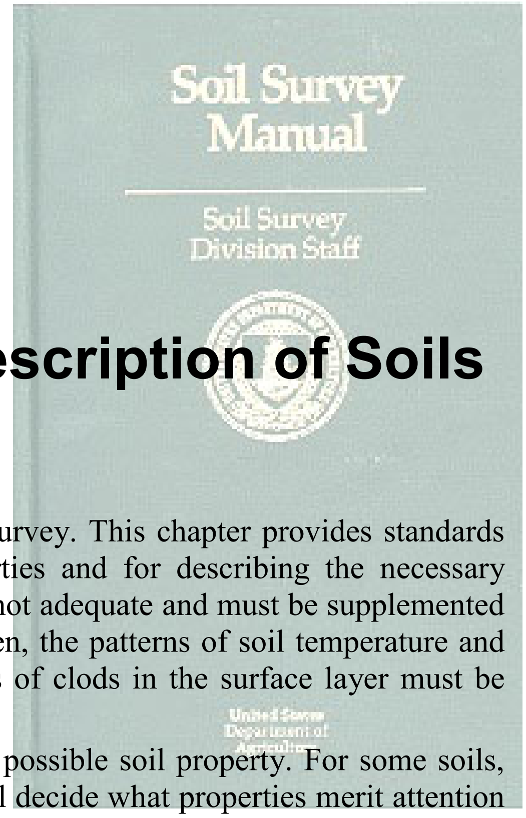
CHAPTER

3 Examination and Description of Soils



A description of the soils is essential in any soil survey. This chapter provides standards and guidelines for describing most soil properties and for describing the necessary related facts. For some soils, standard terms are not adequate and must be supplemented by a narrative. 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 must be observed over time and summarized.

This chapter does not include a discussion of every possible soil property. For some soils, other properties need to be described. Good judgment will decide what properties merit attention in detail 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 it easier to code data for automatic processing. If forms are used, they must include space for all possible information. Formats for recording and retrieving information about pedons will be discussed in more detail in chapter 5.

Each investigation of the internal properties of a soil is made on a soil body of some dimensions. The body may be larger than a pedon or represent a portion of a pedon. During field operations, many soils are investigated by examining the soil material removed by a sampling tube or an 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. They can be studied more rapidly than entire pedons; consequently, a much larger number can be studied in many more places. For many soils, the information obtained from such a small sample describes the pedon from which it is taken with few omissions. For other soils, however, important properties of a pedon are not observable in the smaller sample, and detailed studies of entire pedons may be 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.

Some General Terms Used in Describing Soils

Several of the general terms for internal elements of the soil are described here; other more specific terms are described or defined in the following sections.

A soil profile is exposed by a vertical cut through the soil. It is commonly conceived as a plane at right angles to the surface. In practice, a description of a soil profile includes soil properties that can be determined only by inspecting volumes of soil. A description of a pedon is commonly based on examination of a profile, and the properties of the pedon are projected from the properties of the profile. The width of a profile ranges from a few decimeters to several meters or more. It should be sufficient to include the largest structural units.

A soil horizon is a layer, approximately parallel to the surface of the soil, distinguishable from adjacent layers by a distinctive set of properties produced by the soil-forming processes. The term layer, rather than horizon, is used if all of the properties are believed to be inherited from the parent material or no judgment is made as to whether the layer is genetic.

The solum (plural, sola) of a soil consists of a set of horizons that are related through the same cycle of pedogenic processes. In terms of soil horizons described in this chapter, a solum consists of A, E, and B horizons and their transitional horizons and some O horizons. Included are horizons with an accumulation of carbonates or more soluble salts if they are either within, or contiguous, to other genetic horizons and are judged to be at least partly produced in the same period of soil formation. The solum of a soil presently at the surface, for example, includes all horizons now forming. It includes a bisequum (to be discussed). It does not include a buried soil or a 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 a 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 alluvium or recently exposed soft sediment does not have a solum.[1]

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The lower limit, in a general sense, in many soils should be related to the depth of rooting to be expected for perennial plants assuming that water state and chemistry are not limiting. In some soils the lower limit of the solum can be set only arbitrarily and needs to be 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. To conceive of hardened carbonate accumulations extending for 5 meters or more below the B horizon as part of the solum is more difficult. 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. Much the same kind of problem exists in some deeply weathered soils in which the

[1] As much as 50 cm of recently deposited sediment is disregarded in classifying the underlying set of genetic horizons (Soil Taxonomy). These thin deposits are not part of the solum bat may be otherwise important. By the same convention, a soil is not considered to be buried (*Soil Taxonomy*) unless there is at least 50 cm of overlying sediment that has no genetic horizons in the lower part.

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. Roots of plants, for example, may derive much of their moisture from fractured bedrock close to the surface. Descriptions should indicate the nature of the soil-rock contact and as much as can be determined about the upper part of the underlying rock.

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

Most soils have a single sequum, but some have two or more. A Spodosol, for example, can form in the upper part of an 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. Here, too, the soils are 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. Nevertheless, the distinction is useful when it can be made. Where some of the C material of the upper sequum remains, the distinction is clear.

Studying Pedons

Pedons representative of an extensive mappable area are generally more useful than pedons that represent the border of an area or a small inclusion.

For a soil description to be of greatest value, the part of the landscape that the pedon represents and the vegetation should be described. This is referred to as the setting. The level of detail will depend on the objectives. A complete setting description should include information about the encompassing polypedon and, possibly, the polypedons conterminous with the encompassing polypedon (Soil Survey Staff, 1975). Furthermore, the setting may include information about the portion of the polypedon that differs from the central concept of the polypedon.

The description of a body of soil in the field, whether an entire pedon or a sample within it, should record the kinds of layers, their depth and thickness, and the properties of each layer. Generally, external features are observed throughout the extent of the polypedon; internal features are observed from the study of a pedon or that part of a pedon that is judged to be representative of the polypedon (see appendix).

A pedon for detailed study of a soil is tentatively selected and then examined preliminarily to verify that it represents the desired segment of its range.

A pit exposing a vertical face approximately 1 meter across to an appropriate depth is satisfactory for most soils. [2]

After the sides of the pit are cleaned of all loose material disturbed by digging, the exposed vertical faces are examined, usually 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 (ch. 5) after the layers have been identified but before the vertical section is disturbed in the description-writing process. A point-count for estimation of the volume of stones or other features also is done before the layers are disturbed.

A horizontal view of each layer is useful. This exposes structural units that otherwise may not be observable. 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 often seen more clearly in a horizontal section.

Excavations associated with roads, railways, gravel pits, and other soil disturbances provide easy access for studying soils; old exposures, however, must be used cautiously. The soils dry out or freeze and thaw from both the surface and the sides. Frequently, the soil structure in such excavations is more pronounced than is typical; salts may accumulate near the edges of exposures or be removed by seepage; and other changes may have taken place.

Depth to and Thickness of Horizons and Layers

Depth is measured from the soil surface. The soil surface is the top of the mineral soil; or, for soils with an 0 horizon, the soil surface is the top of the part of the 0 horizon that is at least slightly decomposed. Fresh leaf or needle fall that has not undergone observable decomposition is excluded from soil and may be described separately. The top of any surface horizon identified as an O horizon, whether Oi, Oe, or Oa, is considered the soil surface.

For soils with a cover of 80 percent or more rock fragments on the surface, the depth is measured from the surface of the rock fragments.

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 and is followed by the values that represent the depths from the soil surface to the upper and lower boundaries, in that order. 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. The 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 usual terms for description of topography of the boundary are inadequate. These variations are described separately. For example, "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 horizon or layer and the upper boundary of the horizon or layer below share a common irregularity.

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[2] For soils having cyclic horizons or layers recurring at intervals between 2 m and 7 m, a pit large enough to study at least one half of the cycle is necessary.

The thickness of each horizon or layer is the vertical distance between the upper and lower boundaries. Thickness may vary within a pedon, and this variation should be shown in the description. A range in thickness may be given. It cannot be calculated from the range of upper and lower boundaries but rather must be evaluated across the exposure at different lateral points. The location of upper and lower boundaries are commonly in different places. The upper boundary of a horizon, for example, 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, a wrong conclusion could be that the horizon ranges in thickness from as little as 5 cm to as much as 50 cm.

Land Surface Configuration

Land surface configuration considered here is geometrical and includes soil slope and land surface shape. Landform from a morphogenetic aspect is not considered. It may be applicable to a pedon or to a larger area.

Land surface configuration and relief are quite different as used here, although the meanings may be similar in other contexts. Relief, in this context, refers to the elevation or differences in elevation above mean sea level, considered collectively, of a land surface on a broad scale. Elevation can be determined from topographic maps or by using a calibrated altimeter.

Soil Slope

Slope has a scale connotation. It refers to the ground surface configuration for scales that exceed about 10 meters and range upward to the landscape as a whole. Slope has gradient, complexity, length, and aspect. The scale of reference commonly exceeds that of the pedon and should be indicated. The scale may embrace a map unit delineation, component of it, or an arbitrary area.

Slope gradient is the inclination of the surface of the soil from the horizontal. It is generally measured with a hand level. The difference in elevation between two points is expressed as a percentage of the distance between those points. If the difference in elevation is 1 meter over a horizontal distance of 100 meters, slope gradient is 1 percent. A slope of 45° is a slope of 100 percent, because the difference in elevation between two points 100 meters apart horizontally is 100 meters on a 45° slope.

