, including vegetation as well as soil material. In some arid soils, dark rock fragments may have reduced the color value of the ground surface appreciably from that of the fine earth of the surface horizon as a whole. Furthermore, dead vegetation may have color values that differ appreciably from those for the fine earth of the surface horizon. Surface color influences reflectivity of light, which influences the capacity to absorb and release radiant energy.

Soil surface colors at a given site commonly range widely due to the presence of more than one kind of cover. It may be necessary to estimate the areal proportion of the color value for each ground surface type separately (such as rock fragments, dead vegetation, or fine earth), and then select a single color value for each important ground surface component. From the areal proportion of the components and their color value, a weighted average color value for the ground surface may be computed.

Soil Structure

Soil structure refers to units composed of primary particles. Cohesion within these units is greater than the adhesion among units. As a consequence, the soil mass under stress tends to rupture along predetermined planes or zones. These planes or zones form the boundary of the structural units. Compositional differences of the fabric matrix appear to exert weak or no control over where the bounding surfaces occur. If compositional differences control the bounding surfaces of the body, then the term "concentration" is used. The term "structural unit" is used for any repetitive soil body that is commonly bounded by planes or zones of weakness that are not an apparent consequence of compositional differences. A structural unit that is the consequence of soil development is called a *ped*. The surfaces of peds persist through cycles of wetting and drying in place. Commonly, the surface of the ped and its interior have different composition or organization, or both, because of soil development. In contrast to peds, soil-forming processes exert weak or no control on the boundaries of earthy clods. *Clods* commonly form in the surface layer due to the rearrangement of primary particles to a denser configuration through plowing or other mechanical disturbance. The same terms and criteria used to describe structured soils should be used to describe the shape, grade, and size of clods. Commonly, clods have a blocky shape and are large enough to affect tilth adversely. Although the descriptive terms are used for both structural units and clods, this does not infer that clods are the result of pedogenic processes like structural units are. To avoid misunderstanding, the word "clods" is substituted for "structure" in written descriptions (e.g., strong, coarse, angular blocky clods).

Some soils lack structure and are referred to as *structureless*. In structureless layers or horizons, no units are observable in place or after the soil has been gently disturbed, such as after tapping a spade containing a slice of soil against a hard surface or dropping a large fragment of the soil on the ground. When structureless soils are ruptured, coherent soil fragments or single grains, or both, result. Structureless soil material may be either *single grain* or *massive*. In addition to lacking structure, soil material of single grains is loose. On rupture, more than 50 percent of the mass consists of discrete mineral particles.

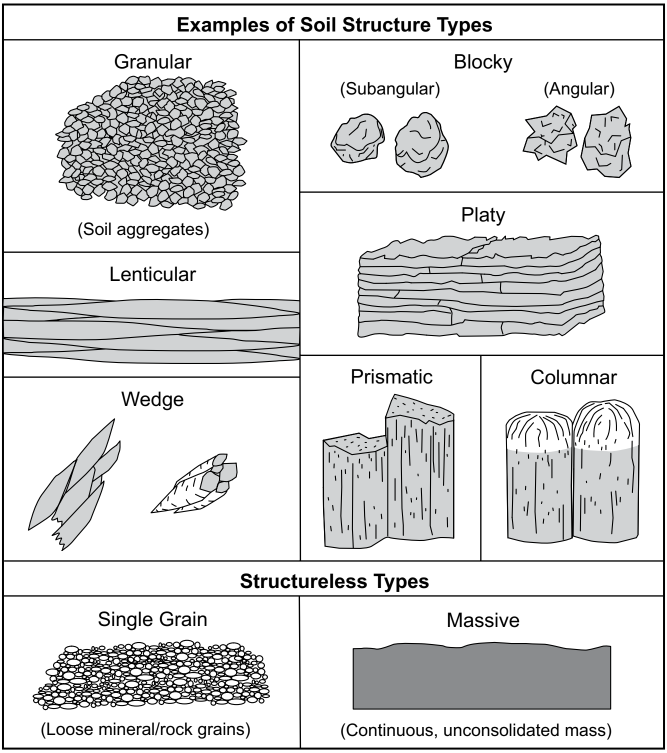
Some soils have *simple structure*, where each unit is an entity without component smaller units. Others have *compound structure*, where large units are composed of smaller units separated by persistent planes of weakness.

In soils that have structure, the shape, size, and grade (distinctness) of the units are described. Field terminology for soil structure has separate sets of terms designating each of the three properties that, when used in combination, form the names for structure. For example, "strong fine granular structure" is used to describe a soil that separates almost entirely into discrete units that are loosely packed, roughly spherical, and mostly between 1 and 2 mm in diameter. The designation of structure by grade, size, and shape can be modified with other appropriate terms to describe other characteristics, e.g., "moderate medium lenticular structure with peds tilted about 15 degrees from horizontal (upslope)." Surface characteristics of units are described separately.

Shape

Several basic shapes of structural units are recognized in soils (fig. 3-16). Supplemental statements about the variations in shape of individual peds are needed in detailed descriptions of some soils. The following terms describe the basic shapes and related arrangements:

Figure 3-16



Examples of soil structure types.

Platy.—The units are flat and platelike. They are generally oriented horizontally.

Prismatic.—The individual units are bounded by flat to rounded vertical faces. Units are distinctly longer vertically, and the faces are typically casts or molds of adjoining units. Vertices are angular or subrounded; the tops of the prisms are somewhat indistinct and normally flat. Figure 3-17 shows a soil profile with prismatic structure in the subsoil.

Columnar.—The units are similar to prisms and bounded by flat or slightly rounded vertical faces. The tops of columns, in contrast to those of prisms, are very distinct and normally rounded.

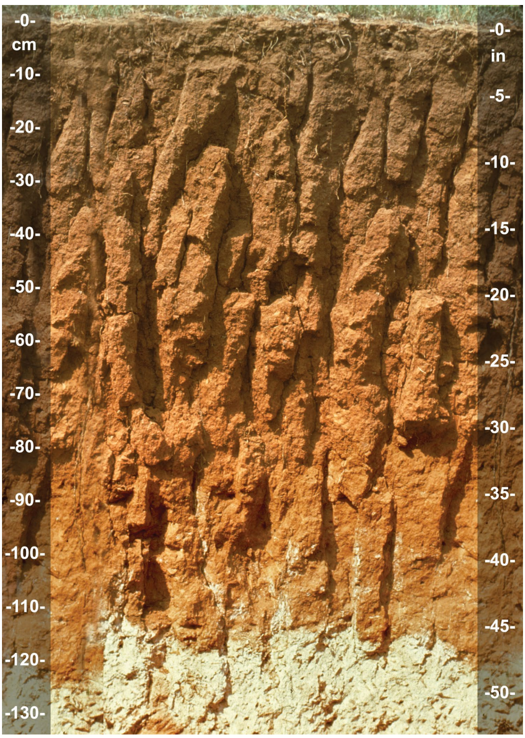
Blocky.—The units are blocklike or polyhedral. They are bounded by flat or slightly rounded surfaces that are casts of the faces of surrounding peds. Typically, blocky structural units are nearly equidimensional but grade to prisms and plates. The structure is described as *angular blocky* (fig. 3-18) if the faces intersect at relatively sharp angles and as *subangular blocky* if the faces are a mixture of rounded and plane faces and the corners are mostly rounded.

Granular.—The units are approximately spherical or polyhedral. They are bounded by curved or very irregular faces that are not casts of adjoining peds.

Wedge.—The units are approximately elliptical with interlocking lenses that terminate in acute angles. They are commonly bounded by small slickensides.

Lenticular.—The units are overlapping lenses parallel to the soil surface. They are thickest in the middle and thin towards the edges. Lenticular structure is commonly associated with moist soils, texture classes high in silt or very fine sand (e.g., silt loam), and high potential for frost action.

Figure 3-17



Prismatic soil structure. (Photo courtesy of John Kelley)

Figure 3-18

Peds with angular blocky structure. (Photo courtesy of John Kelley)

Size

The six size classes are *very fine, fine, medium, coarse, very coarse,* and *extremely coarse.* The extremely coarse class is used only for prismatic, columnar, and wedge-shaped structures. The size limits of the classes differ according to the shape of the units. Table 3-6 gives the size limit classes. The size limits refer to the smallest dimension of plates, lenses, prisms, and columns. For the lens-shaped structures (wedge and lenticular), the measurement is taken at the thickest part of the smallest dimension, not the tapered edges. If the units are more than twice the minimum size of the largest class, the actual size is given, e.g., "moderate very coarse prisms 100 to 150 cm across."

Grade

Grade indicates the distinctness of units. Criteria for grade classes are the ease of separation into discrete units and the proportion of units that hold together when the soil is handled. Three classes are used:

Weak.—The units are barely observable in place. When they are gently disturbed, the disturbed soil material parts into a mixture

Table 3-6

Size Class Terms for Peds with Various Soil Structure Types

Classes	Shape of structure		
	Platy* and granular (mm)	Prismatic, columnar, and wedge (mm)	Blocky and lenticular* (mm)
Very fine	< 1	< 10	< 5
Fine	1 to < 2	10 to < 20	5 to < 10
Medium	2 to < 5	20 to < 50	10 to < 20
Coarse	5 to < 10	50 to < 100	20 to 50
Very coarse	≥ 10	100 to < 500	≥ 50
Extremely coarse	N/A	≥ 500	N/A

* In describing plates, "thin" is used instead of "fine" (i.e., very thin and thin) and "thick" instead of "coarse" (i.e., thick and very thick).

of whole and broken units, the majority of which exhibit no planes of weakness. Faces that indicate persistence through wet-dry cycles are evident if the soil is handled carefully. Distinguishing structureless soils from those with weak structure can be difficult. Weakly expressed structural units in virtually all soil materials have surfaces that differ in some way from the interiors.

Moderate.—The units are well formed and evident in undisturbed soil. When disturbed, the soil material parts into a mixture of mostly whole units, some broken units, and material that is not in units. Peds part from adjoining peds to reveal nearly entire faces that have properties distinct from those of fractured surfaces.

Strong.—The units are distinct in undisturbed soil. They separate cleanly when the soil is disturbed. When removed, the soil material separates mainly into whole units. Peds have distinctive surface properties.

The distinctness of individual structural units and the relationship of cohesion within units to adhesion between units determine grade of structure. Cohesion alone is not specified. For example, individual structural units in a sandy loam A horizon may have strong structure yet be less durable than individual units in a silty clay loam B horizon of weak structure. The degree of disturbance required to determine structure grade depends largely on moisture content and percentage and kind of clay. Only slight disturbance may be necessary to separate the units of a moist sandy loam having strong granular structure, while considerable disturbance may be required to separate units of a moist clay loam having strong blocky structure.

Compound Structure

Smaller structural units can hold together to form larger units. Grade, size, and shape are described for both kinds of units and the relationship of one set to the other is indicated, e.g., "strong medium angular blocks within moderate coarse prisms" or "moderate coarse prismatic structure parting to strong medium subangular blocky."

Extra-Structural Cracks

Cracks are macroscopic vertical planar voids that are much smaller in width than in length and depth. A crack represents the release of strain as a consequence of drying. In contrast to the relatively narrow voids surrounding peds in most soils, the cracks discussed here are the result of localized stress release, which forms planar voids that are wider than the repetitive planar voids normally associated with structural units.

Importance

Cracks, especially large ones, affect water flow into and through the soil, causing it to bypass the soil matrix (bypass flow). They exert significant control on ponded infiltration and hydraulic conductivity, especially if they extend to (or close to) the surface. Cracks are generally associated with soils that are subject to pronounced shrinking and swelling. They can indicate potential engineering hazards to homes, roads, and other structures. For taxonomic purposes, the width and depth of cracks as well as their temporal open-close cycles have importance. The areal percentage of such cracks, either on a vertical exposure or on the ground surface, can be measured by line-intercept methods.

Kinds of Cracks

Cracks are characterized as either *crust-related* or *trans-horizon*. Crust-related cracks are shallow cracks that initiate at the surface and are restricted to a surface crust layer. They form primarily from raindrop impact and soil puddling followed by drying and consolidation.

Trans-horizon cracks commonly extend across more than one horizon. They may extend upward to the soil surface and downward to significant depth. These cracks are commonly associated with soils that have a high content of smectitic clay minerals. They open as the soil dries out and close upon rewetting. Less commonly, some trans-horizon cracks form upon dewatering and subsequent consolidation of poorly drained sediments with high *n* value (fluid materials), e.g., upon drainage of some soils that are classified as Hydraquents. Once formed, these cracks do not open and close seasonally but rather remain open permanently.

Crust-related cracks.—Two kinds of crust-related cracks are recognized: reversible and irreversible.

Surface-initiated reversible crust-related cracks form as a result of drying from the surface downward. They close after relatively slight surficial wetting and have little influence on ponded infiltration rates. These cracks tend to be very shallow (less than about 0.5 cm) and are transient (i.e., close upon wetting).

Surface-initiated irreversible crust-related cracks form as a result of the near-surface water reduction in material with an exceptionally high water content, commonly from frost action. These cracks tend to be shallow (between about 0.5 and 2 cm) and seasonally transient. The cracks may not close completely when rewet and extend through the crust. They increase ponded infiltration rates, but only to a small degree.

Trans-horizon cracks.—Two kinds of trans-horizon cracks are recognized: reversible and irreversible.

Subsurface-initiated reversible trans-horizon cracks form as a result of appreciable reduction in water content from field capacity in horizons or layers with considerable extensibility (fig. 3-19). They close in a period of days if the horizon is brought to the *moderately moist* or wetter state. They extend upward to the soil surface unless there is a relatively thick overlying horizon that is very weakly compacted (loose or very friable) and does not permit the propagation of cracks. These cracks greatly influence ponded infiltration rates, hydraulic conductivity, and evaporation.

Subsurface-initiated irreversible trans-horizon cracks are the permanent cracks described in *Soil Taxonomy* (as described for soil families). They have a similar origin to surface-initiated irreversible cracks, although quite different agencies of formation are involved. Rather than forming due to shrinkage of the surface layer upon air drying, these cracks form due to subsoil drainage and subsequent consolidation of some very fluid soils.

Figure 3-19

Large reversible trans-horizon cracks extend from the soil surface deep into the subsoil of this clayey soil, which is classified as a Vertisol.

Descriptions of Cracks

Descriptions of cracks include:

Relative frequency.—Average number of cracks per square meter.
Depth.—Average depth of penetration.
Kind.—Reversible crust-related, irreversible crust-related, reversible trans-horizon, or irreversible trans-horizon.

If the cracks do not extend to the surface, this should be noted. Examples of crack descriptions: “On average, five reversible trans-horizon cracks per square meter extend from the surface to about 50 cm” and “on average, five reversible trans-horizon cracks per square meter beginning below 18 cm extend to about 50 cm.”

Internal Ped and Void Surface Features

Features formed by pedogenic processes commonly occur on or beneath ped or void surfaces. Such features include: (1) coats of various substances covering part or all of surfaces, (2) material concentrated on surfaces due to preferential removal of finer material, (3) stress formations in which thin layers at the surfaces have undergone particle reorientation or packing by stress and/or shear, and (4) material infused beneath surfaces (termed a "hypocoat"). All these features differ from the adjacent material in composition, orientation, and/or packing. *Hypocoats* commonly result from oxidation and reduction processes and are generally described as redoximorphic features (discussed below).

Description of surface features may include kind, location, amount, and distinctness. Color, texture, and other characteristics may also be described, especially if the features contrast strongly with characteristics of adjacent material.

Kinds

Surface features are distinguished by differences in texture, color, packing, particle orientation, or reaction to selected tests. If a feature is distinctly different from the adjacent material but its kind cannot be determined, it is still described.

Clay films.—Thin layers of oriented, translocated clay; also called clay skins or argillans (fig. 3-20).

Clay bridges.—Illuvial clay linking together adjacent mineral grains (fig. 3-21).

Figure 3-20

Shiny clay films coat the surface of this ped. (Photo courtesy of John Kelley)

Figure 3-21

Sand grains (visible as individual quartz grains) coated and bridged with illuvial clay (smooth yellowish color). (Photo courtesy of John Kelley)

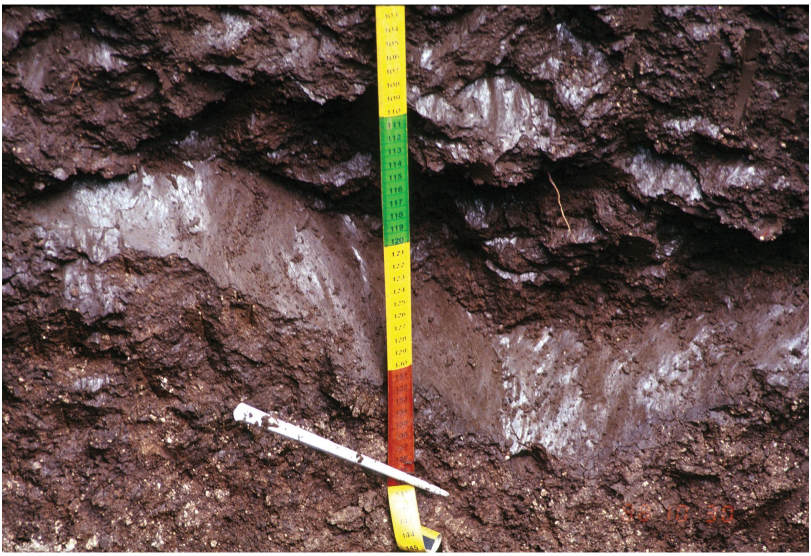
Sand or silt coats.—Sand or silt grains adhering to a ped, void, or crack surface. The grains may be derived from material originally in a horizon from which finer particles have been removed. These coats are also referred to as *skeletans.* Sand or silt coats may also form by translocation and deposition of sand or silt from upper horizons or via oxidation-reduction reactions that preferentially remove iron and/or manganese and, in some cases, clay. Coats inferred to form from oxidation-reduction reactions are described as redoximorphic features.