Overland flow gradient is the slope of the soil surface in the direction of flow of surface water if it were present. The following examples show equivalences between percentage gradient and degree of slope angle:

Percentage	Angle	Angle	Percentage
0	0°00′	0°	0
5	2°52′	2°	3.5
10	5°43′	4°	7.0
15	8°32′	6°	10.5
20	11°19′	8°	14.0
25	14°02′	10°	17.6
30	16°42′	12°	21.2
35	19°17′	15°	26.8
40	21°48′	20°	36.4

Percentage	Angle	Angle	Percentage
50	26°34′	25°	46.6
60	30°58′	30°	57.7
70	34°59′	35°	70.0
80	38°39′	40°	83.9
90	41°59′	45°	100.0
100	45°00′	50°	119.2

Slope Complexity refers to surface form on the scale of a mapping unit delineation. In many places internal soil properties are more closely related to the slope complexity than to the gradient. Slope complexity has an important influence on the amount and rate of runoff and on sedimentation associated with runoff.

A guide to terminology for various slope classes defined in terms of gradient and complexity is given in table 3-1. The terms are used in discussing soil slope, and they can also be used in naming slope phases, as discussed in the next chapter.

Table 3-1. Definitions of slope classes

Classes Simple slopes	Complex slopes	Slope gradient limits	
		Lower Percent	Upper Percent
Nearly level	Nearly level	0	3
Gently sloping	Undulating	1	8
Strongly sloping	Rolling	4	16
Moderately steep	Hilly	10	30
Steep	Steep	20	60
Very steep	Very steep	>45	

Terms are provided for both simple and for complex slopes in some classes. Complex slopes are groups of slopes that have definite breaks in several different directions and in most cases markedly different slope gradients within the areas delineated.

Significance of slope gradient is tied to other soil properties and to the purposes of soil surveys. Conventions are, therefore, provided in table 3-1 to adjust the slope limits of the various classes. Gently sloping or undulating soils, for example, can be defined to range as broadly as 1 to 8 percent or as narrowly as 3 to 5 percent. Classes may exceed the broadest range indicated in table 3-1 by a percentage point or two where the range is narrow and by as much as 5 percent or more where the range is broad.

If the detail of mapping requires slope classes that are more detailed than those in table 3-1, some of the classes can be divided as follows:

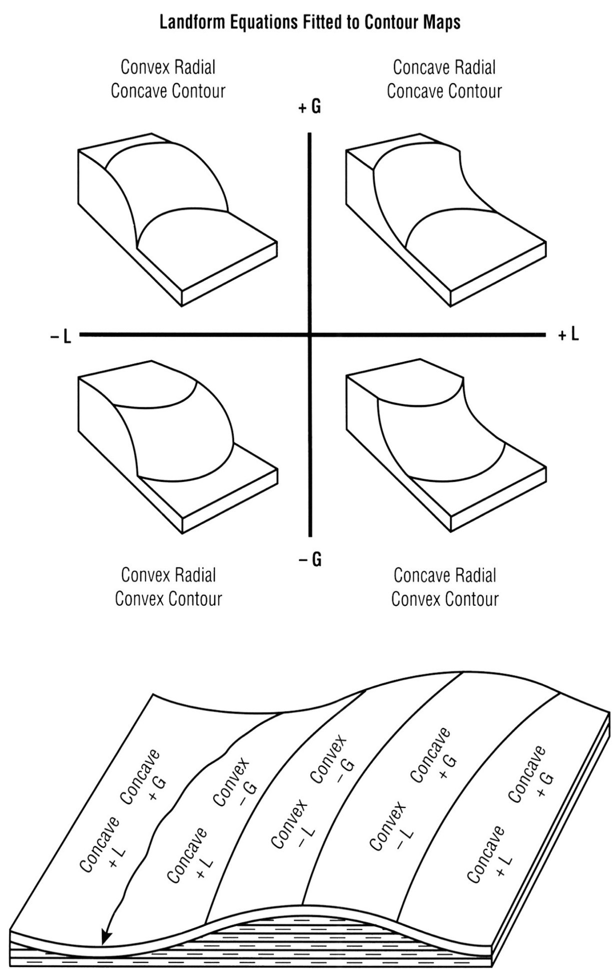
Nearly level:	Level, Nearly level
Gently sloping:	Very gently sloping, Gently sloping
Strongly sloping:	Sloping, Strongly sloping, Moderately sloping
Undulating:	Gently undulating, Undulating
Rolling:	Rolling, Strongly rolling

In a highly detailed survey, for example, slope classes of 0 to 1 percent and 1 to 3 percent would be named "level" and "nearly level."

Slope length has considerable control over runoff and potential accelerated water erosion. Terms such as "long" or "short" can be used to describe slope lengths that are typical of certain kinds of soils. These terms are usually relative within a physiographic region. A "long" slope in one place might be "short" in another. If such terms are used, they are defined locally. For observations at a particular point, it may be useful to record the length of the slope that contributes water to the point in addition to the total length of the slope. The former is called point runoff slope length. The sediment transport slope length is the distance from the expected or observed initiation upslope of runoff to the highest local elevation where deposition of sediment would be expected to occur. This distance need not be the same as the point runoff slope length.

Slope aspect is the direction toward which the surface of the soil faces. The direction is expressed as an angle between 0 degree and 360 degrees (measured clockwise from true north) or as a compass point such as east or north-northwest. Slope aspect may affect soil temperature, evapotranspiration, and winds received.

FIGURE 3-1



Illustrations of four combinations of concavity and complexity.

Land Surface Shape

Land surface shape has two components (fig. 3-1). One component is in a direction roughly parallel to the contours of the landform (or the contour lines on a map) as seen from directly overhead. The other component of shape is a direction perpendicular to the contours; that is, the shape of the slope as seen from the side. The shape parallel to the contours is less commonly consistent for a soil than is the shape perpendicular to the contours.

The shape parallel to the contours (across the slope) can be described by the shape of the contours. The shape is linear if contours are substantially a straight line, as on the side of a lateral moraine. An alluvial fan has a convex contour, as does a spur of the upland projecting into a valley. A cove on a hillside or a cirque in glaciated landscapes has concave contours. In figure 3-1, the two upper blocks have concave contours and the two lower blocks have convex contours. Where the contour is convex, runoff water tends to spread laterally as it moves down the slope. Where the contour is concave, runoff water tends to be concentrated toward the middle of the landform.

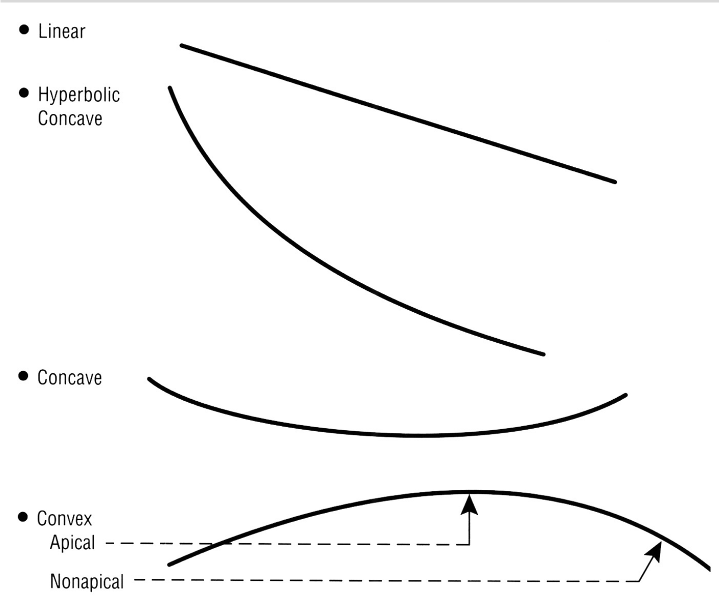
The shape of the surface at right angles to the contours (up and down the slope) may also be described as linear, convex, or concave. Shape in this direction is usually identified simply as slope shape in contrast to slope contour in the other dimension. The surface of a linear slope is substantially a straight line when seen in profile at right angles to the contours. The gradient neither increases nor decreases significantly with distance. An example is the dip slope of a cuesta. On a concave slope (fig. 3-1, right), gradient decreases down the slope as on foot slopes. Runoff water tends to decelerate as it moves down the slope, and if it is loaded with sediment, the water tends to deposit the sediment on the lower parts of the slope. The soil on the lower part of the slope also tends to dispose of water less rapidly than the soil above it. On a convex slope (fig. 3-1, left), such as the shoulder or a ridge, gradient increases down the slope and runoff tends to accelerate as it flows down the slope. Soil on the lower part of the slope tends to dispose of water by runoff more rapidly than the soil above it. The soil on the lower part of a convex slope is subject to greater erosion than that on the higher part.

The configuration of the surface of a soil may be described in terms of both the shape of the contour and the shape of the slope. For example, a surface can be described as having a convex contour and a convex slope (an alluvial fan) or a linear contour and concave slope (the base of a moraine).

Description of an areal shape from the shape of two intersecting lines at right angles is applicable to all scales and does not require a contour map. The lines commonly would be parallel to and at right angles to the contour. Four line shapes are illustrated in figure 3-2: linear, hyperbolic concave (declining slope gradient along the line), concave, and convex. Convex site may be usefully separated into apical (summit) and nonapical (shoulder) positions.

<u>Microrelief</u> refers to differences in ground-surface height, measured over distances of meters. Naturally formed features contrast with those

FIGURE 3-2



Four shapes of lines for description of land surface shapes.