Other coats.—Coats composed of iron, aluminum, or manganese oxides; organic matter; salts; or carbonates. They are described by properties that can be observed in the field. Laboratory analyses may be needed for verification.

Stress surfaces.—Pressure faces, also referred to as *stress cutans*. These surfaces are smoothed or smeared. They form through rearrangement caused by shear forces. They may persist through successive drying and wetting cycles. Although similar in appearance to clay films, pressure faces can be distinguished by sand grains that protrude slightly above the surface and are not coated with clay.

Slickensides.—Stress surfaces that are polished and striated (fig. 3-22). They typically have dimensions exceeding 5 cm. They are produced when a relatively large volume of soil slides over another. They are common below a depth of 50 cm in swelling clays (clays subject to large changes in water state). Slickensides associated with structural surfaces resulting from pedogenesis are considered *pedogenic* in nature. Those associated with faults or mass soil movement are considered *geogenic*.

Figure 3-22



Prominent slickensides in the Bss horizon of a Vertisol.

Location

Various surface features may occur on some or all structural units, channels, pores, primary particles or grains, soil fragments, rock fragments, or pararock fragments. The kind and orientation of the surface on which features are observed are always described (e.g., "clay films are on vertical but not horizontal faces of peds").

Amount

The percentage of the total surface area occupied by a particular surface feature over the extent of the horizon or layer is described.

Amount can be characterized using the following classes:

Very few .... less than 5 percent
Few .... 5 to less than 25 percent
Common .... 25 to less than 50 percent
Many................ 50 to less than 90 percent
Very many........ 90 percent or more

These classes are also used to describe the amount of bridges connecting particles. This amount is based on the percentage of particles of a designated size that are joined to adjacent particles of similar size by bridges at contact points.

Distinctness

Distinctness refers to the ease and degree of certainty with which a surface feature can be identified. It is related to thickness, color contrast with the adjacent material, and other properties. However, it is not itself a measure of any one of them (e.g., some thick coats are faint and some thin coats are prominent). The distinctness of some surface features changes markedly as water state changes. The classes of distinctness are:

Faint.—Feature is evident only on close examination with 10X magnification and cannot be identified positively in all places without greater magnification. The contrast with the adjacent material in color, texture, and other properties is minimal.

Distinct.—Feature can be detected without magnification, although magnification or tests may be needed for verification. The feature contrasts enough with the adjacent material that differences in color, texture, or other properties are evident.

Prominent.—Feature is conspicuous without magnification when compared to a surface broken through the soil. Color, texture, or other property or a combination of properties contrasts sharply with properties of the adjacent material, or the feature is thick enough to be conspicuous.

The typical order of description is: amount, distinctness, color, texture, kind, and location. For example: "few distinct grayish brown (10YR 5/2) clay films on vertical faces of peds" or "many distinct brown (10YR 4/3) clay bridges between mineral grains." Only properties that add to the understanding of the soil are listed. If texture of the surface feature is obvious, as in most stress surfaces, it is not described. Kind and location are needed for all features identified. Volume, if important, is estimated separately.

Concentrations

Concentrations are identifiable bodies within the soil that form and accumulate due to pedogenesis. Pedogenic processes responsible for concentration development in the soil include chemical dissolution and precipitation, oxidation/reduction, and accrual due to physical or biological processes. Some concentrations are thin and sheet-like, some are nearly equidimensional, and others have irregular shapes. They may contrast sharply with the surrounding material in strength, composition, or internal organization, or their differences with the surrounding material may be slight. Rock and pararock fragments or inherited minerals (such as pockets of mica flakes) are not considered concentrations.

Kinds

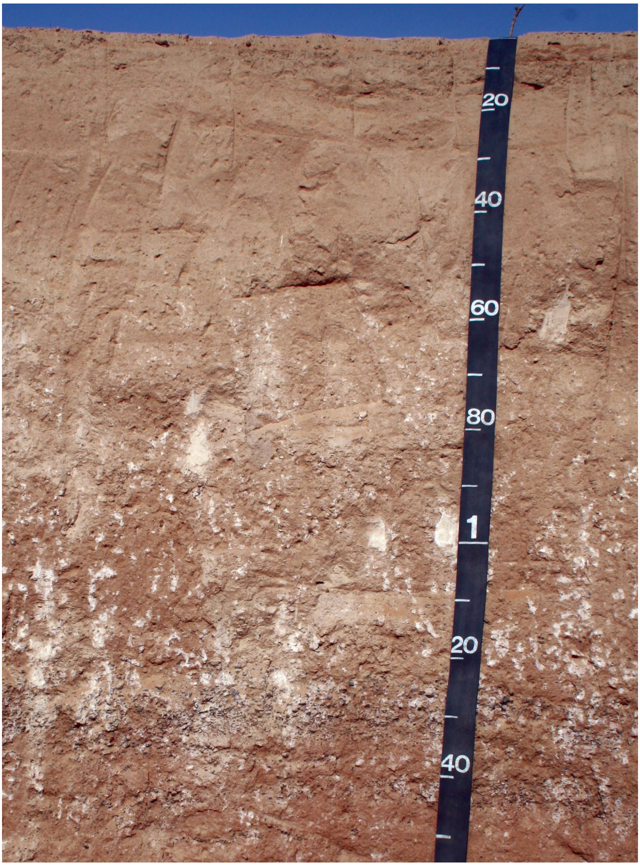
Masses are non-cemented concentrations that commonly cannot be removed from the soil as a discrete unit. Masses may consist of, but are not limited to, calcium carbonate (fig. 3-23), fine crystals of gypsum or soluble salts, or iron and manganese oxides. In most cases, masses form in place.

Plinthite consists of reddish, iron-enriched bodies that have a low content of organic matter. In contrast to most other masses, plinthite bodies are coherent enough to be separated readily from the surrounding soil.

Plinthite commonly occurs within and above reticulately mottled horizons (fig. 3-24). It has higher penetration resistance than adjacent brown or gray bodies or than red bodies that do not harden. Soil layers that contain plinthite rarely become dry in their natural setting. Plinthite bodies are commonly about 5 to 20 mm across their smallest dimension. They are *firm* or *very firm* when moist, *hard* or *very hard* when air dry, and *moderately cemented* on repetitive wetting and drying, especially when exposed to sunlight (e.g., in road banks and gully walls).

Upon repeated wet-dry cycles, plinthite may irreversibly harden and convert to indurated ironstone. Plinthite bodies commonly occur as discrete nodules or plates. The plates are oriented horizontally. The nodules occur above, and the plates within, the upper part of the reticulately mottled horizon. The plates generally have a uniformly reddish color and have sharp boundaries with the surrounding brown or gray material. The part of the iron-rich body that is not plinthite normally stains the fingers if rubbed while wet, but the plinthite center does not. Plinthite has a harsh, dry feel when rubbed, even if wet. Horizons

Figure 3-23

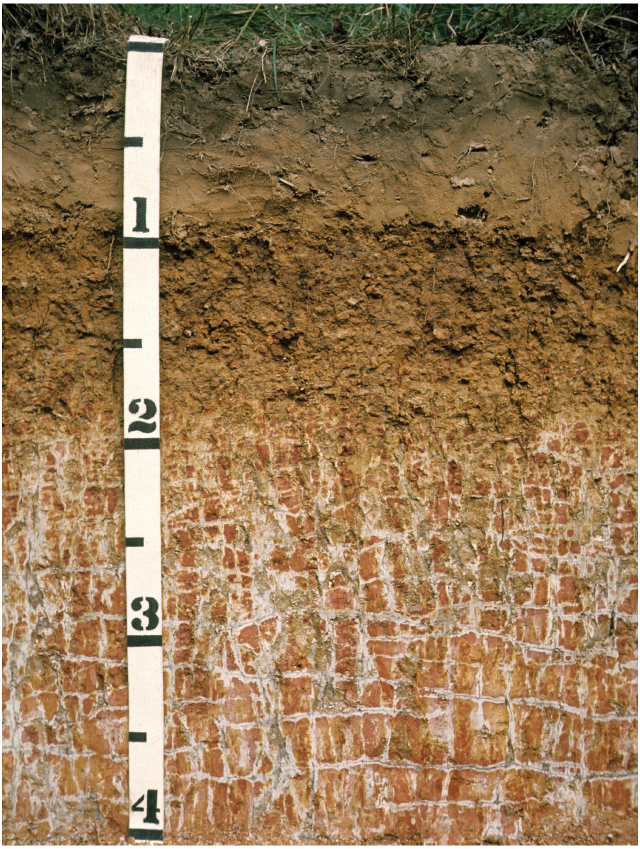


Masses of secondary calcium carbonate (white bodies below a depth of about 60 cm) in the calcic horizon of an Aridisol.

containing plinthite are more difficult to penetrate with an auger than adjacent horizons at the same water state and with the same clay content. Plinthite generally becomes less cemented after prolonged submergence in water. An air-dried sample can be dispersed by normal procedures for particle-size distribution.

Ironstone is an iron-oxide concentration that is at least weakly cemented. Ironstone nodules commonly occur in layers above plinthite. They are thought to be plinthite that has cemented irreversibly because of repeated wet-dry cycles. Commonly, the center of iron-rich bodies cement upon repeated wetting and drying while the periphery does not.

Figure 3-24



A soil in which a reticulately mottled zone with plinthite (darkest red colors) is below a depth of about 2 feet.

Nodules and **concretions** are cemented bodies of various shapes that can be removed from the soil intact and do not slake in water. They do not have a crystal structure discernable by field observation (10X lens). Concretions differ from nodules by internal organization. They possess a crude internal symmetry organized around a point, a line, or a plane. The internal structure typically takes the form of concentric layers that are visible to the naked eye. A coat or a thin outer layer of an otherwise undifferentiated body does not indicate a concretion. Nodules, by contrast, lack evident internal organization.

Crystals are macro-crystalline forms of relatively soluble salts that form in place. They may occur singly or in clusters (fig. 3-25). Gypsum,

Figure 3-25

A cluster of gympsum crystals (selenite) in an Aridisol.

calcite, halite, and other salt crystals are common in arid and semiarid soils. Crystals composition should be denoted if known.

Finely disseminated materials are small precipitates dispersed throughout the matrix. The material is not observable with the naked eye but can be detected by chemical reactions (e.g., effervescence of calcium carbonate with dilute HCl). An example is calcium carbonate that has accrued due to dust fall and its subsequent dissolution and re-precipitation throughout the matrix of a horizon.

Biological concentrations are discreet bodies accumulated by biological process. Examples include fecal pellets and wormcasts.

Inherited minerals consist of distinct, observable mineral particles in the soil that formed from geologic rather than pedogenic processes. Mica flakes and glauconite pellets are examples.

Describing Concentrations Within the Soil

Concentrations within the soil may have several important attributes, including number or amount, size, shape, consistence, color, composition, kind, and location. Not all attributes are necessarily described. The order as listed above is convenient for describing them, e.g., "many, fine, irregular, hard, light gray (10YR 7/1) carbonate nodules distributed uniformly through the horizon." Descriptions for kind have already been discussed in this section, and those for consistence and color are discussed in other parts of this chapter.

Amount or **quantity** of concentrations refers to the relative volume of a horizon or other specified unit occupied by the bodies. The classes are the same as those used for quantity of redoximorphic features and mottles:

Few .... less than 2 percent
Common .... 2 to less than 20 percent
Many.......... 20 percent or more

Size may be measured directly or designated by a class. The dimension to which size-class limits apply depends on the shape of the body described. If the body is nearly uniform, the shortest dimension is measured, such as the effective diameter of a cylinder or the thickness of a plate. For irregular bodies, the longest dimension is measured (if needed, more measurements can be given for clarification). The classes are the same as those used for mottles and redoximorphic features:

Fine........................ less than 2 mm
Medium .... 2 to less than 5 mm
Coarse.................... 5 to less than 20 mm
Very coarse .... 20 to less than 76 mm
Extremely coarse ... 76 mm or more

Shape of concentrations varies according to kinds of concentrations and commonly within a concentration. (Shape terms are generally not used to describe crystals, however, because the crystal type itself implies its shape.) The terms for concentration shape are:

Cubic.—Roughly equidimensional, blocklike structures.
Cylindrical.—Cylindrical or tubular shape; one dimension is greater than the other two.
Dendritic.—Branched, elongated, tubular forms.
Irregular.—Concentrations characterized by nonrepeating spacing or shape, but not elongated (as a dendritic form).
Lenticular.—Roughly disk-shaped forms, thickest in the middle and thinning toward the edges.
Pendular.—Coatings or nodules formed on the undersides of rock fragments.
Platy.—Shaped like a plate; one dimension is much smaller than the other two.
Reticulate.—Crudely interlocking structures (common with some plinthite concentrations).

Rosettelike.—Interlocking blade-like structures forming a petal-like structure.
Spherical.—Approximately equidimensional and well rounded.
Threadlike.—Thin, elongated filament-like structures (but not dendritic).

Composition of bodies (calcium carbonate, iron-manganese, gypsum, etc.) is described if known and if important for understanding their nature or the nature of the soil in which they occur. Some of the physical attributes of the interior of a feature are implied by the name. Other features, such as enclosed mineral grains, patterns of voids, or similarity to the surrounding soil, may be important.

A distinction is made between bodies composed dominantly of a single substance and those composed of earthy material impregnated by various substances. For many bodies, the chemical composition cannot be determined with certainty in the field. If the substance dominates the body, then the body is described as a substance body (durinode nodules, carbonate concretions, salt crystals, etc.). If the substance impregnates other material, the body is described as a body of substance accumulation (carbonate masses, gypsum masses, plinthite, etc.).

Carbonates and iron commonly dominate or impregnate nodular or concretionary bodies. Discrete nodules of clay occur in some soils; argillaceous impregnations are less common. Materials dominated by manganese are rare; manganese is conspicuous in some nodules that have a high content of iron, called "iron-manganese nodules." Crystals are commonly calcite, gypsum, and other salts (such as sodium chloride) and less commonly barite, selenite, or satin spar. Some concentrations have biological sources, such as fecal pellets and wormcasts.

Pedogenic Carbonates

Carbonates that have translocated within the soil and subsequently precipitated in place from the soil solution are considered to be pedogenic. They are not simply inherited from the parent material. They are the same as "identifiable secondary carbonates" discussed in *Soil Taxonomy*.

Forms of Carbonate Accumulation

The term "forms" refers to the outward expression of bodies of pedogenic carbonate accumulations. Carbonate itself exists as crystals, predominantly calcite ($CaCO_3$), in the size range of fine silt to coarse clay (approximately 10 to 1 μm). These crystals precipitated on the surfaces of rocks, sand, and silt particles or in association with roots and microorganisms. With time, carbonate crystals accumulate within the soil fabric and are visible as:

Filaments.—Threadlike concentrations of carbonate typically < 1 mm in diameter and a few centimeters long.

Root casts.—Branching (and commonly tubular) forms of carbonate accumulation (carbonate pseudomorphs of roots).

Bands.—Sheet-like deposits of carbonate typically ranging from about 1 to several millimeters thick. They form along the bedding planes of finely stratified parent material and are separated by soil with little or no macroscopic carbonate.

Joint fillings.—Vertical bands of carbonate in the fracture planes of large prisms in soil. Joint fillings, in profile, range from less than 1 to a few centimeters in width.

Coatings.—Deposits of carbonate on the surfaces of rock fragments and sand grains. They may be continuous or discontinuous and have a rupture resistance ranging from non-cemented to extremely weakly cemented.

Pendants.—Deposits of laminar carbonate coatings on rock that are very weakly cemented to indurated. They are more common on the bottom of rocks than on the top. They commonly have stalactite-like protrusions radiating perpendicularly away from the rock fragment.

Masses.—Bodies of carbonate accumulation of various shapes that are non-cemented or extremely weakly cemented and cannot be removed as discrete units from soil.

Nodules.—Rounded bodies of carbonate accumulation that are very weakly cemented to indurated and can be removed as discrete units from soil.

Concretions.—Rounded bodies of carbonate accumulation that are very weakly cemented to indurated. They have spherically concentric layers surrounding a nucleus.

Cylindroids.—Cylindrical bodies of carbonate accumulations that are very weakly cemented to indurated. Many are cicada casts impregnated with calcium carbonate while others developed in soil material filling former root channels or small krotovinas. Cylindroids are typically less than 2.5 cm thick. They are typically vertical but may also be diagonal or horizontal.

Beds.—Carbonate accumulations along bedding planes of parent material that are similar to bands but differ in size (ranging from a few centimeters to a meter or more thick). They range from non-cemented to indurated, occur below the main zone of pedogenic horizons, and preserve the original sedimentary structure.

Plugged horizons.—Pedogenic carbonate accumulations that occur at the soil-horizon-landscape scale, which is larger than the soil-profile scale, at which filaments, nodules, and other carbonate forms occur. They are characterized by laterally continuous pedogenic carbonate that has engulfed soil particles, filled most or all pores, and obliterated the original sedimentary structure. Most plugged horizons are strongly cemented to indurated, although some are non-cemented.

Laminar horizons.—Smooth, strongly cemented to indurated deposits of carbonate that develop on top of plugged horizons (or shallow bedrock). They have a fabric that contains much more carbonate than the underlying plugged horizon and essentially no allogenic skeletal grains.

Laminae.—Thin (less than 1 mm to a few millimeters) individual layers of carbonate comprising the laminar horizon. They typically parallel one another, but one set may truncate another set at various angles.

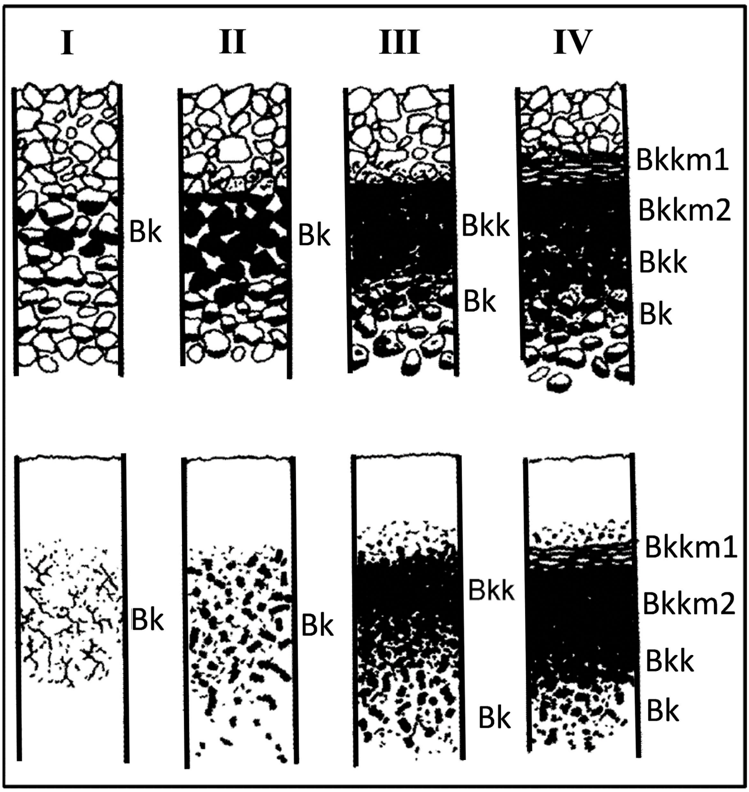
Pisoliths.—Subangular to spheroidal carbonate masses (2 to more than 100 mm in diameter) that form within highly developed petrocalcic horizons. They are characterized by concentric banding and an internal structure of disrupted laminae or by disrupted concentric banding that may or may not have detrital material at the core.

Ooliths.—Spheroidal carbonate masses (less than 2 mm in diameter) that form within highly developed petrocalcic horizons. They have an internal structure of laminae that may or may not have detrital material at the core.

Stages of Carbonate Accumulation

Pedogenic carbonate that forms in soils in arid and semiarid climates is closely linked to age (i.e., progressively older geomorphic surfaces have soils with commensurately greater amounts of carbonate). Gile et al. (1966) described carbonate accumulation through four successive morphogenic stages with a distinction between gravelly and nongravelly soils (fig. 3-26). Soils that form in *gravelly parent materials* progress from pebble coatings (Stage I) to interpebble fillings (Stage II), a plugged horizon (Stage III), and eventually a laminar horizon atop the plugged horizon (Stage IV). Soils that form in *nongravelly parent materials* progress from filaments (Stage I) to nodules (Stage II), a plugged horizon (Stage III), and eventually a laminar horizon atop the plugged horizon (Stage IV). Bachman and Machette (1977) and Machette (1985) recognized two additional stages. Stage V is characterized by laminae less than 1 cm thick and may contain pisoliths as well as vertical faces and fractures coated with laminated carbonate. Stage VI is characterized by multiple generations of recemented laminae, breccia, and pisoliths. The time required to reach a certain morphogenetic stage depends on soil particle size and quantity of carbonate inputs. Gravelly soils pass through the stages more quickly than nongravelly soils because they have less surface area and less total pore space. Pedogenic carbonate that forms above the phreatic zone by means of capillary rise does not necessarily proceed through the morphogenetic stages.

Figure 3-26



Schematic diagram of diagnostic carbonate morphology for the four main stages of carbonate accumulation in two morphogenetic sequences (Gile et al., 1966).

Redoximorphic Features

Redoximorphic features (RMF) include color patterns, mineral concentrations, and a reduced (in respect to iron) soil state that form via coupled oxidation/reduction reactions involving iron and manganese under anaerobic soil conditions. Saturation or near saturation limits oxygen diffusion in soil. Microbial activity consumes existing oxygen, and an anaerobic condition results. Under anaerobic conditions, certain microbes utilize chemical species other than oxygen as the terminal electron acceptor for carbon metabolism. Such microbially mediated redox processes follow a sequence based on electrochemical or redox potential, which is a measure of anaerobic intensity. The metabolic energy gain for an organism is the energy difference between reduced carbon and the specific electron acceptor. The oxidant with the highest redox potential is utilized first, followed by the oxidant with the next highest potential. The favorability order for electron acceptors in soil is:

$$O_2 > NO_3^{2-} > Mn\ (VI) > Fe\ (III) > SO_4^{2-} > CO_2 > H^+$$

Iron (Fe), and to a lesser extent manganese (Mn), serve as soil color pigments. Thus, oxidation and reduction of these species results in color variations and/or concentrations indicative of soil wetness. Reduced iron, Fe(II), and manganese ions are mobile in soil compared to their oxidized state. They are subject to leaching or migration from higher concentration (an anaerobic zone, such as a ped interior) to lower concentration (aerobic zone, such as a ped surface). Upon oxygen exposure (higher redox potential), reduced species become oxidized and immobile and form iron and manganese concentrations, which commonly are redder than the adjacent matrix. Areas that lose iron or manganese are pigment depleted (redox depletions) and have a grayer or lighter color due to the clean, exposed mineral surface. Depletions of chroma 2 or less are key morphological indicators of seasonal or periodic saturation. It is important to note that depletions form via iron or manganese reduction while concentrations form via iron or manganese oxidation.

Chemical and physical soil properties influence oxidation-reduction reactions. Thus, RMF formation may not occur in saturated soils in certain settings. For example, higher pH decreases the electron-accepting tendency of a chemical species so that RMF formation is less likely in alkaline soils. Similarly, because cold temperature reduces microbial activity, RMF may not form during winter months even though the soil is saturated. Moreover, oxidation/reduction reactions may not produce visually observable RMF, such as in red soil parent materials or horizons in which organic matter controls soil color.

Once formed, iron-oxide concentrations are stable in an oxidized soil and depletions remain pigment-free. Thus, some RMF may be relict in that they formed under an anaerobic condition that no longer exists. For example, a stream terrace that currently lacks internal wetness due to stream downcutting may retain RMF formed when a water table existed at a higher position in the soil. If proven relict, RMF can be described as such. Redoximorphic features in anthropologically drained soils are not considered relict because original conditions can be restored.

Describing Redoximorphic Features

Because RMF have a strong relationship to soil wetness, they are typically described separately from other color variations or concentrations. Mottles (color variations not due to iron loss or accrual, such as variegated weathered rock) are described with soil color. The characteristics routinely described for RMF include quantity, size, contrast, color, kind, and location. If important, the moisture state, shape, hardness, and boundary can also be described. Guidelines for describing color and the associated moisture state are the same as those for recording color (see previous section). Terms for describing hardness of cemented redox concentrations are given in the section "Rupture Resistance" below (cementation classes). Terms for describing quantity, size, contrast, color, and location of RMF are the same as those for describing concentrations within the soil (see section above). Kinds of RMF are discussed below.

Redox Concentrations

Redox concentrations are localized accretions of Fe and/or Mn, which may occur as cemented nodules or amorphous phases, that result in enhanced pigmentation and/or a cemented precipitate. Generally, concentrations form through iron oxidation from Fe(II) to Fe(III), which yields a color redder than that of the adjacent matrix (fig. 3-27). In strongly reducing conditions, however, ferrous iron [Fe(II)] may accrete, especially in the presence of S, forming a concentration that is black or blue gray in color. Redox concentrations have the following forms:

Masses.—Non-cemented bodies or localized regions of enhanced pigmentation due to Fe and/or Mn accretion. Masses that occur as coatings or thin matrix impregnations along pores (such as root channels) are referred to as pore linings.

Nodules or concretions.—Cemented bodies of iron-manganese oxides that formed through successive wet-dry cycles. (See the discussion of concentrations above for more detail).

Figure 3-27

Redoximorphic features that consist of a redox concentration, as an iron mass (reddish area along ped surface) and an iron depletion (light-colored area surrounding the root channel in ped interior). (Photo courtesy of John Kelley)

Redox Depletions

Redox depletions are localized zones of decreased pigmentation due to a loss of iron or manganese, with or without clay loss. The pigment loss produces a color grayer, lighter, or less red than that of the adjacent matrix (fig. 3-27). The pigment loss reveals the underlying mineral color. Redox depletions have a hue that is yellower, greener, or bluer than that of the adjacent matrix and/or a higher value and/or a lower chroma. Redox depletions include, but are not limited to, what were previously called “low chroma mottles” (chroma < 2), which are key indicators of seasonal or periodic soil saturation. Redox depletions occur in the following forms:

Iron depletions.—Localized zones that have lost iron and/or manganese pigment due to oxidation or reduction reactions under anaerobic conditions but that have a clay content similar to that of the adjacent matrix.

Clay depletions.—Localized zones that have lost iron, manganese, and clay. These features are commonly referred to as *silt coatings* or *skeletans.* Silt coatings may form by eluvial processes rather than from oxidation and reduction. Soil features of inferred eluvial origin (for example, albic materials, silt coatings, and skeletans) are not considered or described as a redox depletion.

Reduced matrix.—A soil horizon, layer, or zone that is reduced in respect to iron. It has an *in situ* matrix chroma < 2 and/or a hue of 5GY, 5G, or 5BG that reflects the presence of Fe(II). The color of a soil sample becomes visibly redder or brighter (oxidizes) when exposed to air. The color change typically occurs within 30 minutes. A 0.2% solution of alpha,alpha-dipyridyl dissolved in 1N ammonium acetate (NH_4OAc) pH 7 can verify the presence of Fe^{+2} in the field (Childs, 1981).

Consistence

Soil consistence in the general sense refers to the soil material's degree of cohesion and adhesion or resistance to deformation or rupture. As described here, consistence includes: (1) resistance of soil material to rupture, (2) resistance to penetration, (3) plasticity, toughness, and stickiness of puddled soil material, and (4) the manner in which the soil material behaves when subject to compression. Although several tests are described, only those which may be useful should be applied. In addition to descriptions of soil consistence, this section discusses the classes for excavation difficulty, which is reflective of the consistence properties of the soil.

Consistence is *not* synonymous with consistency. Originally, consistency was used in soil engineering to define degree of resistance to penetration by thumb or thumbnail (test designation D 2488, ASTM, 2011). The engineering term was generalized for use in soil survey and called "consistence." The set of tests to determine consistency, however, is different from those for consistence. Consistence is highly dependent on the soil water state and the description has little meaning unless the water state class is specified or is implied by the test. For rupture resistance, separate class terms are provided for tests on dry soil (moderately dry or very dry soil water states) and moist soil (slightly dry through satiated soil moisture states). To determine cementation class, the sample is air dried, then submerged in water for at least 1 hour, and checked for slaking. Stickiness, plasticity, and toughness tests are performed on puddled soil material. Stickiness determinations are made at the highest moisture content, when the sample is most sticky. Tests for manner of failure are best performed on moderately moist or wetter samples. Penetration resistance depends strongly on moisture state, which should always be noted.

The class definitions for rupture resistance and toughness include both qualitative descriptions as well as quantitative limits for the stress or force applied to the sample. Since the perception of the relative amount of force required to cause a sample to fail varies by individual, one should learn what the various classes of applied force feel like personally. The tactile sense of the class limits may be learned by applying force to top-loading scales and sensing the pressure through the tips of the fingers or through the ball of the foot. Postal scales may be used for the resistance range testable with the fingers. A bathroom scale may be used for higher rupture resistance. To calculate force in newtons, multiply kg by 10, or pounds by 4.54. One joule is equal to the energy delivered by dropping a 1-kg weight from a height of 10 cm. (The 3 joules class limit is approximately equivalent to dropping a 2-pound weight from a height of 1 foot). An easy to develop training tool for calibrating one's fingers to estimate applied force is to record the force required to compress springs with varying degrees of resistance using scales as described above. A set of small springs that approximate the class limits for rupture resistance classes can then be used as "known samples" for estimating rupture resistance and toughness classes. For determinations on the natural fabric, variability among specimens is likely to be large. Multiple measurements may be necessary. Recording median values helps reduce the influence of the extremes measured.

Rupture Resistance for Blocklike Specimens

Table 3-7 shows the classes of resistance to rupture and the means of determination for specimens that are blocklike. Different class sets are provided for moderately dry and very dry soil material and for slightly dry and wetter soil material. Unless otherwise specified, the soil water state is assumed to be that indicated for the horizon or layer when described. Cementation is an exception. To test for cementation, the specimen is air dried and then submerged in water for at least 1 hour. Cemented materials will resist slaking. Cementation class placements do not pertain to the soil material at the field water state.

The blocklike specimen should be 25 to 30 mm on edge. Direction of stress relative to the in-place axis of the specimen is not defined unless otherwise indicated. The specimen is compressed between the extended thumb and forefinger, between both hands, or between the foot and a nonresilient flat surface. If the specimen resists rupture by compression, a weight is dropped onto it from increasingly greater heights until rupture. Failure is at the initial detection of deformation or rupture. Stress applied in the hand should be for a period of 1 second.

Specimens of standard size and shape are not always available. While large blocks can be trimmed to the standard size, smaller blocks cannot. Blocks of specimens that are smaller than 25 to 30 mm on edge may still be tested, but the observed force required for rupture needs to be adjusted to approximate what would be expected if the block were the standard size. The force withstood may be assumed to decrease as the reciprocal of the dimension along which the stress is applied. For example, if a moist block specimen with a length of 10 mm along the direction the force is applied ruptures at 4 N stress, the following equation can be used to adjust the observed stress at failure to that for a standard 28-mm block:

Adjusted stress value =
[(28 mm/actual cube length mm)^2 x observed stress (N) at failure]

For the 10-mm specimen in the example above, [(28/10)^2 x 4 N] equals an adjusted stress of about 31 N. According to table 3-7, the rupture resistance class is firm.

Soil structure complicates the evaluation of rupture resistance. If a specimen of standard size can be obtained, rupture resistance of the standard specimen is reported. Other individual constituent structural units can also be described. Typically, the constituent structural units must exceed about 5 mm in the direction of applied stress. Expression must exceed weak for the rupture resistance of the individual structural units to be evaluated.

If structure size and expression are such that a specimen cannot be obtained, then the soil material overall is loose. Structural unit resistance to rupture may be determined if the size is large enough (exceeds about 5 mm in the direction of applied stress) for a test to be performed. Soils with moderate or strong structure and structural units that are less than 5 mm in the direction of applied stress are considered very friable or loose.

Table 3-7

Rupture Resistance Classes for Blocklike Specimens

Classes			Test description	
Moderately dry and very dry	**Slightly dry and wetter**	**Air dried, submerged**	**Operation**	**Stress applied***
Loose	Loose	Not applicable	Specimen not obtainable	
Soft	Very friable	Non-cemented	Fails under very slight force applied slowly between thumb and forefinger	< 8 N
Slightly hard	Friable	Extremely weakly cemented	Fails under slight force applied slowly between thumb and forefinger	8 to < 20 N
Moderately hard	Firm	Very weakly cemented	Fails under moderate force applied slowly between thumb and forefinger	20 to < 40 N
Hard	Very firm	Weakly cemented	Fails under strong force (maximum of about 80 N) applied slowly between thumb and forefinger	40 to < 80 N
Very hard	Extremely firm	Moderately cemented	Cannot be failed between thumb and forefinger but can be between both hands or by placing on a nonresilient surface and applying gentle force underfoot	80 to < 160 N

Table 3-7.—continued				
Classes			**Test description**	
Moderately dry and very dry	**Slightly dry and wetter**	**Air dried, submerged**	**Operation**	**Stress applied***
Extremely hard	Slightly rigid	Strongly cemented	Cannot be failed in hands but can be underfoot by full body weight (about 800 N) applied slowly	160 to < 800 N
Rigid	Rigid	Very strongly cemented	Cannot be failed underfoot by full body weight but can be by blow of < 3 J	800 N to < 3 J
Very rigid	Very rigid	Indurated	Cannot be failed by blow of < 3 J	≥ 3 J

* Both force (newtons; N) and energy (joules; J) are employed. The number of newtons is 10 times the kilograms of force. One joule is the energy delivered by dropping a 1 kg weight 10 cm.