FIGURE 3-3

Characteristic microrelief of the gilgai type (Texas).

that are tillage-determined. In areas of similar relief, the surface may be nearly uniform, or it may be interrupted by mounds, swales, or pits. Examples include the microrelief created when trees are blown over, referred to as cradle-knoll microrelief. This consists of the knoll left by the earth that clung to the roots of the tree when it was uprooted and the depression from which it came. Coppice dunes form where windblown soil material accumulates around widely spaced plants in arid regions. Gilgai produced by expansion and contraction of soils is a form of microrelief (fig. 3-3). Mima mounds and biscuit-scabland are other examples of microrelief, although individual mounds may cover 100 square meters or more. Descriptions should indicate whether mounds or depressions are closed, form a network, or are in a linear pattern. If mounds rest on a smooth surface, their size and spacing should be described. At a specific site within an area having microrelief, it is important to note whether a described pedon is at a high point, on a slope, in a depression, or at some combination of these places. Internal soil properties in mounds may be different from the properties in depressions.

Roughness refers to a ground surface configuration with a repeat distance between prominences of less than 50 cm and for areas less than about 10 m across. This scale applies to most tillage operations and affects aspects of land surface water flow such as detention, infiltration, runoff, and erosion. Roughness, as used here, pertains to the ground surface and includes rock fragments on the surface. It does not include vegetation. If vegetation is included, the fact should be indicated. Roughness along a line, referred to as one-dimensional roughness, can be measured more easily than can roughness for an area. Area measurements, however, permit the separation of random and tillage-determined roughness. The orientation to which the observation of one-dimensional roughness pertains must be specified relative to the direction of surface runoff or of air movement. Position within the tillage-determined relief, if present, should be indicated for one-dimensional roughness. An example of such a position would be the nontraffic interrow in a tilled field. The standard deviation of the ground surface height is the primary descriptor. There are a number of approaches to the measurement of roughness, and those who are in agronomic disciplines should be consulted. The measurements depend on the variation in height from a leveled reference. Photographs may be used to illustrate the classes; placement in classes may be made directly from the photographs.

Vegetation

Correlations between vegetation and soils are made for three main purposes: (1) understanding soil genesis, (2) recognizing soil boundaries, and (3) making predictions from soil maps about the kind and amount of vegetation produced.

The principal kinds of plants present are listed in order of their abundance. In annual cropland, the plant or plants that have been grown should be recorded, including significant weeds. In forested areas, separate treatment is often necessary for forest trees, understory of small trees and shrubs, and the ground cover. Many soils in range have an overstory of shrubs or low trees. These are listed separately from the grasses, forbs, and other ground cover. An idea of the density of stand or plant cover, such as average canopy cover of trees or shrubs, should be given. The range in size of dominant species of trees can be given as "diameter breast height," if desired. Estimated percentage of the ground covered by grasses and forbs should be included.

Common names of the plants may be used, if such names are clear and specific. In areas where the plants are important for the use and interpretation of the soil map, the soil survey record should include both common and scientific names of plants.

If possible, the kinds and amounts of plants in the potential natural vegetation on a soil should be estimated. This vegetation is closely related to the soil and its genesis. Generally, a close relationship exists between native vegetation and kinds of soil, yet there are important exceptions. Observations of the growth of native vegetation and cultivated crops aid in recognizing soil boundaries and provide direct information about the behavior of specific plants on different kinds of soil. Within fields of a single crop, differences of vigor, stand, or color of the crop or of weeds commonly mark soil differences and are valuable clues to the location of soil boundaries.

By studying many sites of the same kind of soil under different land-use history, the potential plant community and principles of plant succession for that kind of soil can be ascertained, particularly if range and forestry specialists provide assistance. Farmers learn which crops do well and which do poorly on different kinds of soil and adjust their cropping patterns accordingly. If the differences are large—as between crop failure and reasonable performance—the near absence of a given crop on a specific kind of soil questions the suitability of that kind of soil for the crop. If the differences are small, many nonsoil factors can determine the farmer's choice of fields for a given crop. Yield information for cultivated crops, range, and trees should be associated with pedon descriptions insofar as possible.

Ground Surface Cover

The ground surface of most soils is covered to some extent at least part of the year by vegetation. Furthermore, in many soils rock fragments form part of the mineral material at the soil surface. Together, the vegetal material that is not part of the surface horizon and the rock fragments form the ground surface cover. The proportion of cover, together with its characteristics, is very important in determining thermal properties and resistance to erosion.

At one extreme, estimation of cover can be made visually without quantitative measurement. At the other extreme, transect techniques can be used to make a rather complete modal analyses of the ground surface. More effort is justified on ground surface documentation if it is relatively permanent. In many instances, a combination of rapid visual estimates and transect techniques is appropriate.

The ground surface may be divided into fine earth and material other than fine earth. The latter consists of rock fragments and both alive and dead vegetation. Vegetation is separated into canopy and noncanopy. A canopy component has a relatively large cross sectional area capable of intercepting rainfall compared to the area near enough to the ground surface to affect overland water flow. In practice, the separation of canopy from noncanopy should be coordinated with the protocols for computation of susceptibility to erosion. Noncanopy material is commonly referred to as mulch. It includes rock fragments and vegetation.

The first step in evaluation is to decide upon the ground surface cover components. The number is usually one to three. A common three-component land surface consists of trees, bushes, and areas between the two. The areal proportion of each component must be established. This may be done by transect. If a canopy component is present, the area within the drip line as a percent of the ground surface is determined. For each canopy component, the effectiveness must be established. Effectiveness is the percent of vertical raindrops that would be intercepted. Usually the canopy effectiveness is estimated visually, but a spherical densitometer may be used. In addition to the canopy effectiveness, the mulch (rock fragments plus vegetation) must be established for each component.

Transect techniques may be employed to determine the mulch percentage. The mulch can be subdivided into rock fragments and vegetation. From the areal proportions of the components and their respective canopy efficiencies and mulch percentages, the soil-loss ratio may be computed for the whole land surface (Wischmeier, 1978). In addition to the observations for the computation of the soil-loss ratio, information may be obtained about the percent of kinds of plants, size of rock fragments, amount of green leaf area, and aspects of color of the immediate surface that would affect absorption of radiant energy in an area.

Parent Material

Parent material refers to unconsolidated organic and mineral materials in which soils form. The parent material of a genetic horizon cannot be observed in its original state; it must be inferred from the properties that the horizon has inherited and from other evidence. In some soils, the parent material has changed little, and what it was like can be deduced with confidence. In others, such as some very old soils of the tropics, the specific kind of parent material or its mode or origin is speculative.

Much of the mineral matter in which soils form is derived in one way or another from hard rocks. Glaciers may grind the rock into fragments and earthy material and deposit the mixture of particles as glacial till. On the other hand, rock may be weathered with great chemical and physical changes but not moved from its place of origin; this altered material is called "residuum from rock."

In some cases, little is gained from attempting to differentiate between geologic weathering and soil formation because both are weathering processes. It may be possible to infer that a material was weathered before soil formation. The weathering process causes some process constituents to be lost, some to be transformed, and others to be concentrated.

Parent material may not necessarily be residuum from the bedrock that is directly below, and the material that developed into a modern soil may be unrelated to the underlying bedrock. Movement of soil material downslope is an important process and can be appreciable even on gentle slopes, especially on very old landscapes. Also, locally associated soils may form in sedimentary rock layers that are different.

Seldom is there certainty that a highly weathered material weathered in place. The term "residuum" is used when the properties of the soil indicate that it has been derived from rock like that which underlies it and when evidence is lacking that it has been modified by movement. A rock fragment distribution that decreases in amount with depth, especially over saprolite, indicates that soil material probably has been transported downslope. Stone lines, especially if the stones have a different lithology than the underlying bedrock, provide evidence that the soil did not form entirely in residuum. In some soils, transported material overlies residuum and illuvial organic matter and clay are superimposed across the discontinuity between the contrasting materials. A certain degree of landscape stability is inferred for residual soils. A lesser degree is inferred for soils that developed in transported material.

Both consolidated and unconsolidated material beneath the solum that influence the genesis and behavior of the soil are described in standard terms. Besides the observations themselves, the scientist records his judgment about the origin of the parent material from which the solum developed. The observations must be separated clearly from inferences.

The lithologic composition, structure and consistence of the material directly beneath the solum are important. Evidence of stratification of the material—textural differences, stone lines, and the like—need to be noted. Commonly, the upper layers of outwash deposits settled out of more slowly moving water and are finer in texture than the lower layers. Windblown material and volcanic ash are laid down at different rates in blankets of varying thickness. Examples of such complications are nearly endless.

Where alluvium, loess, or ash are rapidly deposited on old soils, buried soils may be well preserved. Elsewhere the accumulation is so slow that the solum thickens only gradually. In such places, the material beneath the solum was once near the surface but may now be buried below the zone of active change.

Where hard rocks or other strongly contrasting materials lie near enough to the surface to affect the behavior of the soil, their depths need to be measured accurately. The depth of soil over such nonconforming materials is an important criterion for distinguishing different kinds of soil.

Geological materials need to be defined in accordance with the accepted standards and nomenclature of geology. The accepted, authoritative names of the geological formations are recorded in soil descriptions where these can be identified with reasonable accuracy. As soil research progresses, an increasing number of correlations are being found between particular geological formations and the mineral and nutrient content of parent materials and soils. For example, certain terrace materials and deposits of volcanic ash that are different in age or source, but otherwise indistinguishable, vary widely in the content of cobalt. Wide variations in the phosphorus content of two otherwise similar soils may reflect differences in the phosphorus content of two similar limestones that can be distinguished in the field only by specific fossils.

Igneous rocks formed by the solidification of molten materials that originated within the earth. Examples of igneous rocks that weather to important soil material are granite, syenite, basalt, andesite, diabase, and rhyolite.