Rupture Resistance for Plate-Shaped Specimens

The following procedure is used to determine rupture resistance for plate-shaped specimens, such as surface crusts, peds with platy or lenticular structure, and similar plate-shaped specimens for which the length and width are several times more than the thickness. The specimen should be 10 to 15 mm on edge. It should be about 5 mm thick, or the thickness of occurrence if less than 5 mm. For surface crusts, the thickness includes the crust proper and the soil material adhering beneath it. For some crusts with closely spaced cracks, however, the specimens may be too small to make the test applicable. The specimen is grasped on edge between extended thumb and forefinger. Force is applied along the longest of the two principal dimensions. Table 3-8 lists the classes and their criteria. Compression to failure should be about 1 second in duration.

For calibration of finger force applied with the quantitative class limits, a scale may be used to both rupture the specimens directly and develop the finger tactile sense. Force is applied with the forefinger through a bar 5 mm across on the scale to create a similar bearing area to that of the plate-shaped specimen. The specimen is compressed between the thumb and forefinger of one hand while simultaneously the same felt pressure is exerted on the scale with the forefinger of the other hand. The scale is read at the failure of the specimen.

For specimens that cannot be broken between thumb and forefinger, the resistance to rupture may be evaluated using a small penetrometer. The specimen is formed by orienting the two larger surfaces parallel to one another and then creating a flat surface. It is placed with one of the larger faces downward on a nonresilient surface. Force is applied through the 6-mm-diameter penetrometer tip until rupture occurs.

Table 3-8

Rupture Resistance Classes Applied to Crushing Plate-Shaped Specimens

Classes	Force *(newtons)*
Fragile	< 3 N
Extremely weak	Not removable
Very weak	Removable; < 1 N
Weak	1 to < 3 N
Medial	3 to < 20 N
Moderate	3 to < 8 N
Moderately strong	8 to < 20 N
Resistive	≥ 20 N
Strong	20 to < 40 N
Very strong	40 to < 80 N
Extremely strong	≥ 80 N

Plasticity

Plasticity is the degree to which puddled soil material is permanently deformed without rupturing by force applied continuously in any direction. Table 3-9 lists the classes and their criteria. Plasticity is determined on material smaller than 2 mm.

The determination is made using thoroughly puddled soil material at a water content where maximum plasticity is expressed. This water content is above the plastic limit but less than the water content at which maximum stickiness is expressed. The water content is adjusted by adding or removing water during hand manipulation. The plastic limit used in engineering classifications, which is closely related, indicates the water content at which a roll that consists of < 0.4 mm material, is 3 mm in diameter, and was formed at a higher water content breaks apart (method D 4318 in ASTM, 2011).

Table 3-9

Plasticity Classes

Classes	Criteria
Nonplastic	A roll 4 cm long and 6 mm thick that can support its own weight if held on end cannot be formed.
Slightly plastic	A roll 4 cm long and 6 mm thick can be formed and can support its own weight if held on end. A roll 4 mm thick cannot support its own weight.
Moderately plastic	A roll 4 cm long and 4 mm thick can be formed and can support its own weight, but a roll 2 mm thick cannot support its own weight.
Very plastic	A roll 4 cm long and 2 mm thick can be formed and can support its own weight.

Toughness

Toughness is related to plasticity. Table 3-10 lists the classes and their criteria. The classes are based on the relative force necessary to form, with the fingers, a roll 3 mm in diameter of < 2 mm soil material at a water content near the plastic limit (test D 2488 in ASTM, 2011).

Table 3-10

Toughness Classes

Classes	Criteria
Low	The specimen diameter at or near the plastic limit can be reduced to 3 mm by exertion of < 8 N.
Medium	The specimen diameter at or near the plastic limit requires 8 to < 20 N to be reduced to 3 mm.
High	The specimen diameter at or near the plastic limit requires > 20 N to be reduced to 3 mm.

Stickiness

Stickiness refers to the capacity of a soil to adhere to other objects. Table 3-11 lists the classes and their criteria. The determination is made on puddled < 2 mm soil material at the water content at which the material is most sticky. The sample is crushed in the hand, water is applied, and manipulation continues between thumb and forefinger until maximum stickiness is reached.

Table 3-11

Stickiness Classes

Classes	Criteria
Nonsticky	After release of pressure, practically no soil material adheres to thumb or forefinger.
Slightly sticky	After release of pressure, soil material adheres perceptibly to both digits. As the digits are separated, the material tends to come off one or the other digit rather cleanly. The material does not stretch appreciably on separation of the digits.
Moderately sticky	After release of pressure, soil material adheres to both digits and tends to stretch slightly rather than to pull completely free from either digit.
Very sticky	After release of pressure, soil material adheres so strongly to both digits that it stretches decidedly when the digits are separated. Soil material remains on both digits.

Manner of Failure

The manner in which specimens fail under increasing force ranges widely and typically is highly dependent on water state. The categories of manner of failure are *brittleness*, *fluidity*, and *smeariness* (see table 3-12). To evaluate brittleness or smeariness, a roughly cubical specimen 25–30 mm on edge is pressed between extended forefinger and thumb. To evaluate fluidity, a handful of soil material is squeezed in the hand (fig. 3-28). Some soil materials are brittle even wet, some can be compressed markedly without cracks appearing, others behave like liquids if wet, and others smear if subjected to shear stress until failure. Soil in the slightly moist or dry states, if coherent, is nearly always brittle and commonly does not exhibit smeariness; consequently, manner of failure is generally only useful for moderately moist or wetter soil material. Smeariness is a property most commonly associated with soils having andic soil properties (i.e., soils classified as Andisols and some Spodosols).

Table 3-12

Manner of Failure Classes

Classes	Operation	Test result
Brittleness		
Brittle	Gradually increasing compressive pressure is applied to a 25–30 mm specimen held between extended thumb and forefinger.	Specimen retains its size and shape (no deformation) until it ruptures abruptly into subunits or fragments.
Semi-deformable	Same as above	Deformation occurs prior to rupture. Cracks develop and specimen ruptures before it is compressed to half its original thickness.
Deformable*	Same as above	Specimen can be compressed to half its original thickness without rupture. Radial cracks may appear and extend inward less than half the radius distance under normal compression.
Fluidity		
Nonfluid	A handful of soil material is squeezed in the hand.	No material flows through the fingers after full compression.
Slightly fluid*	Same as above	After full compression, some material flows through the fingers but most remains in the palm of the hand.
Moderately fluid*	Same as above	After full pressure, most material flows through the fingers; a small residue remains in the palm of the hand.
Very fluid*	Same as above	Under very gentle pressure, most material flows through the fingers like a slightly viscous fluid and very little or no residue remains.

Table 3-12.—continued		
Classes	**Operation**	**Test result**
Smeariness		
Non-smeary	Gradually increasing pressure is applied to a 25–30 mm specimen held between extended thumb and forefinger in such a manner that some shear force is exerted on the specimen.	At failure, the specimen does not change suddenly to a fluid, the fingers do not skid, and no smearing occurs.
Weakly smeary	Same as above	At failure, the specimen changes suddenly to fluid, the fingers skid, and the soil smears. Afterward, little or no free water remains on the fingers.
Moderately smeary	Same as above	At failure, the specimen changes suddenly to fluid, the fingers skid, and the soil smears. Afterward, some free water can be seen on the fingers.
Strongly smeary	Same as above	At failure, the specimen changes suddenly to fluid, the fingers skid, and the soil smears and is very slippery. Afterward, free water is easily seen on the fingers.

* The approximate equivalent *n* values (Pons and Zonneveld, 1965) are as follows:

Deformable	< 0.7
Slightly fluid	0.7–1
Moderately fluid	1–2
Very fluid	≥ 2

Penetration Resistance

Penetration resistance is the capacity of the soil in its confined state (*in situ*) to resist penetration by a rigid object. Shape and size of the penetrating object must be defined. Penetration resistance depends strongly on the water state, which should be specified.

Figure 3-28

A field test on a soil with a moderately fluid manner of failure class. (Photo courtesy of John Kelley)

The classes in table 3-13 pertain to the pressure required to push the flat end of a cylindrical rod with a diameter of 6.4 mm a distance of 6.4 mm into the soil in about 1 second (Bradford, 1986). Three generalized classes and seven more narrowly defined classes are used. Orientation of the axis of insertion should be specified. A correction should be made for the weight of the penetrometer if the axis of insertion is vertical and the resistance is small. If rock fragments are present, the lower values measured are typically more descriptive of the fine-earth fabric.

The pocket penetrometer, shown in Bradford (1986), is the standard instrument. Penetrometers with the same 6.4-mm-diameter flat-end tip and a dial reading device are available. The resistance can be read with less variability using the dial device. The scale on the barrel of the pocket penetrometers should be converted to units of force. The supplied scale on such instruments commonly is based on a regression between penetration resistance and unconfined, compressive strength measurements and has no application in the context used here. Penetration resistance is expressed in units of pressure. The preferred unit is the megapascal (MPa). For the 6.4-mm-diameter tip, the measured force in kilograms is

Table 3-13

Penetration Resistance Classes

Classes	Penetration resistance *(MPa)*
Small	< 0.1
Extremely low	< 0.01
Very low	0.01 to < 0.1
Intermediate	0.1 to < 2
Low	0.1 to < 1
Moderate	1 to < 2
Large	> 2
High	2 to < 4
Very high	4 to < 8
Extremely high	> 8

multiplied by 0.31 to obtain the pressure in megapascals. To extend the range of the instrument, weaker and stronger springs may be substituted. Values in megapascals obtained with any diameter of flat-end rod are used to determine the class (see table 3-13).

In addition to the flat-end tip, cone-shaped tips may be mounted on the penetrometers with flat ends as well as other penetrometers. Two 30-degree cone penetrometer tips are specified by the American Society of Agricultural Engineers (Ayers and Perumpral,1982). One has a base area of 1.3 cm^2 and the other of 3.2 cm^2. The tips should be inserted where the base of the cone is flush with the soil surface. Insertion times of 2 seconds and 4 seconds should be used for the smaller and larger cones, respectively. A relationship between the cone tips and the specified rod with a flat end must be established before cone measurements. Table 3-13 can be modified to use the corresponding cone measurements.

Determination of penetration resistance while the soil layer is at or near its maximum water content is useful in evaluation of root limitations. The relationship between penetration resistance and root growth has been the subject of numerous studies—Blanchar et al. (1978), Campbell et al. (1974), Taylor et al. (1966), and Taylor and Ratliff (1969). These studies suggest the following generalities (which can be modified for particular plants and soils): (i) if the soil material is wet or very moist and there are no closely spaced vertical structural planes, the limit of 2 MPa (6.4-mm flat-end rod) indicates strong root restriction for several important annual crops (this is the basis for the penetration resistance criterion in the criteria for physical root restriction); (ii) if MPa is between 2 and 1, root restriction may be assumed to decrease roughly linearly; (iii) if MPa is below 1, root restriction may be assumed to be small.

Excavation Difficulty

Table 3-14 gives the classes of excavation difficulty and their criteria. The classes can be used to describe both non-cemented and cemented or indurated horizons, layers, or pedons for a one-time observation or over time. In most cases, excavation difficulty is related to and controlled by a water state.

Table 3-14

Excavation Difficulty Classes

Classes	Criteria
Low	Material can be excavated with a spade using arm-applied pressure only. Neither application of impact energy nor application of pressure with the foot to a spade is necessary.
Moderate	Arm-applied pressure to a spade is insufficient. Excavation can be accomplished quite easily by application of impact energy with a spade or by foot pressure on a spade.
High	Excavation with a spade can be accomplished, but with difficulty. Excavation is easily possible with a full length pick using an over-the-head swing.
Very high	Excavation with a full length pick using an over-the-head swing is moderately to markedly difficult. Excavation is possible in a reasonable period of time with a backhoe mounted on a 40 to 60 kW (50 to 80 hp) tractor.
Extremely high	Excavation is nearly impossible with a full length pick using an over-the-head arm swing. Excavation cannot be accomplished in a reasonable time period with a backhoe mounted on a 40 to 60 kW (50 to 80 hp) tractor.

Roots

Quantity, size, and location of roots in each layer are recorded. Features of the roots—length, flattening, nodulation, and lesions—and their relationships to special soil attributes or to structure may be recorded as notes.

Quantity of Roots

Quantity of roots is described in terms of numbers of each size per unit area. The observed value is used to assign a class. The classes for quantity of roots pertain to an area in a horizontal plane unless otherwise stated. However, most soil profiles are described from a vertical plane and the number of roots observed per unit area may differ depending on the orientation. Therefore, a horizontal cross-section should be used when practical to determine quantity of roots. The required unit area for observation changes according to root size: 1 cm^2 for very fine and fine roots, 1 dm^2 for medium and coarse roots, and 1 m^2 for very coarse roots.

Ideally, class limits correspond to a root abundance level where there are sufficient roots to exploit much of the soil water that is present in the withdrawal range of the plant over the growing season. This can be difficult because species differ in the efficiency of their roots. Soybeans and cotton are several fold more efficient than grasses, and there are undoubtedly other differences among specific groups. The quantity classes have been formulated so that the *few-common* separation is about where the annual grasses have insufficient numbers of roots for seasonally complete exploitation. The *few* class can be subdivided if useful. The *moderately few-very few* separation is where soybeans and cotton would have insufficient numbers.

The quantity classes are:

Few .... less than 1 per unit area
Very few .... less than 0.2 per unit area
Moderately few ... 0.2 to less than 1 per unit area
Common .... 1 to less than 5 per unit area
Many...................... 5 or more per unit area

Size Classes of Roots

Roots are described in terms of a specified diameter size. The size classes are:

Very fine .... less than 1 mm
Fine......................... 1 to less than 2 mm
Medium .... 2 to less than 5 mm
Coarse..................... 5 less than 10 mm
Very coarse............ 10 mm or larger

Location of Roots

The location of roots within a layer may be described in relation to other features of the layer. Relationships to layer boundaries, animal traces, pores, and other features are described as appropriate. The description may indicate, for example, whether roots are inside structural units or only along parting planes between structural units. A convenient order is quantity, size, location. The description "many very fine and common fine roots" implies that roots are uniformly distributed, since location is not given. Examples of descriptions with locational information are: "common very fine and common fine roots concentrated along vertical faces of structural units" and "common very fine roots inside peds, many medium roots between structural units."

In some soils, the pattern or root growth may not correspond to soil horizons or layers. A summary statement of root development by increments of 15 cm or 30 cm (or some other convenient thickness) can be helpful. In other soils, root distribution may be summarized by grouping layers. For example, in a soil having a strongly developed clayey illuvial horizon and a horizon sequence of Ap-A-E1-E2-Bt1-Bt2, root development might have one pattern throughout the A horizons, another pattern in the E horizons, and yet another pattern in the B horizons. In this case, root distribution can be described for the A, E, and B horizons, each horizon treated as a whole.

For annual plants, the time of the root observation may be indicated. Root traces (channels left by roots that have died) and the dead roots themselves can be clues to soil properties that change with time. The rate of root decay depends on the species, root size, and the soil moisture and temperature regimes. Local experience can determine the time after maturity or harvest that the root distribution is affected by decay. Root traces in deep layers may persist for years. Many of these traces have organic coatings or linings. If they occur below the normal rooting depth of annual crops, they were left by deeper-rooted plants, perhaps native perennials. The presence of dead roots below the current rooting depth may indicate a change in the soil water regime. The roots may have grown normally for a few years, then died when the soils were saturated for a long period.

In addition to recording the rooting depths at the time of observation, generalizations about the rooting depth may be useful. These generalizations should emphasize very fine and fine roots, if present, because roots of these sizes are active in absorption of water and nutrients. The generalizations may be for a few plants or plant communities that are of particular importance. For observation of annual plants, the generalization should assume plant maturity.

Pores

Pore space is a general term for voids in the soil material. The term includes matrix, non-matrix, and interstructural pore space.

Kinds of Pores

Matrix pores (also called interstitial pores) are formed by the agencies that control the packing of the primary soil particles. In fine and medium textured soils these pores are typically smaller than non-matrix pores. Additionally, their aggregate volume and size change markedly with water state for soil horizons or layers with high extensibility. In coarse textured soils, the interstitial pore size is controlled dominantly by the primary particle packing and remains fairly stable, although pores may become filled with finer material over time.

Non-matrix pores are relatively large voids that occur not only when the soil is dry but also when it is moderately moist or wetter. The voids are not bounded by the planes that delimit structural units. *Interstructural pores* are delimited by structural units. The interstructural porosity may be inferred from the structure description. Commonly, interstructural pores are at least crudely planar.

Non-matrix pores may be formed by roots, animals, compressed air, and other agents. The size distribution of these pores typically is not associated with the particle-size distribution and the related matrix pore-size distribution. For water movement at low suction and conditions of satiation, the non-matrix and interstructural porosity have particular importance.

Non-matrix pores are described by quantity, size, shape, and vertical continuity—generally in that order. Quantity classes pertain to numbers per unit area—1 cm^2 for very fine and fine pores, 1 dm^2 for medium and coarse, and 1 m^2 for very coarse.

Quantity Classes of Pores

The pore quantity classes are:

Few .... less than 1 per unit area
Common .... 1 to less than 5 per unit area
Many.......... 5 or more per unit area

Size Classes of Pores

Pores are described relative to a specified diameter size. The five pore size classes are:

Very fine .... less than 1 mm
Fine......................... 1 to less than 2 mm
Medium .... 2 to less than 5 mm
Coarse..................... 5 to less than 10 mm
Very coarse .... 10 mm or more

Shape Classes of Pores

Common non-matrix pore shapes include:

Vesicular.—Small, approximately spherical or elliptical. These cavities are caused by entrapped air bubbles, most commonly occurring in or below mineral or biological crusts or desert pavement, especially in arid soils. As the size and/or number of near-surface vesicular pores increases, infiltration is drastically reduced and surface runoff increases. A horizon dominated by vesicular pores is identified as a vesicular master horizon (capital letter V).
Tubular.—Approximately cylindrical and elongated, as in worm channels.
Dendritic tubular.—Like tubular, but branching as in root channels.
Irregular.—Nonconnected. These cavities or chambers are commonly called "vughs."

Continuity Classes of Pores

Vertical continuity involves assessment of the average vertical distance through which the minimum pore diameter exceeds 0.5 mm when the soil layer is moderately moist or wetter. Three classes are used:

Low............ less than 1 cm
Moderate.... 1 to less than 10 cm
High........... 10 cm or more

Additionally, the designation “continuous” is used if the non-matrix pores extend through the thickness of the horizon or layer. Vertical continuity has extreme importance in assessing the capacity of the soil layer to transmit free water vertically.

Special aspects are noted, such as orientation in an unusual direction, concentration in one part of a layer, or conditions where tubular pores are plugged with clay at both ends. Some examples of descriptions of pores are “many fine tubular pores,” “few fine tubular pores and many medium tubular pores with moderate vertical continuity,” and “many medium vesicular pores in a horizontal band about 1 cm wide at the bottom of the horizon.”

Animals

The mixing, changing, and moving of soil material by animals is a major factor affecting properties of some soils. The features resulting from animal activity reflect mainly mixing or transport of material from one part of the soil to another or to the surface. The original material may be substantially modified physically or chemically.

The features that animals produce on the land surface may be described. Termite mounds, ant hills, heaps of excavated earth beside burrows, the openings of burrows, paths, feeding grounds, earthworm castings, other castings, and other traces on the surface are easily observed and described. Simple measurements and estimates (such as the number of structures per unit area, proportionate area occupied, and volume of above-ground structures) give quantitative values that can be used to calculate the extent of activity and even the number of organisms.

The marks of animals below the ground surface are more difficult to observe and measure. Observations are confined mainly to places where pits are dug. The volume of soil generally studied is limiting. For the marks of many animals, the normal pedon for soil characterization is large enough to provide a valid estimate. For some animals, however, the size of the marks is too large for the usual pedon.

Krotovinas are irregular tubular streaks in a layer that consists of material transported from another layer. They are caused by the filling of tunnels made by burrowing animals in one layer with material from outside the layer. In a profile, they appear as rounded or elliptical volumes of various sizes. They may have a light color in dark layers or a dark color in light layers, and their other qualities of texture and structure may be unlike those of the soil around them.

Description of Animal-Related Features

The features produced by animals in the soil are described in terms of amount, location, size, shape, and arrangement and also in terms of the color, texture, composition, and other properties of the component material. There are no special conventions for descriptions. Common words should be used in conjunction with appropriate special terms for the soil properties and morphological features that are described elsewhere in this manual.

Selected Chemical Properties

This section discusses selected chemical properties that are important for describing and identifying soils. Included in the discussion are reaction, carbonates, manganese oxides, salinity, sodicity, sulfates, and sulfides.

Reaction

The numerical designation of reaction is expressed as pH. With this notation, pH 7 is neutral. Values lower than 7 indicate acidity; higher values indicate alkalinity. Soils as a whole range in pH from slightly less than 2.0 to slightly more than 11.0. Individual soils have a much narrower pH range within these overall limits. Reaction varies seasonally and is affected by such factors as moisture, temperature, plant growth, and microbial activity. A significant change in pH also occurs when some naturally wet soils that contain sulfides are drained. In these cases, sulfuric acid forms and pH may decrease to below 2.0.

The standard field pH measurement is performed with a 1:1 soil:water mixture so that comparisons of pH readings are on an equivalent basis. A more dilute sample (for example, a 1:5 soil:water mixture) generally has a higher pH, and less dilute samples generally have lower pH.

While the standard for measuring pH in the field is a 1:1 soil:water mixture, other methods of measuring pH are also used in soil survey for specific purposes, especially those required for some taxonomic criteria in Soil Taxonomy. They include:

0.01 M $CaCl_2$.—This method has the advantage of dampening seasonal variation in pH. It is used for some taxonomic family-level criteria.

1N KCl.—This method is used to infer aluminum saturation levels in some great groups of Oxisols (e.g., Acrudox). If the criteria are met, aluminum toxicity may be a concern.

1M NaF.—This method is used to infer the presence of short-range order minerals. It is used in the criteria for the isotic mineralogy class.

Various methods can be used to measure pH in the field. Pocket pH meters are a popular tool. Care must be taken to clean the sensor tip between readings and to periodically calibrate the meter to standard samples of known pH. It is also important to ensure calibration reagents are fresh. Other common measurement methods include the use of indicator solution dyes, colorimetric kits, and paper pH indicator strips. Proper storage of these materials—out of direct sunlight and not exposed to extreme temperatures—is important. Over time, the test materials become less reliable. It is important to record the method of pH reading.

Reaction Class Terms

Reaction class terms are commonly used to communicate information about soil pH. The terms are given in table 3-15.

Table 3-15

Reaction Class Terms and Their Ranges in pH

Class term	pH range
Ultra acid	< 3.5
Extremely acid	3.5–4.4
Very strongly acid	4.5–5.0
Strongly acid	5.1–5.5
Moderately acid	5.6–6.0
Slightly acid	6.1–6.5
Neutral	6.6–7.3
Slightly alkaline	7.4–7.8
Moderately alkaline	7.9–8.4
Strongly alkaline	8.5–9.0
Very strongly alkaline	> 9.0

Carbonates of Divalent Cations

A solution of cold, 1-normal hydrochloric acid (1N HCl) is used to test for the presence of free carbonates in the field. The proper concentration is made by combining 1 part concentrated HCl (37%) with 11 parts distilled water. Add acid to water, not water to acid. Care must be taken when handling concentrated HCl as it can cause severe skin burns. The application of a few drops of HCl to a sample containing carbonates results in the evolution of CO_2 gas, which forms bubbles (effervescence). The amount and expression of effervescence is affected by size distribution of the carbonates and their mineralogy as well as the overall amount of carbonates present. Consequently, effervescence is a qualitative test and cannot be used to estimate the quantitative amount of carbonate.

Effervescence Class Terms

The five classes of effervescence and their criteria are shown in table 3-16.

Table 3-16

Effervescence Class Terms

Effervescence class	Criteria
Noneffervescent	No bubbles form
Very slightly effervescent	Few bubbles form
Slightly effervescent	Numerous bubbles form
Strongly effervescent	Bubbles form a low foam
Violently effervescent	Bubbles quickly form a thick foam

An example of the use of effervescence class in a description is “strongly effervescent with 1N HCl.” While calcium carbonate reliably effervesces when treated with cold dilute hydrochloric acid, effervescence is not always easily observable for some sandy soils. Dolomite reacts to cold dilute acid slightly or not at all and may be overlooked. It can be detected by heating the sample, using more concentrated acid, and grinding the sample. The effervescence of powdered dolomite with cold dilute acid is slow (a few minutes) and frothy.

Calcium Carbonate Equivalent

Calcium carbonate equivalent refers to the amounts of $CaCO_3$ in soil. Other names include soil carbonate, soil inorganic carbon, pedogenic carbonate, caliche, nari, tosca, croute calcaire, kankar, and soil lime (Monger et al., 2015). The most common mineral form is calcite.

A quantitative field test for measuring the soil carbonate uses a simple volume calcimeter (see Soil Survey Staff, 2009, for details). For this procedure, a small sample (commonly 0.33 g) is placed in a syringe. A

10 percent HCl solution is placed in a second syringe which is connected to the first syringe by a rubber tube. The HCl solution is injected into the syringe containing the soil sample and the evolution of CO_2 gas is recorded and adjusted to compensate for temperature and elevation. Soil carbonate is recorded to the nearest whole number.

Manganese Oxides

Hydrogen peroxide (H_2O_2, 3-4% solution, commonly available in pharmacies) can be used to test for the presence of manganese oxides (MnO_2, a kind of redoximorphic concentration). The effervescence classes used for carbonates (table 3-16) are also used for describing the presence of manganese oxides. The effervescence class and reagent are recorded, e.g., "violently effervescent in 3% H_2O_2."

It should be noted that organic matter also reacts to hydrogen peroxide. This reaction is typically slow, while MnO_2 reacts quickly. Hydrogen peroxide is also used for a color change test to detect the presence of reduced monosulfides (e.g., FeS) in subaqueous soils.

Salinity and Sodicity

Accurate determinations of salinity and sodicity in the field require special equipment and are not necessarily part of each pedon investigation. Reasonable estimates of salinity and sodicity can be made if field criteria are correlated to more precise laboratory measurement.

Salinity

The electrical conductivity (EC) of a saturation paste extract is the standard method for measuring salinity and is denoted as ECe. Electrical conductivity is related to the amount of salts that are more soluble than gypsum in the soil. A small amount (up to 2 dS/m) of dissolved gypsum may also contribute to the EC.

The preparation of a saturation paste extract is most commonly performed in the laboratory rather than in the field. Pocket electrical conductivity meters can be used in the field for measuring electrical conductivity of soil:water solutions of various ratios (e.g., 1:1, 1:2, 1:5, etc.). The EC values recorded reflect the concentration of the mixture. Lower readings are associated with higher amounts of water relative to soil. Electrical conductivity measured this way should be denoted with the soil:water ratio (e.g., $EC_{1:1}$, $EC_{1:5}$). There is no universal correction factor to equate these results to the standard saturation paste extract method performed in the laboratory. General correlations between field-measured EC using a soil:water solution and laboratory-measured ECe for the same samples may be possible for soils in a localized geographic area having similar salt chemistry and other properties and similar environmental conditions. Additional samples having only field-measured EC may then be estimated as to their expected ECe values for classification purposes and assignment to salinity classes. Care must be taken to not extend the relationship beyond the area for which it was established.

The 1:5 soil:water mixture (by volume) is commonly used as a field test for measuring EC of subaqueous soil samples. These results are recorded as described above (e.g., $EC_{1:5}$ 10.5 dS/m). The salinity classes shown in table 3-17 are not applicable to these measurements.

The standard international unit of measure for EC is decisiemens per meter (dS/m) corrected to a temperature of 25 °C. (Millimhos per centimeter [mmhos/cm] are equivalent to dS/m, but this notation is not preferred.) Measured electrical conductivity is reported in soil descriptions. Table 3-17 shows the classes of salinity used if the electrical conductivity (ECe) has not been determined but salinity is inferred.

Table 3-17

Salinity Class Terms

Salinity class	**Electrical conductivity (ECe)** *dS/m (mmhos/cm)*
Nonsaline	< 2
Very slightly saline	2 to < 4
Slightly saline	4 to < 8
Moderately saline	8 to < 16
Strongly saline	≥ 16

Field measurements of electrical conductivity can be made using other methods, such as electromagnetic induction or salinity probes (see chapter 6). Again, these measures are useful for the area where they are made but the observed values are not equivalent to EC measured with a saturation paste extract or with various soil:water ratios.

Sodicity

The sodium adsorption ratio (SAR) is the standard measure of the sodicity of a soil. It is a measure of the equilibrium between sodium ions in the soil solution and the exchangeable sodium ions adsorbed on the soil cation-exchange complex. The sodium adsorption ratio is calculated from the concentrations (in milliequivalents per liter) of sodium, calcium, and magnesium in the saturation extract:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

Formerly, the primary measure of sodicity was the exchangeable sodium percentage, which equals exchangeable sodium (meq/100 g soil) divided by the cation-exchange capacity (meq/100 g soil) times 100. The test for exchangeable sodium percentage, however, has proved unreliable in soils containing soluble sodium silicate minerals or large amounts of sodium chloride.

Sodium is toxic to some crops and affects soil physical properties, mainly saturated hydraulic conductivity. A sodic condition has little effect on hydraulic conductivity in highly saline soils. A soil that is both saline and sodic may, when artificially drained, drain freely at first. After some of the salt has been removed, however, further leaching of salt becomes difficult or impossible. The sodium adsorption ratio (SAR) typically decreases as a soil is leached because the amount of change depends in part on the composition of the water used for leaching.

The following procedure can be used to predict whether the soil will be sodic after leaching. If the initial SAR is greater than 10 and the initial electrical conductivity is more than 20 dS/m, the SAR is determined on a sample after first leaching it with the intended irrigation water. For soils with an electrical conductivity of more than 20 dS/m, the SAR is determined after first leaching the sample with distilled water to an electrical conductivity of about 4 dS/m.

No classes for sodium levels in the soil are provided. Laboratory analysis is required to document the SAR of individual horizons. Soils that have high sodium levels, but are not otherwise saline, commonly have pH of 9.0 or greater. Soils that are both saline and sodic tend to have pH values of less than 8.5. In addition, some sodic soils, especially in slightly depressional areas, may be black at the surface due to dispersion of clay and organic matter and poor drainage. In some sodic soils, natric horizons exhibit columnar structure.

Sulfates

Gypsum (hydrous calcium sulfate: $CaSO_4 \cdot 2H_2O$) can be inherited from the parent material or can precipitate from supersaturated solutions in the soil or substratum. It can alleviate the negative effects of sodium on soil structure, allowing the use of irrigation water that has a relatively high amount of sodium. Soils that contain large amounts of gypsum can settle unevenly after irrigation, and frequent releveling may be required. Soil subsidence due to gypsum dissolution, especially from concentrated flow of rainwater from roofs or paved areas, can be a serious hazard to roads and buildings. Gypsum is soluble in water. The electrical conductivity of a distilled water solution with gypsum is about 2 dS/m. In the absence of other salts, salinity is not a hazard except for such sensitive plants as strawberries and some ornamentals. Gypsum and other sulfates may cause damage to concrete.

Gypsum is commonly tabular or fibrous and tends to accumulate as clusters of crystals or as coats on peds. Some is cemented. Gypsum can typically be identified by its form and lack of effervescence with acid. Gypsum in parent material may not be readily identifiable. If determined, the amount of gypsum is given in the description. If not, the amount may be estimated. Semiquantitative field methods for determining amounts of gypsum are available.

Some soils contain large amounts of sodium sulfate, which looks like gypsum in hand specimens of soil. Sodium sulfate is in the form of thenardite (Na_2SO_4) at temperatures above 32.4 °C and in the form of mirabilite ($Na_2SO_4 \cdot 10H_2O$) at lower temperatures. The increase in volume and decrease in solubility as thenardite changes to mirabilite can cause extreme salt heaving. In saline-sodium soils, sodium sulfate is a common water-soluble salt.

Sulfides

Sulfides, mainly iron sulfide, occur in some tidal marsh soils and in some sedimentary rocks, such as those associated with coal or shale. In marsh soils, soil layers with significant sulfide content are commonly permanently saturated and are neutral in color (N) or have hue of 5Y, 5GY, 5BG, or 5G; value of 2, 3, or 4; and chroma of 1 or less (Fanning et. al., 2002; IUSS Working Group WRB, 2015). When these materials are exposed (e.g., when marsh soils are drained or sulfide-bearing rock is excavated), oxidation commonly produces sulfuric acid. Sulfuric acid is toxic to plants and animals in the soil and to fish and other aquatic organisms in nearby waters. The solutions produced are extremely acid and are highly corrosive to exposed metal and concrete. Soils and rock that may have potential sulfur acidity (especially material dredged from coastal water areas and applied on the land) should be tested for the presence of sulfide salts.

A few soils with appreciable amounts of sulfides contain enough carbonates to neutralize all or part of the acidity when the sulfides are oxidized. In these soils, the total amounts of both calcium carbonate and sulfides are needed to determine if effective neutralization can occur naturally.

No reliable field methods are available for determining the amount of sulfides in marshes. A simple test to confirm the presence of sulfides (but not the amount) uses 30% hydrogen peroxide (H_2O_2) to determine if rapid oxidation causes a significant decrease in pH as compared to a similar sample treated with water (Soil Survey Staff, 2009).

Marsh soils may give off a sulfurous odor. This odor is not a reliable indicator of the presence of significant amounts of oxidizable sulfides; however, odor can be a reliable indicator that sulfides are present. The sulfurous odor ("rotten egg smell"), if detected, should be noted in the soil description. Qualitative class terms for odor intensity are:

Slight.—Odor is faint, only detected close to nose.
Moderate.—Odor is readily noticeable, even at arm's length from the nose.
Strong.—Odor is intense and readily noticed as soon as sample is exposed to the air.

Drained or excavated marsh soils that contain large amounts of sulfides commonly have yellow efflorescences of the mineral jarosite on the exteriors of clods (fig. 3-29).