Sedimentary rocks formed from sediments laid down in previous geological ages. The principal broad groups of sedimentary rocks are limestone, sandstone, shale, and conglomerate. There are many varieties of these broad classes of sedimentary rocks; for example, chalk and marl are soft varieties of limestone. Many types are intermediate between the broad groups, such as calcareous sandstone and arenaceous limestone. Also included are deposits of diatomaceous earth, which formed, from the siliceous remains of primitive plants called diatoms.

Metamorphic rocks resulted from profound alteration of igneous and sedimentary rocks by heat and pressure. General classes of metamorphic rocks important as parent material are gneiss, schist, slate, marble, quartzite, and phyllite.

The principal broad subdivisions of parent material are discussed in the following paragraphs.

Material Produced by Weathering of Rock in Place

The nature of the original rock affects the kinds of material produced by weathering. The rock may have undergone various changes, including changes in volume and loss of minerals—plagioclase feldspar and other minerals. Rock may lose mineral material without any change in volume or in the original rock structure, and saprolite is formed. Essentially, saprolite is a parent material. The point where rock weathering ends and soil formation begins is not always clear. The processes may be consecutive and even overlapping. Quite different soils may form from similar or even identical rocks under different weathering conditions. Texture, color, consistence, and other characteristics of the material should be included in the description of soils, as well as important features such as quartz dikes. Useful information about the mineralogical composition, consistence, and structure of the parent rock itself should be added to help in understanding the changes from parent rock to weathered material.

Transported Material

The most extensive group of parent materials is the group that has been moved from the place of origin and deposited elsewhere. The principal groups of transported materials are usually named according to the main agent responsible for their transport and deposition. In most places, sufficient evidence is available to make a clear determination; elsewhere, the precise origin is uncertain.

In soil morphology and classification, it is exceedingly important that the characteristics of the material itself be observed and described. It is not enough simply to identify the parent material. Any doubt of the correctness of the identification should be mentioned. For example, it is often impossible to be sure whether certain silty deposits are alluvium, loess, or residuum. Certain mud flows are indistinguishable from glacial till. Some sandy glacial till is nearly identical to sandy outwash. Fortunately, hard-to-make distinctions are not always of significance for soil behavior predictions.

Material moved and deposited by water

Alluvium.—Alluvium consists of sediment deposited by running water. It may occur on terraces well above present streams or in the normally flooded bottom land of existing streams. Remnants of very old stream terraces may be found in dissected country far from any present stream. Along many old established streams lie a whole series of alluvial deposits in terraces—young deposits in the immediate flood plain, up step by step to the very old deposits on the highest terraces. In some places recent alluvium covers older terraces.

Lacustrine deposits.—These deposits consist of material that has settled out of bodies of still water. Deposits laid down in fresh-water lakes associated directly with glaciers are commonly included as are other lake deposits, including some of Pleistocene age that are not associated with the continental glaciers. Some lake basins in the Western United States are commonly called playas; the soils in these basins may be more or less salty, depending on climate and drainage.

Marine sediments.—These sediments settled out of the sea and commonly were reworked by currents and tides. Later they were exposed either naturally or following the construction of dikes and drainage canals. They vary widely in composition. Some resemble lacustrine deposits.

Beach deposits.—Beach deposits mark the present or former shorelines of the sea or lakes. These deposits are low ridges of sorted material and are commonly sandy, gravelly, cobbly, or stony. Deposits on the beaches of former glacial lakes are usually included with glacial drift.

Material moved and deposited by wind

Windblown material can be divided into groups based on particle size or on origin. Volcanic ash and cinders are examples of materials classed by both particle size and origin. Other windblown material that is mainly silty is called loess, and that which is primarily sand is called eolian sand. Eolian sand is commonly but not always in dunes. Nearly all textures intermediate between silty loess and sandy dune material can be found.

Volcanic ash, pumice, and cinders are sometimes regarded as unconsolidated igneous rock, but they have been moved from their place of origin. Most have been reworked by wind and, in places, by water. Ash is volcanic ejecta smaller than 2 mm. Ash smaller than 0.05 mm may be called "fine ash." Pumice and cinders are volcanic ejecta 2 mm or larger.

Loess deposits typically are very silty but may contain significant amounts of clay and very fine sand. Most loess deposits are pale brown to brown, although gray and red colors are common. The thick deposits are generally massive and have some gross vertical cracking. The walls of road cuts in thick loess stand nearly vertical for years. Other silty deposits that formed in other ways have some or all of these characteristics. Some windblown silt has been leached and strongly weathered so that it is acid and rich in clay. On the other hand, some young deposits of windblown material (loess) are mainly silt and very fine sand and are low in clay.

Sand dunes, particularly in warm, humid regions, characteristically consist of fine or medium sand that is high in quartz and low in clay-forming materials. Sand dunes may contain large amounts of calcium carbonate or gypsum, especially in deserts and semideserts.

During periods of drought and in deserts, local wind movements may mix and pile up soil material of different textures or even material that is very rich in clay. Piles of such material have been called "soil dunes" or "clay dunes." Rather than identify local accumulations of mixed material moved by the wind as "loess" or "dunes," however, it is better to refer to them as "wind-deposited material."

Also important but not generally recognized as a distinctive deposit is dust, which is carried for long distances and deposited in small increments on a large part of the world. Dust can circle the earth in the upper atmosphere. Dust particles are mostly clay and very fine silt and may be deposited dry or be in precipitation. The accumulated deposits are large in some places. An immense amount of dust has been distributed widely throughout the ages. The most likely sources at present are the drier regions of the world. Large amounts of dust may have been distributed worldwide during and immediately following the glacial periods.

Dust is an important factor affecting soils in some places. It is the apparent source of the unexpected fertility of some old, highly leached soils in the path of wind that blows from extensive deserts some hundreds of kilometers distant. It explains unexpected micronutrient distribution in some places. Besides dust, fixed nitrogen, sulfur, calcium, magnesium, sodium, potassium, and other elements from the atmosphere are deposited on the soil in varying amounts in solution in precipitation.

Material moved and deposited by glacial processes

Several terms are used for material that has been moved and deposited by glacial processes. Glacial drift consists of all of the material picked up, mixed, disintegrated, transported, and deposited by glacial ice or by water from melting glaciers. In many places glacial drift is covered by a mantle of loess. Deep mantles of loess are usually easily recognized, but very thin mantles may be so altered by soil-building forces that they can scarcely be differentiated from the underlying modified drift.

Glacial till.—This is that part of the glacial drift deposited directly by the ice with little or no transportation by water. It is generally an unstratified, heterogeneous mixture of clay, silt, sand, gravel, and sometimes boulders. Some of the mixture settled out as the ice melted with very little washing by water, and some was overridden by the glacier and is compacted and unsorted. Till may be found in ground moraines, terminal moraines, medial moraines, and lateral moraines. In many places it is important to differentiate between the tills of the several glaciations. Commonly, the tills underlie one another and may be separated by other deposits or old, weathered surfaces. Many deposits of glacial till were later eroded by the wave action in glacial lakes. The upper part of such wave-cut till may have a high percentage of rock fragments.

Glacial till ranges widely in texture, chemical composition, and the degree of weathering that followed its deposition. Much till is calcareous, but an important part is noncalcareous because no carbonate rocks contributed to the material or because subsequent leaching and chemical weathering have removed the carbonates.

Glaciofluvial deposits.—These deposits are material produced by glaciers and carried, sorted, and deposited by water that originated mainly from melting glacial ice. Glacial outwash is a broad term for material swept out, sorted, and deposited beyond the glacial ice front by streams of melt water. Commonly, this outwash is in the form of plains, valley trains, or deltas in old glacial lakes. The valley trains of outwash may extend far beyond the farthest advance of the ice. Near moraines, poorly sorted glaciofluvial material may form kames, eskers, and crevasse fills.

Glacial beach deposits.—These consist of rock fragments and sand. They mark the beach lines of former glacial lakes. Depending on the character of the original drift, beach deposits may be sandy, gravelly, cobbly, or stony.

Glaciolacustrine deposits.—These deposits are derived from glaciers but were reworked and laid down in glacial lakes. They range from fine clay to sand. Many of them are stratified or varved. A varve consists of the deposition for a calendar year. The finer portion reflects slower deposition during the cold season and the coarser portion deposition during the warmer season when runoff is greater.

Good examples of all of the glacial materials and forms described in the preceding paragraphs can be found. In many places, however, it is not easy to distinguish definitely among the kinds of drift on the basis of mode of origin and landform. For example, pitted outwash plains can scarcely be distinguished from sandy till in terminal moraines. Distinguishing between wave-cut till and lacustrine material is often difficult. The names themselves connote only a little about the actual characteristics of the parent material.

Material moved and deposited by gravity

Colluvium is poorly sorted debris that has accumulated at the base of slopes, in depressions, or along small streams through gravity, soil creep, and local wash. It consists largely of material that has rolled, slid or fallen down the slope under the influence of gravity. Accumulations of rock fragments are called talus. The rock fragments in colluvium are usually angular, in contrast to the rounded, water-worn cobbles and stones in alluvium and glacial outwash.

Organic Material

Organic material accumulates in wet places where it is deposited more rapidly than it decomposes. These deposits are called peat. This peat in turn may become parent material for soils. The principal general kinds of peat, according to origin are:

Sedimentary peat. the remains mostly of floating aquatic plants, such as algae, and the remains and fecal material of aquatic animals, including coprogenous earth.

Moss peat. the remains of mosses, including Sphagnum.

Herbaceous peat. the remains of sedges, reeds, cattails, and other herbaceous plants.