Two simple laboratory tests are commonly used to detect excess oxidizable sulfides (Soil Survey Staff, 2009). In one test, pH is measured before and after the soil is incubated for several weeks at field capacity. A large drop in pH, or a pH of 3.5 or less after drying, indicates excessive amounts of sulfides. In the other test, the sample is treated with 30- to 36-percent hydrogen peroxide and heated to complete oxidation and to drive off the excess peroxide. Then, pH is measured. If the decrease in pH is large, sulfides are probably present. Use of an electronic meter rather than colorimetric methods to measure pH is preferred because of the possible oxidation of indicator dyes. Special dyes suitable for this test are available. If the qualitative tests for oxidizable sulfides are positive, laboratory determinations of sulfur content are required for precise interpretations and recommendations regarding use and management.

Soil Water

This section discusses "water regimes"—schemes for the description of the state of the soil water at a particular time and for the change in soil water state over time. Soil water state is evaluated from water suction, quantity of water, whether the soil water is liquid or frozen, and the

Figure 3-29

Jarosite concentrations (yellowish color) that formed due to oxidation in this drained marsh soil containing sulfides.

occurrence of free water within the soil and on the land surface. The complexity and detail of water regime statements can range widely.

Inundation Classes

Free water may occur above the soil. Inundation is the condition when the soil area is covered by liquid free water. Flooding is temporary inundation by flowing water. If the water is standing, as in a closed depression, the term ponding is used. Flooding and ponding are temporal conditions. In most cases, soils are not described while inundated (exceptions include subaqueous soils and some soils that are subject to ponding of very long duration). To the extent possible, estimates for inundation should include frequency, duration, and months of occurrence. Depth of inundation is also commonly recorded. Table 3-18 shows the classes for frequency and duration of inundation. The *rare* and *very rare* frequency classes may be combined. The *very frequent* class takes precedence over *frequent* if both definitions are met. *Very frequent* flooding includes tidal inundation. Frequency of flooding should reflect the current conditions. A soil that would be frequently flooded in its natural state, but is now protected by a dam or levee, should be assigned the class that reflects the level of protection provided.

Table 3-18

Frequency and Duration of Inundation Classes (Flooding or Ponding)

Class	Criteria
Frequency	
None	No reasonable possibility of inundation; one chance out of 500 in any year or less than 1 time in 500 years.
Very rare	Inundation is very unlikely but is possible under extremely unusual weather conditions; less than 1 percent chance in any year or less than 1 time in 100 years but more than 1 time in 500 years.
Rare	Inundation is unlikely but is possible under unusual weather conditions; 1 to 5 percent chance in any year or nearly 1 to 5 times in 100 years.
Occasional	Inundation is expected infrequently under usual weather conditions; more than 5 to 50 percent chance in any year or 6 to 50 times in 100 years.
Frequent	Inundation is likely to occur often under usual weather conditions; more than 50 percent chance in any year (i.e., more than 50 times in 100 years) but 50 percent or less chance in all months in any year.
Very frequent	Inundation is likely to occur very often under usual weather conditions; more than a 50 percent chance in all months of any year.
Duration	
Extremely brief	0.1 hour to less than 4 hours (flooding only)
Very brief	4 hours to less than 48 hours
Brief	2 days to less than 7 days
Long	7 days to less than 30 days
Very long	30 or more days

Internal Soil Water State

This section discussions the occurrence of water within the soil, classes used to describe the soil water state at the time the soil is described, and methods for evaluating soil water in the field.

Classes

In describing classes of soil water state for individual layers or horizons, only matrix suction is considered in the definition of the classes.[3] Osmotic potential is not considered. For water contents of medium and fine textured soil materials at suctions of less than about 200 kPa, the reference laboratory water retention is for the natural soil fabric. Class limits are expressed both in terms of suction and water content. To make field and field office evaluation more practicable, water content refers to gravimetric rather than volumetric quantities. The classes apply to mineral and organic soil material. The frozen condition is indicated separately by the symbol "f." This symbol indicates the presence of ice; some of the water may not be frozen. If the soil is frozen, the water content or suction pertains to what it would be if not frozen.

Three classes and eight subclasses for water state are defined in table 3-19. Classes and subclasses may be combined as desired. The desired specificity and characteristics of the water desorption curve determine whether classes or subclasses should be used. Coarse soil material has little water below the 1500 kPa retention, and so subdivisions of dry generally are not useful.

Dry is separated from *moist* at 1500 kPa suction. *Wet* is separated from *moist* at the condition where water films are readily apparent. The water suction at the moist-wet boundary is assumed to be about 0.5 kPa for coarse soil materials and 1 kPa for other materials. The formal definition of coarse soil material is given later.

Three subclasses of dry are defined—*very dry, moderately dry*, and *slightly dry*. Very dry cannot be readily distinguished from air dry in the field. The water content extends from ovendry to 0.35 times the water retention at 1500 kPa. The upper limit is roughly 150 percent of the air-dry water content. The limit between moderately dry and slightly dry is a water content 0.8 times the retention at 1500 kPa.

The **moist** class is subdivided into *slightly moist, moderately moist,* and *very moist*. Depending on the kind of soil material, laboratory retention at 5 or 10 kPa suction (method 4B, Soil Survey Staff, 2014a) determines the *upper water retention* (UWR). A suction of 5 kPa is used for coarse soil material; a suction of 10 kPa is used for other material.

To be considered coarse, the soil material that is strongly influenced by volcanic ejecta must be nonmedial and have few or no vesicular pores in the mineral particles. If not strongly influenced by volcanic ejecta, it must meet the sandy or sandy-skeletal family particle-size criteria and also

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[3] The primary unit for suction is the pascal (Pa). The kilopascal (kPa), equal to 1000 pascals, is commonly employed. One kPa = 1000 Pa = .01 bar = 10 cm of H_2O.

Table 3-19

Water State Classes

Class	Criteria[a]
Dry (D)	> 1500 kPa suction
Very dry (DV)	< 0.35 x 1500 kPa retention
Moderately dry (DM)	0.35 to < 0.8 x 1500 kPa retention
Slightly dry (DS)	0.8 to 1.0 x 1500 kPa retention
Moist (M)	≤ 1500 kPa to > 1.0 or 0.5 kPa[b]
Slightly moist (MS)	1500 kPa suction to MWR[c]
Moderately moist (MM)	MWR to UWR[c]
Very moist (MV)	UWR to > 1.0 or 0.5 kPa[b] suction
Wet (W)	≤ 1.0 kPa or 0.5 kPa[b]
Nonsatiated[d] (WN)	> 0.0 to ≤ 1.0 kPa or ≤ 0.5 kPa[b]
Satiated[e] (WA)	≤ 0.0 kPa

[a] Criteria use both suction and gravimetric water contents as defined by suction.
[b] 0.5 kPa only if coarse soil material (see text).
[c] UWR indicates upper water retention, which is the laboratory water retention at 5 kPa for coarse soil material and 10 kPa for other material (see text). MWR indicates midpoint water retention, which is halfway between the upper water retention and the retention at 1500 kPa.
[d] Peds glisten; no free water present.
[e] Peds glisten; free water present.

be coarser than loamy fine sand, have less than 2 percent organic carbon, and have less than 5 percent water at 1500 kPa suction. Furthermore, the computed total porosity of the < 2 mm fabric must exceed 35 percent.[4]

Very moist has an upper limit at the moist-wet boundary and a lower limit at the upper water retention. Similarly, *moderately moist* has an

[4] Total porosity = 100 - (100 x Db/Dp), where Db is the bulk density of the < 2 mm material at or near field capacity and Dp is the particle density. The particle density may be computed from the following:
Dp = 100/[[(1.7xOC)/Dp1] + [(1.6xFe)/Dp2] + [[100 - [(1/7xOC) + (1.6xFe)]]/Dp3]]
where OC is the organic carbon percentage and Fe is the extractable iron by method 6C2 (Soil Survey Staff, 2014a) or an equivalent method. The particle density of the organic matter (Dp1) is assumed to be 1.4 Mg/m^3, that of the minerals from which the extractable iron originates (Dp2) to be 4.2 Mg/m^3, and that of the material exclusive of the organic matter and the minerals contributing to the extractable Fe (Dp3) to be 2.65 Mg/m^3.

upper limit at the upper water retention and a lower limit at the midpoint in gravimetric water content between retention at 1500 kPa and the upper water retention. This lower limit is referred to as the *midpoint water retention* (MWR). *Slightly moist* extends from the midpoint water retention to the 1500 kPa retention.

The **wet** class has *nonsatiated* and *satiated* subclasses distinguished on the basis of absence or presence of free water. Miller and Bresler (1977) defined satiation as the condition in which free water first appears through saturation. The nonsatiated wet state may be applicable at zero suction to horizons with low or very low saturated hydraulic conductivity. These horizons may not exhibit free water. Horizons may have parts that are *satiated wet* and other parts that are *nonsatiated wet* because of low matrix saturated hydraulic conductivity and the absence of conducting macroscopic pores. Free water develops positive pressure with depth below the top of a wet satiated zone.

A class for saturation (that is, zero air-filled porosity) is not provided because the term suggests that all of the pore space is filled with water. This condition typically cannot be evaluated in the field. Furthermore, if saturation is used for the concept of satiation, then a term is not available to describe known saturation. There is an implication of saturation if the soil material is satiated wet and coarse textured or otherwise has properties indicative of high or very high saturated hydraulic conductivity throughout the mass. A satiated condition does not necessarily indicate reducing conditions. Air may be present in the water and/or the microbiological activity may be low. The presence of reducing conditions may be inferred from soil color in some cases. A test may be performed for ferrous iron in solution. The results of the test for ferrous iron should be reported separately from the water state description.

Evaluation

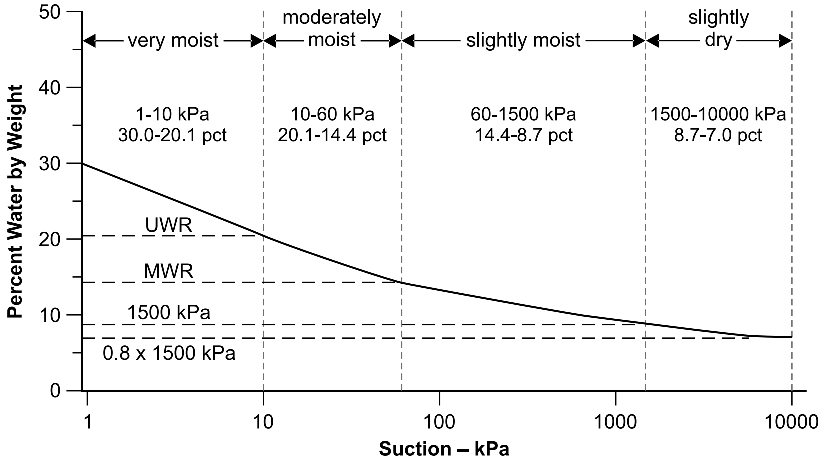
Wet is indicated by the occurrence of prominent water films on surfaces of sand grains and structural units that cause the soil material to glisten. If free water is absent, the term *nonsatiated wet* is used. If free water is present, the term *satiated wet* is used. In the field, the position of the uppermost boundary in the soil profile meeting the satiated wet class is the top of the water in an unlined bore hole after equilibrium has been reached. Lined bore holes or piezometers, installed to several depths across the zone of free water occurrence, are needed to determine the thickness of a perched zone of free water. Piezometers are tubes placed to a designated depth that are open at both ends. They may have a perforated zone at the bottom but do not permit water entry along most of their length. For the purpose of simply obtaining information about the depth of free water and the location and thickness of the free water zone, the installation of bore holes or piezometers is not required. This information can be obtained in the course of observing soils during regular soil survey field operations. Additional information about piezometers can be found in *Installing Monitoring Wells in Soils* (Sprecher, 2008).

Ideally, evaluation within the moist and dry classes should be based on field instrumentation. However, this instrumentation is typically not available and approximations must be made. Gravimetric water content measurements may be used. To make the conversion from measured water content to suction, information is needed on the gravimetric water retention at different suctions. The water retention at 1500 kPa may be estimated from the field clay percentage evaluation if dispersion of clay is relatively complete for the soils concerned. Commonly, the 1500 kPa retention is roughly 0.4 times the clay percentage. This relationship can be refined considerably as the soil material composition and organization are increasingly specified. Another rule of thumb is that the water content at air dryness is about 10 percent of the clay percentage, assuming complete dispersion of clay. Model-based curves that relate gravimetric water content and suction are available for many soils (Baumer, 1986). These curves may be used to determine upper water retention and the midpoint water retention and to place the soil material in a water state class based on gravimetric water contents. Furthermore, in many cases they can be used as the basis for estimating water retention at 10 kPa from measurements at 33 kPa. Figure 3-30 shows a model-based curve for a medium textured horizon and the relationship of water state class limits to water contents determined from the desorption curve. The figure includes the results of a set of tests designed to provide local criteria for field and field office evaluation of water state. These tests are discussed later in this chapter.

Commonly, information on gravimetric water content is not available. Visual and tactile observations must suffice for the placement. Separation between moist and wet and the distinction between the two subclasses of wet may be made visually, based on water-film expression and presence of free water. Similarly, the separation between very dry and moderately dry can be made by visual or tactile comparison of the soil material at the field water content and after air drying. The change on air drying should be very small if the soil material initially is in the very dry class.

Criteria are more difficult to formulate for soil material that is between the moist-wet and the moderately dry-very dry separations. Four tests useful for mineral soils are the color value, ball, rod, and ribbon tests. The three tests that involve tactile examination are performed on soil

Figure 3-30



Model-based curve for a medium textured horizon and the relationship of water state class limits to water contents determined from the desorption curve.

material that has been manipulated and mixed. This manipulation and mixing must be thorough enough to break down aggregates and provide consistent, repeatable results. The change may be particularly large for dense soil. In the field, this limitation should be kept in mind.

Color value test.—The crushed color value of the soil for an unspecified water state is compared to the color value when the soil is at air dryness and when it is moderately moist or very moist. This test generally is useful only if the full range of color value from air dry to moderately moist exceeds one unit of color value. The change in color value and its interpretation depend upon the water desorption characteristics of the soil material. For example, as the water retention at 1500 kPa increases, the difference between the minimum color value in the dry state and the color value in the very moist state tends to decrease.

Ball test.—A quantity of soil is squeezed firmly in the palm of the hand to form a ball about 3 to 4 cm in diameter. This is done in about five squeezes. The sphere should be near the maximum density that can be obtained by squeezing. Different people will prepare the ball differently; however, an individual should learn to perform the procedure consistently.

In one approach, the ball is dropped from progressively increasing heights onto a nonresilient surface. The height in centimeters at which rupture occurs is recorded. Typically heights above 100 cm are not measured. Additionally, the manner of rupture is recorded. If the ball flattens and does not rupture, the term “deforms” is used. If the ball breaks into about five or fewer units, the term “pieces” is used. Finally, if the ball breaks into five or more units, the term “crumbles” is used.

Another approach uses penetration resistance. A penetrometer is inserted in the ball the same way it is done for soil in place. This alternative is only applicable for medium and fine textured soil materials at higher water contents because these materials are relatively plastic and not subject to cracking.

Rod test.—The soil material is rolled between the thumb and forefinger or on a surface to form a rod 3 mm or less in diameter. A rod 2 cm or more in length must be able to remain intact while being held vertically from one end. If the maximum length that can be formed is 2 to 5 cm, the rod is weak. If the maximum length equals or exceeds 5 cm, the rod is strong.

The rod test has close similarities to the plastic limit test (ASTM, 2011). Plastic limit values exceed the 1500 kPa retention at moderate clay contents and approach, but are not commonly lower than, the 1500 kPa retention at high clay contents. If a strong rod can be formed, the water content typically exceeds the 1500 kPa retention. The same is generally true for a weak rod. An adjustment is necessary if 2 to 0.5 mm material is present because the plastic limit is measured on material that passes a number 40 sieve (0.43 mm in diameter).

Ribbon test.—The soil material is smeared out between thumb and forefinger to form a flattened body about 2 mm thick. A ribbon must be at least 2 cm in length. If the maximum length possible is 2 to 4 cm, the ribbon is weak. If the maximum length possible is 4 cm or more, the ribbon is strong.

General relationships of the tests to water state, with the exception of the relationship of the rod test to 1500 kPa retention, have not been formulated. Locally applicable field criteria can be formulated using groupings of soils based on composition.

Natural Drainage Classes

Natural drainage class refers to the frequency and duration of wet periods under conditions similar to those under which the soil developed. Alteration of the water regime by humans, either through drainage or irrigation, is not a consideration unless the alterations have significantly changed the morphology of the soil. Descriptions of these classes follow.

Excessively drained.—Water is removed very rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse textured and have very high saturated hydraulic conductivity or are very shallow.

Somewhat excessively drained.—Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse textured and have high saturated hydraulic conductivity or are very shallow.

Well drained.—Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit root growth for significant periods during most growing seasons. The soils are mainly free of, or are deep or very deep to, redoximorphic features related to wetness.

Moderately well drained.—Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence is commonly moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season but long enough that most mesophytic crops are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 meter, periodically receive high rainfall, or both.