Woody peat. the remains of trees, shrubs, and other woody plants.

Many deposits of organic material are mixtures of peat. Some organic soils formed in alternating layers of different kinds of peat. In places peat is mixed with deposits of mineral alluvium and/or volcanic ash. Some organic soils contain layers that are largely or entirely mineral material.

In describing organic soils, the material is called peat (fibric) if virtually all of the organic remains are sufficiently fresh and intact to permit identification of plant forms. It is called muck (sapric) if virtually all of the material has undergone sufficient decomposition to limit recognition of the plant parts. It is called mucky peat (hemic) if a significant part of the material can be recognized and a significant part cannot.

Descriptions of organic material should include the origin and the botanical composition of the material to the extent that these can be reasonably inferred.

Contrasting Materials

Changes with depth that are not primarily related to pedogenesis but rather to geological processes are contrasting soil materials if they are sufficient to affect use and management. The term discontinuity is applied to certain kinds of contrasting soil materials.

Unconsolidated contrasting soil material may differ in pore-size distribution, particle-size distribution, mineralogy, bulk density, or other properties. Some of the differences may not be readily observable in the field. Some deposits are clearly stratified, such as some lake sediments and glacial outwash, and the discontinuities may be sharply defined.

Contrasting materials can be confused with the effects of soil formation. Silt content may decrease regularly with depth in soils presumed to have formed in glacial till. The higher silt content in the upper part of these soils can be explained by factors other than soil formation. In some of these soils, small amounts of eolian material may have been deposited on the surface over the centuries and mixed by insects and rodents with the underlying glacial till. In others, the silt distribution reflects water sorting.

Inferences about contrasting properties inherited from differing layers of geologic material may be noted when the soil is described. Generally, each identifiable layer that differs clearly in properties from adjacent layers is recognized as a subhorizon. Whether it is recognized as a discontinuity or not depends on the degree of contrast with overlying and underlying layers and the thickness. For many soils the properties inherited from even sharply contrasting layers are not consistent from place to place and are described in general terms. The C layer of a soil in stratified lake sediments, for example, might be described as follows: "consists of layers of silt and clay, 1 to 20 cm thick; the aggregate thickness of layers of silt and that of the layers of clay are in a ratio of about 4 to 1; material is about 80 percent silt."

Erosion

Erosion is the detachment and movement of soil material. The process may be natural or accelerated by human activity. Depending on the local landscape and weather conditions, erosion may be very slow or very rapid.

Natural erosion has sculptured landforms on the uplands and built landforms on the lowlands. Its rate and distribution in time controls the age of land surfaces and many of the internal properties of soils on the surfaces. The formation of Channel Scablands in the state of Washington is an example of extremely rapid natural, or geologic, erosion. The broad, nearly level interstream divides on the Coastal Plain of the Southeastern United States are examples of areas with very slow or no natural erosion.

Landscapes and their soils are evaluated from the perspective of their natural erosional history. Buried soils, stone lines, deposits of wind-blown material, and other evidence that material has been moved and redeposited is helpful in understanding natural erosion history. Thick weathered zones that developed under earlier climatic conditions may have been exposed to become the material in which new soils formed. In landscapes of the most recently glaciated areas, the consequences of natural erosion, or lack of it, are less obvious than where the surface and the landscape are of an early Pleistocene or even Tertiary age. Even on the landscapes of most recent glaciation, however, postglacial natural erosion may have redistributed soil materials on the local landscape. Natural erosion is an important process that affects soil formation and, like man-induced erosion, may remove all or part of soils formed in the natural landscape.

Accelerated erosion is largely the consequence of human activity. The primary causes are tillage, grazing, and cutting of timber.

The rate of erosion can be increased by activities other than those of humans. Fire that destroys vegetation and triggers erosion has the same effect. The spectacular episodes of erosion, such as the soil blowing on the Great Plains of the Central United States in the 1930s, have not all been due to human habitation. Frequent dust storms were recorded on the Great Plains before the region became a grain-producing area. "Natural" erosion is not easily distinguished from "accelerated" erosion on every soil. A distinction can be made by studying and understanding the sequence of sediments and surfaces on the local landscape, as well as by studying soil properties.

Landslip Erosion

Landslip erosion refers to the mass movement of soil. Slides and flows are two kinds of landslip erosion. In the slide process, shear takes place along one or a limited number of surfaces. Slide movement may be categorized as slightly or highly deformed, depending on the extent of rearrangement from the original organization. In flow movement the soil mass acts as a viscous fluid. Failure is not restricted to a surface or a small set of surfaces. Classes of landslip erosion are not provided. Location of the mass movement relevant to landscape features generally and the size of the mass movement in terms of area parallel to the land surface and the depth may be indicated. Information about the time since the mass movement took place may be very useful.

Water Erosion

Water erosion results from the removal of soil material by flowing water. A part of the process is the detachment of soil material by the impact of raindrops. The soil material is suspended in runoff water and carried away. Four kinds of accelerated water erosion are commonly recognized: sheet, rill, gully, and tunnel (piping).

Sheet erosion is the more or less uniform removal of soil from an area without the development of conspicuous water channels. The channels are tiny or tortuous, exceedingly numerous, and unstable; they enlarge and straighten as the volume of runoff increases. Sheet erosion is less apparent, particularly in its early stages, than other types of erosion. It can be serious on soils that have a slope gradient of only 1 or 2 percent; however, it is generally more serious as slope gradient increases.

Rill erosion is the removal of soil through the cutting of many small, but conspicuous, channels where runoff concentrates. Rill erosion is intermediate between sheet and gully erosion. The channels are shallow enough that they are easily obliterated by tillage; thus, after an eroded field has been cultivated, determining whether the soil losses resulted from sheet or rill erosion is generally impossible.

Gully erosion is the consequence of water that cuts down into the soil along the line of flow. Gullies form in exposed natural drainage-ways, in plow furrows, in animal trails, in vehicle ruts, between rows of crop plants, and below broken man-made terraces. In contrast to rills, they cannot be obliterated by ordinary tillage. Deep gullies cannot be crossed with common types of farm equipment.

Gullies and gully patterns vary widely. V-shaped gullies form in material that is equally or increasingly resistant to erosion with depth (fig. 3-4). U-shaped gullies form in material that is equally or decreasingly resistant to erosion with depth (fig.3-5). As the substratum is washed away, the overlying material loses its support and falls into the gully to be washed away. Most-U-shaped gullies become modified toward a V shape once the channel stabilizes and the banks start to spall and slump.

The maximum depth to which gullies are cut is governed by resistant layers in the soil, by bedrock, or by the local base level. Many gullies develop headward; that is, they extend up the slope as the gully deepens in the lower part.

FIGURE 3-4

V-shaped gullies in a material relatively high in clay.

FIGURE 3-5

U-shaped gullies in a soil underlain by more erodible material.

Tunnel erosion may occur in soils with subsurface horizons or layers that are more subject to entrainment in moving free water than is the surface horizon or layer. The free water enters the soil through ponded infiltration into surface-connected macropores. Desiccation cracks and rodent burrows are examples of macropores that may initiate the process. The soil material entrained in the moving water moves downward within the soil and may move out of the soil completely if there is an outlet. The result is the formation of tunnels (also referred to as pipes) which enlarge and coalesce. The portion of the tunnel near the inlet may enlarge disproportionately to form a funnel-shaped feature often referred to as a "jug." Hence, the term "piping" and "jugging." The phenomenon is favored by the presence of appreciable exchangeable sodium.

Deposition of sediment carried by water is likely anywhere that the velocity of running water is reduced—at the mouth of gullies, at the base of slopes, along stream banks, on alluvial plains, in reservoirs, and at the mouth of streams. Rapidly moving water, when slowed, drops stones, then cobbles, pebbles, sand, and finally silt and clay. Sediment transport slope length has been defined as the distance from the highest point on the slope where runoff may start to where the sediment in the runoff would be deposited.

Wind Erosion [3]

Wind Erosion in regions of low rainfall, can be widespread, especially during periods of drought. Unlike water erosion, wind erosion is generally not related to slope gradient. The hazard of wind erosion is increased by removing or reducing the vegetation.

When winds are strong, coarser particles are rolled or swept along on or near the soil surface, kicking finer particles into the air. The particles are deposited in places sheltered from the wind. When wind erosion is severe, the sand particles may drift back and forth locally with changes in wind direction while the silt and clay are carried away. Small areas from which the surface layer has blown away may be associated with areas of deposition in such an intricate pattern that the two cannot be identified separately on soil maps.

Estimating the Degree of Erosion

The degree to which accelerated erosion has modified the soil may be estimated during soil examinations. The conditions of eroded soil are based on a comparison of the suitability for use and the management needs of the eroded soil with those of the uneroded soil. The eroded soil is identified and classified on the basis of the properties of the soil that remains. An estimate of the soil lost is described. Eroded soils are defined so that the boundaries on the soil maps separate soil areas of unlike use suitabilities and unlike management needs.

The depth to a reference horizon or soil characteristic of the soil under a use that has minimized accelerated erosion are compared to the same properties under uses that have favored accelerated erosion. For example, a soil that supports native grass or large trees with no evidence of cultivation would be the basis for comparison of the same or similar soil that has been cleared

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[3] "Wind Erosion" is sometimes used for the sculpture of rocks by wind-blown particles. The term is used in this manual, in soil science generally, and by many geologists for the detachment, transportation, and deposition of soil particles by wind.

and cultivated for a relatively long time. The depth to reference layers is measured from the top of the mineral soil because organic horizons at the surface of mineral soils are destroyed by cultivation.

The depths to a reference layer must be interpreted in terms of recent soil use or history. Cultivation may cause differences in thickness of layers. The upper parts of many forested soils have roots that make up as much as one-half of the soil volume. When these roots decay, the soil settles. Rock fragment removal can also lower the surface. The thickness of surficial zones that have been bulked by tillage should be adjusted downward to what they would be if water had compacted them.

The thickness of a plowed layer of a specific soil cannot be used as a standard for either losses or additions of material because, as a soil erodes, the plow cuts progressively deeper. Nor can the thickness of the uncultivated and uneroded A horizon be used as a standard for all cultivated soil, unless the A horizon is much thicker than the plow layer. If the horizon immediately below the plowed layer of an uneroded soil is distinctly higher in clay than the A horizon, the plow layer becomes progressively more clayey under continued cultivation as erosion progresses; the texture of the plow layer may then be a criterion of erosion.

Comparisons must be made on comparable slopes. Near the upper limit of the range of slope gradient for a soil, horizons may normally be thinner than near the lower limit of the range for the same soil.

Roadsides, cemeteries, fence rows, and similar uncultivated areas that are a small part of the landscape as a whole or are subject to unusual cultural histories must be used cautiously for setting standards, because the reference standards for surface-layer thickness are generally set too high. In naturally treeless areas or in areas cleared of trees, dust may collect in fence rows, along roadsides, and in other small uncultivated areas that are covered with grass or other stabilizing plants. The dust thus accumulated may cause the surface horizon to become several centimeters thicker in a short time.

For soils having clearly defined horizons, differences due to erosion can be accurately determined by comparison of the undisturbed or uncultivated norms within the limitations discussed. Guides for soils having a thin A horizon and little or no other horizon are more difficult to establish. After the thin surface layer is gone or has been mixed with underlying material, few clues remain for estimating the degree of erosion. The physical conditions of the material in the plowed layer, the appearance and amount of rock fragments on the surface, the number and shape of gullies, and similar evidence are relied on. For many soils having almost no horizon expression, attempting to estimate the degree of erosion serves little useful purpose.

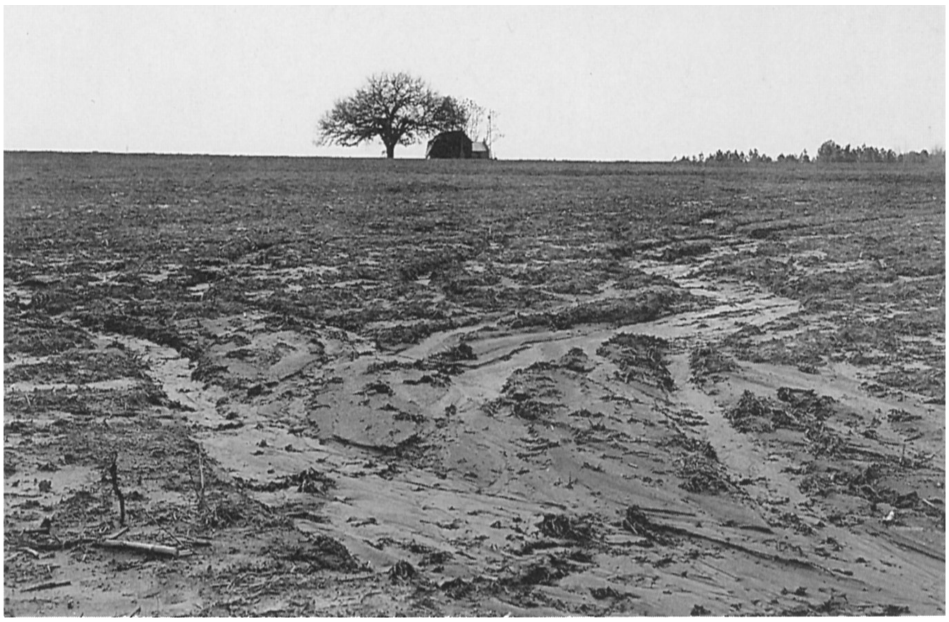
Classes of Accelerated Erosion

The classes of accelerated erosion that follow apply to both water and wind erosion. They are not applicable to landslip or tunnel erosion. The classes pertain to the proportion of upper horizons that have been removed. These horizons may range widely in thickness; therefore, the absolute amount of erosion is not specified.

Class 1. This class consists of soils that have lost some, but on the average less than 25 percent, of the original A and/or E horizons or of the uppermost 20 cm if the original A and/or E horizons were less than 20 cm thick. Throughout most of the area, the thickness of the surface layer is within the normal range of variability of the uneroded soil. Scattered small areas amounting to less than 20 percent of the area may be modified appreciably.

Evidence for class 1 erosion includes (1) a few rills, (2) an accumulation of sediment at the base of slopes or in depressions, (3) scattered small areas where the plow layer contains material from below, and (4) evidence of the formation of widely spaced, deep rills or shallow gullies without consistently measurable reduction in thickness or other change in properties between the rills or gullies. Figure 3-6 is an example of class 1 erosion.

FIGURE 3-6



Sheet erosion. Rills formed as water accumulated in small channels part way down slope. Sediment was deposited at the foot of the slope.

Class 2. This class consists of soils that have lost, on the average, 25 to 75 percent of the original A and/or E horizons or of the uppermost 20 cm if the original A and/or E horizons were less than 20 cm thick. Throughout most cultivated areas of class 2 erosion, the surface layer consists of a mixture of the original A and/or E horizons and material from below. Some areas may have intricate patterns, ranging from uneroded small areas to severely eroded small areas. Where the original A and/or E horizons were very thick, little or no mixing of underlying material may have taken place. Figure 3-7 is an example of class 2 erosion.

FIGURE 3-7

Class 2 erosion. The plowed layer of the light-colored areas is made up mainly of the original surface soil, whereas the plowed layer of the dark-colored areas is a mixture of the original surface soil and an underlying horizon.

Class 3. This class consists of soils that have lost, on the average, 75 percent or more of the original A and/or E horizons or of the uppermost 20 cm if the original A and/or E horizons were less than 20 cm thick. In most areas of class 3 erosion, material below the original A and/or E horizons is exposed at the surface in cultivated areas; the plow layer consists entirely or largely of this material. Even where the original A and/or E horizons were very thick, at least some mixing with underlying material generally took place. Figure 3-8 is an example of class 3 erosion.

FIGURE 3-8

Class 3 erosion. Gullies at the left require a gully symbol. The rills would be obliterated by tillage. Most of the original surface soil between rills has been lost.

Class 4. This class consists of soils that have lost all of the original A and/or E horizons or the uppermost 20 cm if the original A and/or E horizons were less than 20 cm thick. In addition, Class 4 includes some or all of the deeper horizons throughout most of the area. The original soil can be identified only in small areas. Some areas may be smooth, but most have an intricate pattern of gullies. Figure 3-9 is an example of class 4 erosion.

FIGURE 3-9

Class 4 erosion intermingled with class 3 erosion. The areas in the middle and left have lost almost all diagnostic horizons. The areas in the foreground and far background have class 3 erosion.

Soil Water

This section discusses "the water regime"—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 occurrence of free water within the soil and on the land surface. Complexity and detail of water regime statements may range widely.

Inundation Classes

Free water may occur above the soil. Inundation is the condition that 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.

Internal Classes

Definitions.—Table 3-2 contains water state classes for the description of individual layers or horizons. Only matrix suction is considered in definition of the classes.[4] Osmotic potential is not considered. For water contents of medium and fine-textured soil materials at suctions 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. In order to make field and field office evaluation more practicable, water content pertains to gravimetric quantities and not to volumetric. The classes are applicable to organic as well as to mineral soil material. The frozen condition is indicated separately by the symbol "f." The 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.

Table 3-2. 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 or 1/2 kPa[b]
Slightly Moist (MS)	1500 kPa suction to MWR[c]
Moderately Moist (MM)	MWR to UWR[c]
Very Moist (MV)	UWR to 1 or 1/2 kPa[b] suction
Wet (W)	<1 kPa or <1/2 kPa[b]
Nonsatiated (WN)	No free water
Satiated (WA)	Free water present

[a] Criteria use both suction and gravimetric water contents as defined by suction.

[b] 1/2 kPa only if coarse soil material (see text).

[c] UWR is the abbreviation for upper water retention, which is the laboratory water retention at 5 kPa for coarse soil material and 10 kPa for other (see text). MWR is the midpoint water retention. It is halfway between the upper water retention and the retention at 1500 kPa.

[4] The primary unit for suction is the pascal (symbol, Pa). The kilopascal (symbol kPa) is commonly employed. A kilopascal is 1000x a pascal. One bar is 100 kilopascals.

Three classes and eight subclasses are defined. Classes and subclasses may be combined as desired. Symbols for the combinations currently defined are in table 3-2. Specificity desired and characteristics of the water desorption curve would determine whether classes or subclasses would be used. Coarse soil material has little water below the 1500 kPa retention, and so subdivisions of dry generally would be less 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 1/2 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 Laboratory Staff, 1992) determines the *upper water retention*. A suction of 5 kPa is employed for coarse soil material. Otherwise, 10 kPa is used.