Somewhat poorly drained.—Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. Internal free water occurrence is commonly shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall.

Poorly drained.—Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. Internal free water occurrence is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow depth. Free water at shallow depth is common. The water table is commonly the result of low or very low saturated hydraulic conductivity, nearly continuous rainfall, or a combination of these.

Very poorly drained.—Water is removed from the soil so slowly that free water remains at or very near the surface during much of the growing season. Internal free water occurrence is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. In areas where rainfall is high or nearly continuous, slope gradients may be greater.

Subaqueous.—Free water is above the soil surface. Internal free water occurrence is permanent, and there is a positive water potential at the soil surface for more than 21 hours of each day. The soils have a peraquic soil moisture regime.

Internal Free Water Occurrence

Table 3-20 gives the classes and criteria used to describe free water regimes in soils. The term “free water occurrence” is used instead of “satiated wet” in order to facilitate discussion of interpretations. These

Table 3-20

Classes of Internal Free Water

Classes	Criteria
Thickness if perched	
Extremely thin	< 10 cm
Very thin	10 cm to < 30 cm
Thin	30 cm to < 100 cm
Thick	> 100 cm
Depth	
Very shallow	< 25 cm
Shallow	25 cm to < 50 cm
Moderately deep	50 cm to < 100 cm
Deep	100 cm to < 150 cm
Very deep	> 150 cm
Cumulative annual pattern	
Absent	Not observed
Very transitory	Present < 1 month
Transitory	Present 1 to 3 months
Common	Present 4 to 6 months
Persistent	Present 7 to 12 months
Permanent	Present continuously

classes indicate thickness if water is perched, depth to the upper boundary, and the aggregate time of occurrence in the calendar year. The free water need only occur in some parts of the horizon or layer to be recognized. If not designated as perched, the zone of free water is assumed to occur in all horizons or layers from its upper boundary to below a depth of 2 meters or to the depth of observation. Artesian effects also may be noted.

Water State Annual Pattern

The water state annual pattern is a description of field soil water over the year as applied to horizons and layers or to standard depth zones. Table 3-21 gives an example using the classes of internal water states. Months when the layer is frozen are indicated by the symbol "F." Typically, the use of the soil is indicated and the time interval is at least monthly. More general records may be constructed based on less-specific soil uses and on soil concepts at a higher categorical level. Records may be constructed for classes of relative precipitation: *wet*—the wettest 2 years in 10; *dry*—the driest 2 years in 10; and *average*—the conditions 6 years in 10. Unless otherwise indicated, the class placement for relative precipitation is based on the more critical part of the growing season for the vegetation specified in the use. The frequency and duration of inundation for each month also can be given.

Table 3-21

Example of a Water State Annual Pattern

[Months when the layer is frozen are indicated by an "F." Other symbols are defined in table 3-19.]

Depth cm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average 6 years in 10												
Fine, smectitic, mesic Typic Argiudoll [a]												
0–25	MM	MM	MM	MM	MM	MM	MS	DS	DS	MS	MM	MM
	F	F										F
25–50	MM	MM	MM	MM	MM	MM	MM	MS	MS	MS	MS	MM
	F	F	F									
50–100	MS	MS	MM	MM	MM	MM	MM	MS	MS	MS	MS	MS
100–150	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM
150–200	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM

Table 3-21.—continued												
Depth cm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fine-loamy, mixed, superactive, thermic Typic Haploxeralf [b]												
0–30	MM	MM	MS	MS	DS	DS	D1[c]	D1	D1	D1	D1	MS
30–70	MM	MM	MM	MM	MS	DS	D1	D1	D1	DS	MS	MM
70–100	MV	MV	MM	MM	MM	MM	MS	D1	D1	D1	D1	MS
120–170	MM	MM	MM	MS	MS	MS	MS	D1	D1	D1	DS	MS
Driest 2 years in 10												
Fine, smectitic, mesic Typic Argiudoll [a]												
0–25	MM	MM	MM	MM	MM	MS	DS	DS	DS	MS	MS	MM
	F	F										F
25–50	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
	F	F	F									
50–100	MS	MS	MS	MM	MM	MS	MS	MS	MS	MS	MS	MS
100–150	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM
150–200	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM
Fine-loamy, mixed, superactive, thermic Typic Haploxeralf [b]												
0–30	MS	MM	MS	MS	DS	DS	D1	D1	D1	D1	D1	DS
30–70	MM	MM	MM	MM	MS	DS	D1	D1	D1	D1	MS	MS
70–100	MS	MM	MM	MM	MM	MM	MS	D1	D1	D1	D1	DS
120–170	MS	MM	MS	MS	MS	MS	MS	D1	D1	D1	D1	D1
Wettest 2 years in 10												
Fine, smectitic, mesic Typic Argiudoll [a]												
0–25	MM	MM	MV	MV	MV	MM	MM	MM	MM	MM	MM	MM
	F	F										F
25–50	MM	MM	MV	MV	MM	MM	MM	MM	MM	MM	MM	MM
	F	F	F									
50–100	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM
100–150	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM
150–200	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM	MM
Fine-loamy, mixed, superactive, thermic Typic Haploxeralf [b]												
0-30	MM	MM	MM	MS	DS	DS	D1	D1	D1	DS	MS	MM
30-70	MV	MV	MM	MM	MS	DS	D1	D1	D1	DS	MM	MV
70-100	MV	MV	MM	MM	MM	MM	MS	D1	D1	D1	MS	MM
120-170	MM	MM	MS	MS	MS	MS	MS	D1	D1	D1	DS	MS

[a] Otoe County, Nebraska (USDA-NRCS, 2009). Aksarben silty clay loam, 2 to 6 percent slopes. Corn (*Zea mays*) following corn. Assume: contoured, terraced, over 20 percent residue cover. Disk twice in April. Field cultivate once. Plant May 1–15. Cultivate once or twice. Harvest November 1–15. Cattle graze after harvest. Based on a discussion with H.E. Sautter, soil scientist (retired), Syracuse, NE. Monthly water states based on long-term field mapping experience and water balance computations.

[b] San Diego Area, California (USDA-SCS, 1973). Fallbrook sandy loam, 5 to 9 percent slopes, eroded. Mean annual precipitation at Escondido is 344 mm, and potential evaporation at Thornwaite is 840 mm. Study area has slightly greater slope than the upper limit of the map unit. Vegetation is annual range, fair condition. Generalizations were made originally for the 1983 National Soil Survey Conference based on field measurements in 1966 by Nettleton et al. (1969), as interpreted by R.A. Dierking, soil correlator, Portland, OR. At the time, moderately dry and very dry were not distinguished.

[c] D1 = very dry and moderately dry water states.

Water Movement

Water movement concerns rates of flow into and within the soil and the related amount of water that runs off and does not enter the soil. Saturated hydraulic conductivity, infiltration rate, and surface runoff are part of the evaluation (see chapter 2 for a discussion about runoff).

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. It can be thought of as the ease with which pores of a saturated soil permit water movement. Water movement in soil is controlled by two factors: 1) the resistance of the soil matrix to water flow, and 2) the forces acting on each element or unit of soil water. Darcy's law, the fundamental equation describing water movement in soil, relates the flow rate to these two factors. Mathematically, the general statement of Darcy's law for vertical, saturated flow is:

$$Q/At = -K_{sat}\ dH/dz$$

The flow rate Q/At is what soil physicists call the flux density, i.e., the quantity of water Q moving past an area A, perpendicular to the direction of flow, in a time t. The vertical saturated hydraulic conductivity K_{sat} is the reciprocal, or inverse, of the resistance of the soil matrix to water flow. The hydraulic gradient dH/dz is the driving force causing water to move in soil, the net result of all forces acting on the soil water. Rate of water movement is the product of the hydraulic conductivity and the hydraulic gradient.

A distinction is made between saturated and unsaturated hydraulic conductivity. Saturated flow occurs when the soil water pressure is positive, i.e., when the soil matric potential is zero (satiated wet condition). In most soils this condition occurs when about 95 percent of the total pore space is filled with water. The remaining 5 percent is filled with entrapped air. If the soil remains saturated for several months or longer, the percent of the total pore space filled with water may approach 100. Saturated hydraulic conductivity cannot be used to describe water movement under unsaturated conditions.

The vertical saturated hydraulic conductivity K_{sat} is the proportionality constant relating soil water flow rate (flux density) to the hydraulic gradient and is a measure of the ease of water movement in soil. K_{sat} is the reciprocal of the resistance of soil to water movement. As resistance increases, hydraulic conductivity decreases. Resistance to water movement in saturated soil is primarily a function of the arrangement and size distribution of pores. Large, continuous pores have a lower resistance to flow (and thus higher conductivity) than small or discontinuous pores. Soils with high clay content generally have lower hydraulic conductivities than sandy soils because the pore size distribution in sandy soil favors large pores, even though sandy soils typically have higher bulk densities and lower total porosities (total pore space) than clayey soils. As illustrated by Poiseuille's law, the resistance to flow in a tube varies as the square of the radius. Thus, as a soil pore or channel doubles in size, its resistance to flow is reduced by a factor of 4, i.e., hydraulic conductivity increases fourfold.

Saturated hydraulic conductivity can be expressed by different forms of mathematical equations. When the flux and gradient are expressed on a mass basis, the resulting dimensions for K_{sat} are (mass x time)/volume and the SI units (International System of Units) are kg s m^{-3} (kilogram seconds per cubic meter). When they are expressed on a volume basis, the dimensions are (volume x time)/mass and the SI units are m^3 s kg^{-1} (cubic meter seconds per kilogram). If one expresses the flux on a volume basis and the gradient on a weight basis, then the dimensions of K_{sat} are length/time and the SI units are m s^{-1} (meters per second). This last mathematical form has the simplest units, but it only applies under unique conditions in the field. Care must be taken to interpret this correctly and not conclude that hydraulic conductivity is literally the rate of water movement through the soil. Saturated hydraulic conductivity is not a rate of water movement; it is a measure of a saturated soil's ability to transmit water under a hydraulic gradient. Or, in general terms, it is the ease with which pores of a saturated soil permit water to move. Low values indicate restricted movement, and higher values indicate relative ease of movement.

Data on saturated hydraulic conductivity are valuable in overall planning for irrigation, drainage, erosion control, and flood control. K_{sat} can be used to predict flow rate under specified hydraulic gradients and boundary conditions. It is an important component in solute transfer and drainage models. Surface ponding and runoff are regulated to a great extent by saturated hydraulic conductivity. K_{sat} can also be used for estimating transport coefficients of nonaqueous fluids (e.g., air and organic liquids). In addition, because saturated hydraulic conductivity is a powerful indicator of pore geometry, it can be used as an index for soil structure.

Saturated hydraulic conductivity is one of the most variable soil properties. This variability is determined by total porosity, pore-size distribution, and tortuosity of flow paths, all of which are highly affected by land use and management. Different crop management systems on the same soil type may cause 100-fold differences in K_{sat} of surface horizons.

Coefficients of variability in excess of 100 percent for saturated hydraulic conductivity are common. Measured K_{sat} values may vary dramatically with the method used for measurement. Laboratory-determined values rarely agree with field measurements; the differences can be on the order of 100-fold or more. Field methods generally are considered more reliable than laboratory methods, but this may be an illusion due to differences in sample volumes and method. The volume of the sample being tested relates to the possibility of a sample including unusually large pores due to animal burrows, root channels, desiccation cracks, etc. For smaller volumes, this has the character of a "hit or miss" proposition, and the result can be high variability within relatively small areas. For larger sampling volumes, the chance of observing similar K_{sat} values from multiple readings within a study area is higher and the variability among samples is lower. The smallest volume in which the lowest variability can be attained is called the "representative elementary volume" (REV) (Bear, 1972). The REV for K_{sat} measurements is currently unknown. It likely varies by soil type. Because the field is the best setting for approximating a representative elementary volume, field measurements are emphasized.

Because of the highly variable nature of soil hydraulic conductivity, a single measured value is an unreliable indicator of the hydraulic conductivity of a soil. An average of several values provides a reliable estimate, which can be used to place the soil in a particular saturated hydraulic conductivity class. Log averages (geometric means)[5] should be

[5] $meanKs = (Ks_1 x Ks_2 x Ks_3 x ... x Ks_x)^{1/x}$

used rather than arithmetic averages because hydraulic conductivity is a property with log-normal distribution. The antilog of the average of the logarithms of individual conductivity values is the log average, or geometric mean, and should be used to place a soil into the appropriate hydraulic conductivity class. Log averages are lower than arithmetic averages.

Classes of saturated hydraulic conductivity.—In this manual, saturated hydraulic conductivity classes are defined in terms of vertical, saturated hydraulic conductivity. Table 3-22 identifies the vertical, saturated hydraulic conductivity classes used in the National Cooperative Soil Survey. The saturated hydraulic conductivity classes in this manual have a wider range of values than the classes that were previously used by the NCSS, as published in the previous edition of the *Soil Survey Manual* (Soil Survey Staff, 1951) and the *Guide for Interpreting Engineering Uses of Soils* (USDA-SCS, 1971). The dimensions of hydraulic conductivity vary depending on whether the hydraulic gradient and flux density have mass, weight, or volume bases. Values can be converted from one basis to another with the appropriate conversion factor. Typically, the hydraulic gradient is given on a weight basis, the flux density is given on a volume basis, and the dimensions of K_{sat} are length per time. The correct SI units are therefore meters per second.[6] Micrometers per second are also acceptable SI units and, due to fewer decimal places, are more convenient (table 3-22). Table 3-23 gives the equivalent class limits in other commonly used units. Converting to equivalent units is useful when presenting the data to members of the public who may not be familiar with SI units.

Table 3-22

Classes of Saturated Hydraulic Conductivity

Class	K_{sat} (µm/s)
Very high	≥ 100
High	10 to < 100
Moderately high	1 to < 10
Moderately low	0.1 to < 1
Low	0.01 to < 0.1
Very low	< 0.01

[6] The Soil Science Society of America prefers that all quantities be expressed on a mass basis. This results in K_{sat} units of kg s m^{-3}. Other acceptable units are m^3 s kg^{-1}, where all quantities are expressed on a volume basis, and m s^{-1}, where hydraulic gradient is expressed on a weight basis and flux density on a volume basis.

Saturated hydraulic conductivity does not describe the capacity of soils in their natural setting to dispose of water internally. A soil placed in a very high class may contain free water because there are restricting layers below the soil or because the soil is in a depression where water from surrounding areas accumulates faster than it can pass through the soil. The water may actually move very slowly despite a high K_{sat}.

Table 3-23

Saturated Hydraulic Conductivity Class Limits in Equivalent Units

µm/s	m/s	cm/day	in/hr	cm/hr	kg s m^{-3}	m^3 s kg^{-3}
100	10^{-4}	864	14.17	36.0	1.02×10^{-2}	1.02×10^{-8}
10	10^{-5}	86.4	1.417	3.60	1.02×10^{-3}	1.02×10^{-9}
1	10^{-6}	8.64	0.1417	0.360	1.02×10^{-4}	1.02×10^{-10}
0.1	10^{-7}	0.864	0.01417	0.0360	1.02×10^{-5}	1.02×10^{-11}
0.01	10^{-8}	0.0864	0.001417	0.00360	1.02×10^{-6}	1.02×10^{-12}

Guidelines for K_{sat} class placement.—Measured values of K_{sat} are available from the literature or from researchers working on the same or similar soils. If measured values are available, their geometric means should be used for class placement.

Saturated hydraulic conductivity is a fairly easy, inexpensive, and straightforward measurement. If measured values are unavailable, a project to make measurements should be considered. Field methods are the most reliable. Standard methods for measurement of K_{sat} are described in Agronomy Monograph No. 9 (Klute and Dirksen, 1986; Amoozegar and Warrick, 1986) and in SSIR 38 (Bouma et al., 1982).

Researchers have attempted to estimate K_{sat} based on various soil properties. These estimation methods typically use one or more of the following soil physical properties: surface area, texture, structure, bulk density, and micromorphology. The success of the individual methods varies, and no single method works well for all soils. In some cases, a method works well only in a localized area. In other cases, measurement of the predictor variables is more difficult than measurement of hydraulic conductivity. Generally, adjustments must be made for soil properties that affect the integrity and continuity of macropores when the soil is moderately moist or wet. These properties include high sodium concentrations; certain clay mineralogies; grade, size, and shape of soil structure; and the presence of coarse fragments, fragipans, cemented layers, and other miscellaneous features.