> To be considered coarse, the soil material that is strongly influenced by volcanic ejecta must be nonmedial and weakly or nonvesicular. If not strongly influenced by volcanic ejecta, it must meet the sandy or sandy-skeletal family particle size criteria and also be coarser than loamy fine sand, have <2 percent organic carbon, and have <5 percent water at 1500 kPa suction. Furthermore, the computed total porosity of the <2 mm fabric must exceed 35 percent.[5]

Very moist has an upper limit at the moist-wet boundary and a lower limit at the upper water retention. Relatedly, *moderately moist* has an 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. *Slightly moist*, in turn, 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 from the first appearance of free water through saturation. The nonsatiated wet state may be applicable at

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[5] Total porosity = 100 - (100 x Db/Dp), where Db is the bulk density of the < 2mm 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 Laboratory Staff, 1992)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 the material exclusive of the organic matter and the minerals contributing to the extractable Fe (Dp3) to be 2.65 Mg/m^3.

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, because of low matrix saturated hydraulic conductivity and the absence of conducting macroscopic pores, that are *nonsatiated wet*. Free water develops positive pressure with depth below the top of a wet satiated zone.

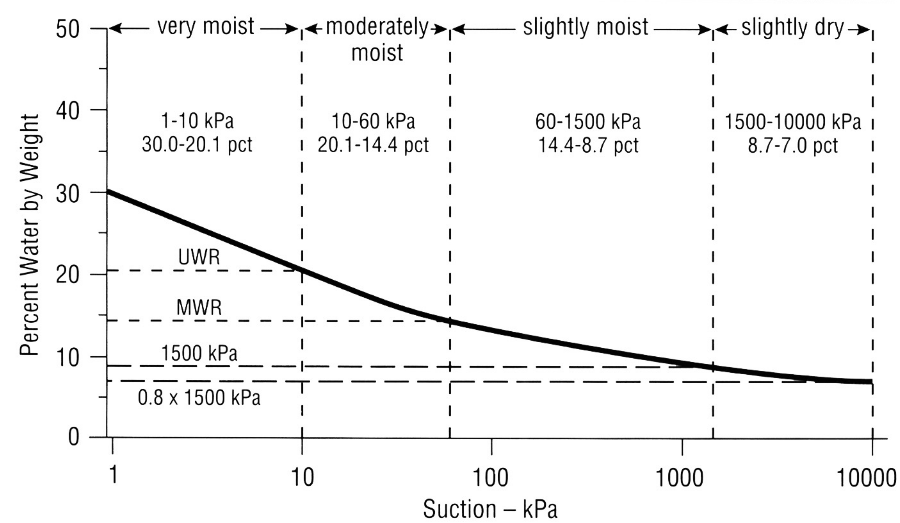
A class for saturation (that is, zero air-filled porosity) is not provided because the term suggests that all of the pore space is filled with water. This condition usually cannot be evaluated in the field. Further, if saturation is used for the concept of satiation, then a term is not available to describe 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 instances and 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. The position of the upper field boundary of the satiated wet class, in a formal sense, is the top of the water in an unlined bore hole after equilibrium has been reached. Determination of the thickness of a perched zone of free water requires the installation of lined bore holes or piezometers to several depths across the zone of free water occurrence. Piezometers are tubes placed to the designated depth that are open at both ends, may have a perforated zone at the bottom, but do not permit water entry along most of their length. In the context here, information about the depth of free water and location and thickness of the free water zone would be obtained in the course of soil examination for a range of purposes and does not necessarily require installation of bore holes.

Ideally, evaluation within the moist and dry classes should be based on field instrumentation. Usually, such instrumentation is not available and approximations must be made. Gravimetric water content measurements may be used. To make the conversion from measured water content to suction it is necessary to have information 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 of concern. 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 is 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. 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. Further such curves would be the basis in many instances for estimation of the water retention at 10 kPa from measurements at 33 kPa. Figure 3-10 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 will be discussed subsequently.

Commonly, gravimetric water content information 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

FIGURE 3-10



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

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 quite 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 follow that may be useful for mineral soils. The three tests that involve tactile examination are performed on soil material that has been manipulated and mixed. This manipulation and mixing may change the tactile qualities from that of weakly altered soil material. 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 at air dryness and while moderately moist or very moist. This test probably has usefulness 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 depends on 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 very moist color value 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. Preparation of the ball will differ among people. The important point is that the procedure is consistent for an individual.

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. Usually 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 less units, the term "pieces" is used. Finally, if the number of units exceeds about five, the term "crumbles" is used.

Alternatively, penetration resistance may be used. The penetrometer is inserted in the ball in the same fashion as would be done for soil in place. This alternative is only applicable for medium and fine- textured soil materials at higher water contents because these soil materials are relatively plastic and not subject to cracking.

Rod test. The soil material is rolled between thumb and first finger or on a surface to form a rod 3 mm in diameter or less. This rod must remain intact while being held vertically from an end for recognition as a rod. Minimum length required is 2 cm. 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, 1984). 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 usually exceeds the 1500 kPa retention. The same is probably true for a weak rod. An adjustment is necessary if material of 2 to 0.5 mm 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 first finger to form a flattened body about 2 mm of thickness. The minimum length of a coherent unit required for recognition of a ribbon is 2 cm. If the maximum length is 2 to 4 cm, the ribbon is weak. If the maximum length equals or exceeds 4 cm, the ribbon is strong.

To establish criteria based on the foregoing tests it is highly desirable to apply the tests first to soil materials that are known to be at water-state class limits. The approach would parallel that used to maintain quality control of field texture evaluation. The first step to obtain such samples is to establish gravimetric water contents for the class limits (table 3-2). Soil material is prepared at these water contents. A known weight of soil material at a measured, initially higher, water content than the desired final content is placed in a commercial, nylon oven-cooking bag. These bags pass from 1 to 10 grams per hour of water at room temperature, depending on the size, the air temperature, humidity, and movement. Water loss from the bag is continued until the predetermined weight (hence, desired water content) is reached. If long-term storage is desired, the soil is next transferred to glass canning jars. The soil material either may be dried from an initially higher field water content after passing through a number 4 sieve (4.8 mm) or may be air-dried, ground, wetted to above the desired final water content, and then dried. It is preferable to pass the soil through a number 4 sieve (4.8 mm) rather than a number 10 (2 mm). The natural organization is retained to a greater extent. As a result, the calibration sample feels more like it would under field conditions. For the higher suctions, consideration should be given to storage of the soil material for a day or two after the water content reduction to improve equilibration.

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 and are probably not feasible. The tests may be applied to groupings of soils based on composition, and then locally applicable field criteria can be formulated. Table 3-3 illustrates much of the range in test results that may be expected within a soil survey in central Nebraska.

Table 3-3. Water state calibration tests on three soil materials differing in texture from central Nebraska.

Soil [a/]	Sand	Silt	Clay	Organic Matter	MWR [b/]	1500 kPa- [b/]	Water Content	Height	Ball Penetration Failure	Resistance	Rod	Ribbon	Color Value
	Pct	Pct	Pct	Pct	Pct	Pct	Pct	cm		MPa	cm	cm	
Hastings	5	57	38	1.4	26.2	18.8	>UWR						3
							MWR	>100	Deform	1.1	7	7	3
							1500 kPa	>100	Deform	Crack	1	3	4
							0.8x1500 kPa	50	Pieces	Crack	No	1/2	4
							Air Dry						5
Lockton	53	33	14	1.6	12.9	7.6	>UWR						2.5
							MWR	60	Pieces		No	3	3
							1500 kPa	30	Pieces		No	2	3.5
							0.8 x 1500 kPa	10	Crumbles		No	No	3.5
							Air Dry						3.5
Valentine	82	13	5	1.1	9.4	3.7	>UWR						3
							MWR	< 2	Pieces		No	No	3.5
							1500 kPa	< 5	Crumbles		No	No	4
							0.8 x 1500 kPa						
							Air Dry						4.5

a/ Hastings is a fine, montmorillonitic, mesic Udic Argiustoll; Lockton is a fine-loamy over sandy or sandy-skeletal, mixed, mesic Cumulic Haplustoll; and Valentine is a mixed, mesic Typic Ustipsamment. The Hastings sample is a silty clay loam; Lockton is a sandy loam; and Valentine is a loamy fine sand. All are from the upper subsoil. Montmorillonite is the dominant clay mineral. Soil materials with certain other clay mineralogies feel drier at 1500 kPa than do these samples.

b/ Both gravimetric. MWR: (10 kPa plus 1500 kPa retention)/2

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 man, either through drainage or irrigation, is not a consideration unless the alterations have significantly changed the morphology of the soil. The classes follow:

Excessively drained. Water is removed very rapidly. The occurrence of internal free water commonly is very rare or very deep. The soils are commonly coarse-textured and have *very high 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 growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness.

Moderately well drained. Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is 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 m, 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. The occurrence of internal free water commonly is 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. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so 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 usually present. This water table is commonly the result of *low* or *very low saturated hydraulic conductivity* of nearly continuous rainfall, or of a combination of these.

Very poorly drained. Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water 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. If rainfall is high or nearly continuous, slope gradients may be greater.

Inundation Occurrence

Table 3-4 contains classes for frequency and for duration of inundation. A record of the month(s) during which the inundation occurs may be useful. Maximum depth of the inundation, as well as the flow velocity, may be helpful.

Table 3-4. Frequency and duration of inundation classes

Class	Criteria
Frequency	
None (N))	No reasonable possibility
Rare (R)	1 to 5 times in 100 years
Occasional (O)	5 to 50 times in 100 years
Frequent (F)	> 50 times in 100 years
Common (C)	Occasional and frequent can be grouped for certain purposes and called common
Duration	
Extremely Brief (BE)	< 4 hours (flooding only)
Very Brief (BV)	4 - 48 hours
Brief (B)	2 - 7 days
Long (L)	7 days to 1 month
Very Long (LV)	> 1 month

Internal Free Water Occurrence

Table 3-5 contains classes for the description of free water regime in soils. The term free water occurrence is used instead of satiated wet in order to facilitate discussion of interpretations. Classes are provided for internal free water occurrence that describe thickness if perched, depth to the upper boundary, and the aggregate time present in the calendar year. The free water need be present only in some parts of the horizon or layer to be recognized. If not designated as perched, it is assumed that the zone of free water occurs in all horizons or layers from its upper boundary to below 2 meters or to the depth of observation. Furthermore, artesian effects may be noted.