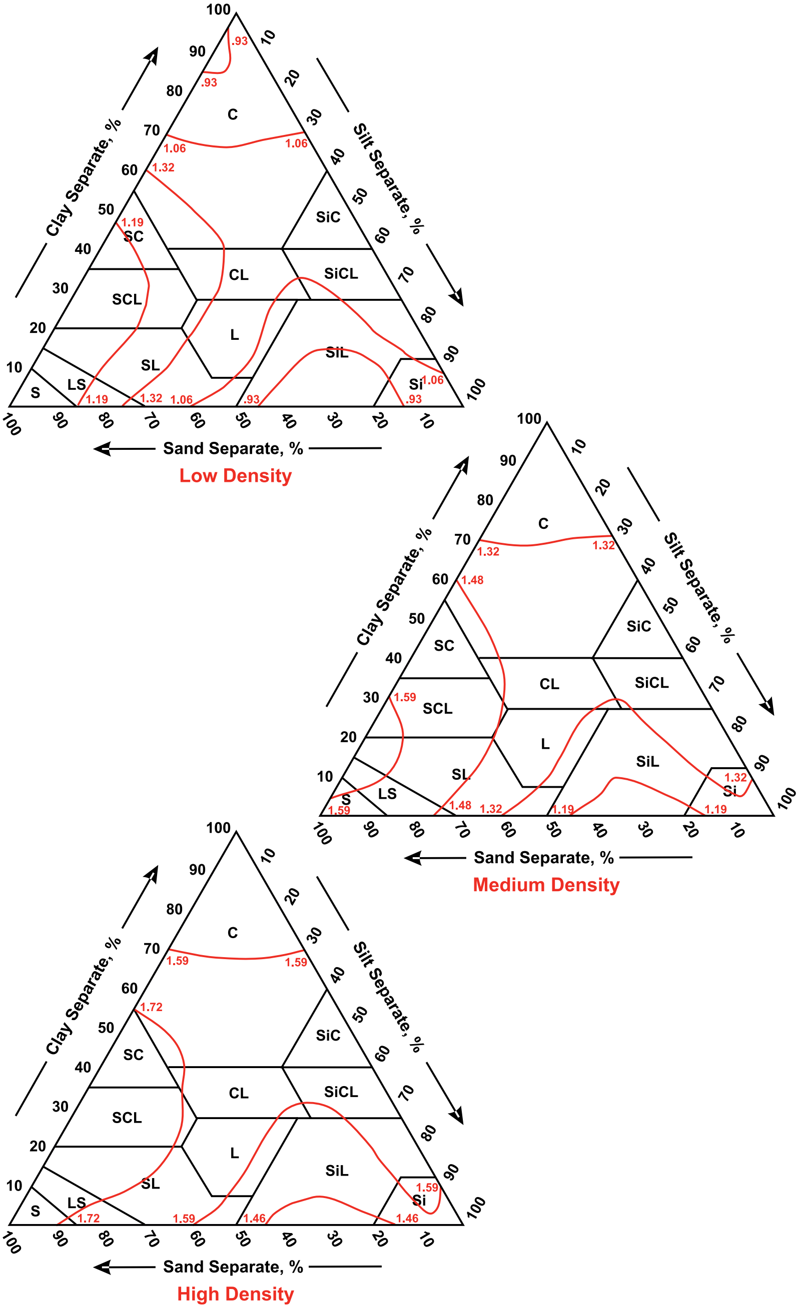
The method presented here is very general (Rawls and Brakensiek, 1983). It was developed from a statistical analysis of several thousand measurements on a variety of soils. It is intended for a wide application and must be used locally with caution. This method does not account for the circumstances mentioned in the previous paragraph. Commonly, the results must be adjusted based on experience and local conditions.

Figures 3-31 and 3-32 used together provide a method for approximating K_{sat} class based on soil texture and bulk density. Each figure consists of three textural triangles. Based on the texture and bulk density of a particular soil horizon, the bulk density class is estimated by determining which triangle in figure 3-31 the horizon belongs to. The chosen bulk density class determines which triangle in figure 3-32 is used to estimate K_{sat} class.

For a particular soil texture with either measured or estimated bulk density, interpolating between the iso-bulk density lines in figure 3-31 yields a bulk density class. The triangle in the figure that provides the value closest to the measured or estimated bulk density for that particular textural class determines which triangle in figure 3-32 should be used. For example, in figure 3-31, a clay loam with both 35 percent sand and clay and a bulk density of 1.20 g/cc plots between the iso-bulk density lines of 1.06 and 1.32 of the textural triangle marked "low" and thus is in the low bulk density class. A clay loam with both 35 percent sand and clay and a bulk density of 1.40 g/cc plots between the iso-bulk density lines of 1.32 and 1.48 on the textural triangle marked "medium" and thus has a medium bulk density class. For soils having medium or average bulk densities, the center triangle is used. The triangles above and below the center triangle are for soils with high and low bulk densities, respectively. The textural triangle in figure 3-32 that corresponds with the bulk density class determined from figure 3-31 is selected, and the clay and sand percentages are plotted to determine K_{sat} class placement. The K_{sat} class is "moderately high" for the clay loam in the low bulk density class and "moderately low" for the clay loam in the medium bulk density class. A numerical value of K_{sat} can be estimated by interpolating between the iso-K_{sat} lines. However, the values should be used with caution. They should be used only to compare classes of soils and not as an indication of the K_{sat} of a particular site. If site values are needed, it is best to make several measurements at the site.

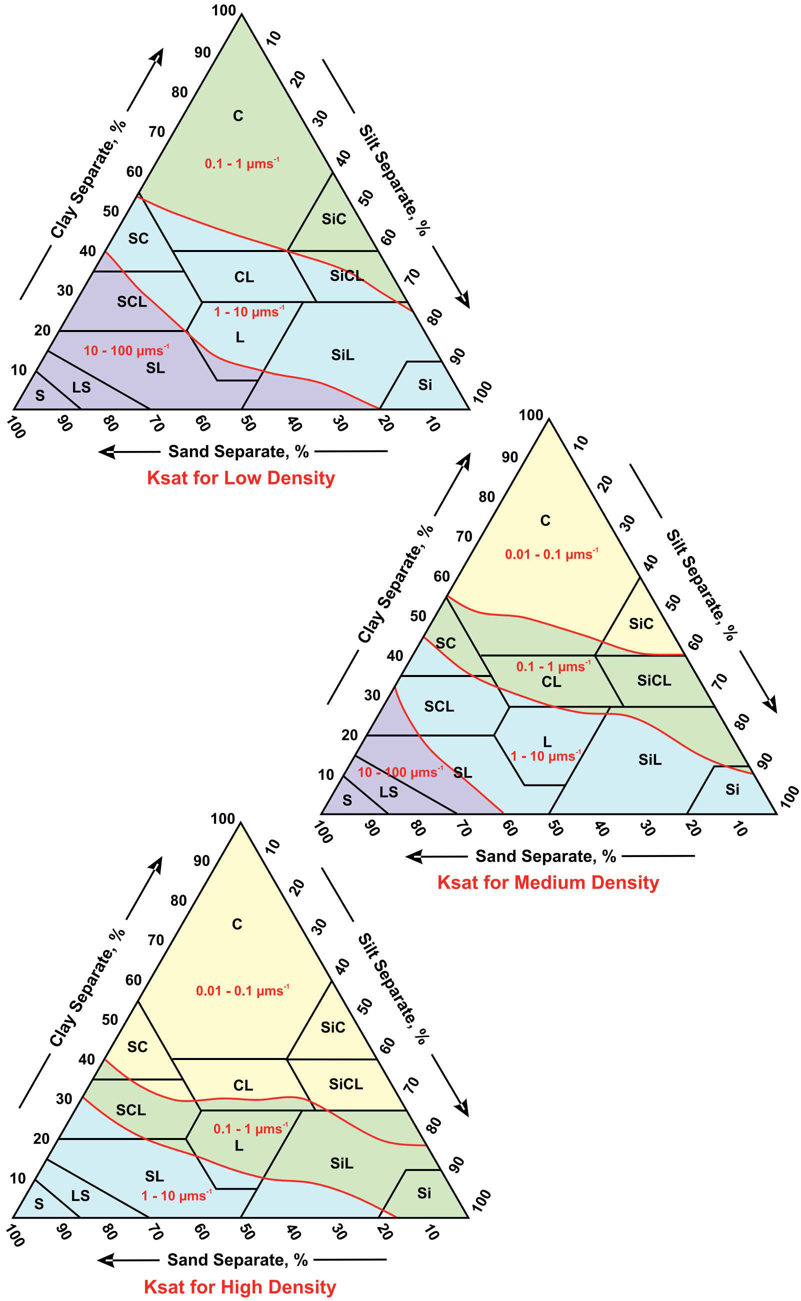
The K_{sat} values determined using the above procedure may need to be adjusted based on other known soil properties. Currently, there are no guidelines for adjusting the estimated K_{sat}. The soil scientist must use best judgment based on experience and the observed behavior of the particular soil.

Figure 3-31



Bulk density classes: low, medium, and high (Rawls and Brakensiek, 1983).

Figure 3-32



Saturated hydraulic conductivity classes based on bulk density and texture relationships.

Saturated hydraulic conductivity can be given for the soil as a whole, for a particular horizon, or for a combination of horizons. The horizon with the lowest value determines the saturated hydraulic conductivity class assigned to the whole soil. If an appreciable thickness of soil above or below the horizon with the lowest value has significantly higher conductivity, then estimates for both parts are typically given (i.e., high over very low).

Infiltration

Infiltration is the process of downward water entry into the soil. It is typically sensitive to near surface conditions as well as to the antecedent water state. Hence, it is subject to significant change with soil use and management and over time. As a result, assigning infiltration values to soil map units for most soil survey projects (unless they are large scale, high-intensity surveys) is generally not practical. The following discussion describing infiltration is provided for background information. Infiltration rate classes are not provided. Field measured values can be recorded as part of the site description for pedons.

Infiltration stages.—Three stages of infiltration may be recognized: preponded (before ponding occurs), transient ponded (ponding is transient), and steady ponded (a constant ponded condition). *Preponded infiltration* pertains to downward entry of water into the soil under conditions where free water is not present on the land surface. At this stage, the rate of water addition determines the rate of water entry. If rainfall intensity increases twofold, then the infiltration increases twofold. In addition, surface-connected macropores are not involved in transporting water downward (water is only moving through the matrix). No runoff occurs during the preponded stage.

As water addition continues, the point may be reached where free water occurs on the ground surface. This condition is called ponding. The term in this context is less restrictive than its use in inundation. The free water may be restricted to depressions and be absent from the majority of the ground surface. Once ponding has taken place, the infiltration is controlled by soil characteristics rather than by the rate of water addition. As a result, surface-connected macropores and subsurface-initiated cracks are involved in transporting water downward.

Infiltration under conditions where free water is present on the ground surface is referred to as ponded infiltration. In the initial stage of ponded infiltration, the rate of water entry typically decreases appreciably with time because of the deeper wetting of the soil, which results in a reduced suction gradient and the closing of cracks and other surface-connected macropores. *Transient ponded infiltration* is the stage at which the ponded infiltration decreases markedly with time. After long, continued wetting under ponded conditions, the rate of infiltration becomes steady. This stage is referred to as *steady ponded infiltration*. Surface-connected cracks, if reversible, close. The suction gradient is small, and the driving force is reduced to near that of the gravitational gradient. If there is no ice and no zones of free water within moderate depths and if surface or near surface features (e.g., a crust) do not control infiltration, the minimum saturated hydraulic conductivity within a depth of ½ to 1 meter is a useful predictor of steady ponded infiltration rate.

Minimum annual steady ponded infiltration.—The steady ponded infiltration rate when the soil is in the wettest state that regularly occurs while not frozen is called the *minimum annual steady ponded infiltration rate*. It can be estimated using the equation for the Green-Ampt infiltration model (see below). The estimated rate is subject to reduction if free water is present at shallow depths. The minimum annual steady ponded infiltration rate has application for prediction of runoff at the wettest times of the year when the runoff potential is typically highest.

Green-Ampt infiltration model.—The Green-Ampt model is one model used to compute infiltration rate. The model assumes that infiltrating water uniformly wets to a depth and stops abruptly at a front. This front moves downward as infiltration proceeds. The soil above the wetting front is in the satiated wet condition throughout the wetted zone.

The equation (Rawls and Brackensick, 1983) describing infiltration is:

$$f = Ka\left(1 + \frac{MxS}{F}\right)$$

Ka is the hydraulic conductivity for satiated, but not necessarily saturated, conditions; *M* is the porosity at a particular water state that has the potential to be filled with water; *S* is the effective suction at the wetting front; and *F* is the cumulative infiltration. The hydraulic conductivity at satiation is somewhat lower than the saturated value because of the presence of entrapped air. The available porosity (M) changes for surficial horizons according to bulk density and for all horizons according to the water state. It is, therefore, sensitive to soil use that may affect both bulk density of surficial horizons and the antecedent water state. The value of the effective suction at the wetting front (S) is determined largely by texture and is a tabulated quantity. The cumulative infiltration (F) increases with time as infiltration proceeds. A consequence of the increase in the cumulative infiltration is that the infiltration rate (f) decreases with time. As the cumulative infiltration becomes large and the depth of wetting considerable, the infiltration rate approaches the value of the hydraulic conductivity for the satiated condition.

Soil Temperature

Soil temperature, like soil moisture, is an important component of the overall soil climate. It exerts a strong influence on biological activities. It also influences the rates of chemical and physical processes within the soil. As a result, the chemical properties of the soil, including organic matter content, mineralogy, and fertility levels, are significantly impacted by soil temperature. When the soil is frozen, biological activities and chemical processes essentially stop. Physical processes that are associated with ice formation are active if unfrozen zones are associated with freezing zones. Below a soil temperature of about 5 °C (referred to as "biologic zero" in *Soil Taxonomy*), growth of roots of most plants is negligible. However, in areas where soils have permanently frozen layers near the surface, even large roots of adapted plants are present immediately above the frozen layer in late summer. Most plants grow best within a restricted range of soil and air temperatures. Knowledge of soil and air temperatures is essential in understanding soil-plant relationships. Temperature, like the soil water state, changes with time. It generally differs from layer to layer at any given time.

Characteristics of Soil Temperature

Heat is both absorbed at and lost from the surface of the soil. Temperature at the surface can change in daily cycles. The soil transmits heat downward when the temperature near the surface is higher than the temperature below. It transmits heat upward when the temperature is warmer within the soil than at the surface. Soil temperatures at various depths within the soil follow cycles. The cycles deeper in the soil lag behind those near the surface. The daily cycles decrease in amplitude as depth increases and are scarcely measurable below 50 cm in most soils. Seasonal cycles are evident to much greater depths if seasonal air temperature differences are pronounced. The temperature at a depth of 10 m is nearly constant in most soils and is about the same as the mean annual temperature of the soil above.

Soil temperature varies at a given site from layer to layer according to the time of the year; yet, if the average annual temperatures at different depths in the same pedon are compared, they typically do not differ. Mean annual soil temperature is one of several useful values that describe the temperature regime of a soil.

The seasonal fluctuation of soil temperature is a characteristic of a soil. Soil temperature fluctuates little seasonally near the equator; it fluctuates widely according to season in the middle and high latitudes. Mean seasonal temperatures can be used to characterize soil temperature. As soil depth increases, the magnitude of the differences in seasonal soil temperature decreases and the seasonal cycles exhibit a delay compared to temperatures at shallower depths.

For soils that freeze in winter, soil temperature is influenced by the release of heat when water changes from liquid to solid. This release is about 80 calories per gram of water. Heat must be dissipated before the water in soil freezes. The rate of thaw of frozen soils is slower, because heat is required to warm the soil in order to melt the ice. In areas of heavy snowfall, the snow provides an insulating blanket and soils do not freeze as deeply or do not freeze at all.

Many factors influence soil temperature. They include amount, intensity, and distribution of precipitation; daily and monthly fluctuations in air temperature; insolation; kinds, amounts, and persistence of vegetation; duration of moisture states and snow cover; kinds of organic deposits; surface soil color; aspect and gradient of slope; elevation; and ground water. All of these factors may be described in a soil survey.

Estimating Soil Temperature

Soil temperature can be monitored over time through the use of automated digital temperature recorders. The recorders are commonly buried in water-tight containers in the soil. They automatically record and store temperature readings at preprogrammed intervals throughout the day (five readings per day is sufficient). Sensors at the ends of wire leads extending from the buried container are commonly placed about 1 meter above the ground (for air temperature) and at a depth of 50 cm in the soil. Additional sensors can be placed at other depths if desired. At the end of the study period (generally 1 year), the recording device is retrieved and the data are downloaded to a computer for analysis. From these data one can calculate mean annual soil temperature as well as mean annual summer and winter temperatures. The relationship between average soil temperature and average air temperature can also be determined for the site. Plots of diurnal, seasonal, and annual temperature variation can be prepared to illustrate the variation of soil temperature through time.

Estimates of soil temperature can be made without 1 or more complete years of collected data. Mean annual soil temperature in temperate, humid, continental climates can be approximated by adding 1 °C to the mean annual air temperature reported by standard meteorological stations at locations near the soil under study. The mean annual soil temperature at a given place can be estimated more reliably by a single reading at a depth of 10 m. If water in wells is at depths between 10 and 20 m, the temperature of the water typically gives a close estimate of mean annual soil temperature. Mean annual soil temperature can also be estimated from the average of four readings at about 50 cm or greater depth, equally spaced throughout the year.

The mean soil temperature for summer can be estimated by averaging three measurements taken at a constant depth between 50 cm and 1 m on the 15th day of each of the three months of the season. Similar methods may be used to estimate soil temperature for other seasons. These methods give values slightly different from the actual soil temperature, due to factors such as vegetation (particularly density of canopy), ground water, snow, aspect, rain, unusual weather conditions, and other factors. Tests for nearly level, freely drained soils, both grass-covered and cultivated, produce comparable values. Over the usual period of a soil survey, systematic studies can be made to establish temperature relationships in the survey area.

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