Table 3-5. Internal free water occurrence classes

Classes	Criteria
Thickness if perched	
Extremely Thin (TE)	<10 cm
Very Thin (TV)	10 to 30 cm
Thin (T)	30 cm to 1 m
Thick (TK)	>1 m
Depth	
Very Shallow (SV)	<25 cm
Shallow (S)	25 cm to 50 cm
Moderately Deep (DM)	50 cm to 1 m
Deep (D)	1.0 to 1.5 m
Very Deep (DV)	>1.5 m
Cumulative Annual Pattern	
Absent (A)	Not observed
Very Transitory (TV)	Present <1 month
Common (C)	Present 1 to 3 months
Transitory (T)	Present 3 to 6 months
Persistent (PS)	Present 6 to 12 months
Permanent (PM)	Present Continuously

Water-State Annual Pattern

The water-state annual pattern is a description of field soil water over the year as applied to horizons, layers, or to standard depth zones. Using the classes of internal water states and of inundation, table 3-6 contains examples. Usually 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 would be based on the more critical part of the growing season for the vegetation specified in the use. The frequency and duration that the soil is inundated each month may be given.

Table 3-6. Illustrative water state annual pattern. (Symbols are defined in table 3-2.)

						Average - 6 years in 10						
Depth cm	**:Jan**	**:Feb**	**:Mar**	**:Apr**	**:May**	**:Jun**	**:Jul**	**:Aug**	**:Sep**	**:Oct**	**:Nov**	**:Dec**
						Fine, montmorillonitic, 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
						Fine-loamy, mixed, 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

[a] Otoe County, Nebraska (Sautter, 1982). Sharpsburg silty clay loam, 2-5 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, Nebraska. Monthly water states based on long-term field mapping experience and water balance computations. The Sharpsburg soil series pertains to the map unit illustrative of a consociation (appendix).

[b] San Diego Area, California (Bowman, 1973). Mean annual precipitation at Escondido is 344 mm and at Thornwaite potential evaporation is 840 mm. Study area in Fallbrook sandy loam, 5 to 9 percent slopes, eroded. The 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 (1968), as interpreted by R.A. Dierking, soil correlator, Portland, Oregon. At the time, moderately dry and very dry were not distinguished.

[c] D1 = DV + DM.

Table 3-6 (continued)

Depth cm	:Jan	:Feb	:Mar	:Apr	:May	:Jun	:Jul	:Aug	:Sep	:Oct	:Nov	:Dec
Driest 2 years in 10												
Fine, montmorillonitic, 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, 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

Depth cm	:Jan	:Feb	:Mar	:Apr	:May	:Jun	:Jul	:Aug	:Sep	:Oct	:Nov	:Dec
Wettest 2 years in 10												
Fine, montmorillonitic, 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, 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

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.

Saturated Hydraulic Conductivity

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:

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

where 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 term dH/dz is the hydraulic gradient, 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; that is, when the soil matric potential is zero (satiated wet condition). In most soils this situation takes place 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 a long time (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 of interest here; it is the factor 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 the resistance increases, the 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 a 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 usually 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; in other words its hydraulic conductivity increases 4-fold.

Hydraulic conductivity is a highly variable soil property. Measured values easily may vary by 10-fold or more for a particular soil series. Values measured on soil samples taken within centimeters of one another may vary by 10-fold or more. In addition, measured hydraulic conductivity values for a soil may vary dramatically with the method used for measurement. Laboratory determined values rarely agree with field measurements, the differences often being on the order of 100-fold or more. Field methods generally are more reliable than laboratory methods.

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 will give a reliable estimate which can be used to place the soil in a particular hydraulic conductivity class. Log averages (geometric means) should be used rather than arithmetic averages because hydraulic conductivity is a log normally distributed property. 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.

Hydraulic conductivity classes in this manual are defined in terms of vertical, saturated hydraulic conductivity. Table 3-7 defines the vertical, saturated hydraulic conductivity classes. The saturated hydraulic conductivity classes in this manual have a wider range of values than the classes of either the 1951 *Soil Survey Manual* or the 1971 *Engineering Guide*. 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. Usually, the hydraulic gradient is given on a weight basis and the flux density on a volume basis and the dimensions of K_{sat} are length per time. The correct SI units thus are meters per second.[6] Micrometers per second are also acceptable SI units and are more convenient (table 3-7). Table 3-8 gives the class limits in commonly used units.

Table 3-7. Saturated hydraulic conductivity classes

Class	Ksat (µm/s)
Very High	$\geq$ 100
High	10 - 100
Moderately High	1 - 10
Moderately Low	0.1 - 1
Low	0.01 - 0.1
Very Low	< 0.01

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

[6] The Soil Science Society of America prefers that all quantities be expressed on a mass basis. This results in Ksat units of kg s m-3. Other units acceptable to their society are m3 s kg-1, the result of expressing all quantities on a volume basis, and m s -1, the result of expressing the hydraulic gradient on a weight basis and flux density on a volume basis.

surrounding areas accumulates faster than it can pass through the soil. The water may actually move very slowly despite a high K_{sat}.

Table 3-8. Saturated hydraulic conductivity class limits in equivalent units

µm/s		m/s	cm/day	in/hr	cm/hr	kg s m^{-3}	m3 s kg^{-3}
100	=	10^{-4}	864.	14.17	36.0	$1.02X10^{-2}$	$1.02X10^{-8}$
10	=	10^{-5}	86.4	1.417	3.60	$1.02X10^{-3}$	$1.02X10^{-9}$
1	=	10^{-6}	8.64	0.1417	0.360	$1.02X10^{-4}$	$1.02X10^{-10}$
0.1	=	10^{-7}	0.864	0.01417	0.0360	$1.02X10^{-5}$	$1.02X10^{-11}$
0.01	=	10^{-8}	0.0864	0.001417	0.00360	$1.02X10^{-6}$	$1.02X10^{-12}$

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, and Amoozegar and Warrick, 1986) and in SSIR 38 (Bouma et al., 1982).

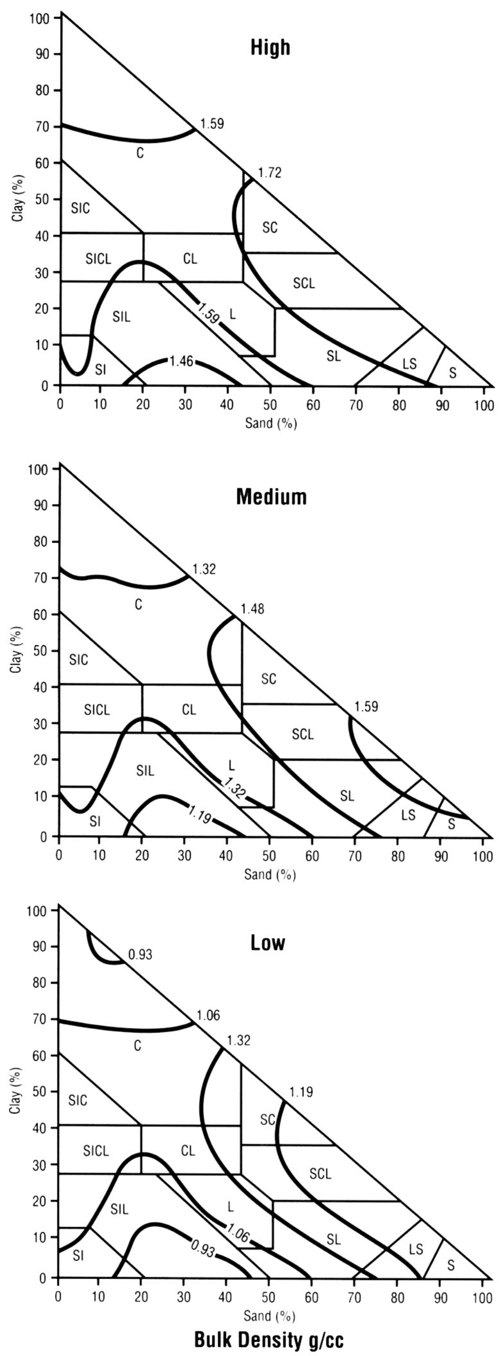
Various researchers have attempted to estimate K_{sat} based on various soil properties. These estimation methods usually use one or more of the following soil physical properties: surface area, texture, structure, bulk density, and micromorphology. The success of the individual methods varies. Often a method does fairly well in a localized area. No one method works really well for all soils. Sometimes, measurement of the predictor variables is more difficult than measurement of hydraulic conductivity. Generally, adjustments must be made for "unusual" circumstances such as high sodium concentrations, certain clay mineralogies, and the presence of coarse fragments, fragipans, and other miscellaneous features.

The method presented here is very general (Rawls and Brakensiek, 1983). It has been developed from a statistical analysis of several thousand measurements in a variety of soils. Because the method is intended for a wide application, it must be used locally with caution. The results, often, must be adjusted based on experience and local conditions.

Figure 3-11 consists of three textural triangles that can be used for K_{sat} class placement, based on soil bulk density and texture. The center triangle is for use with soils having medium or average bulk densities. The triangles above and below are for soils with high and low bulk densities, respectively.

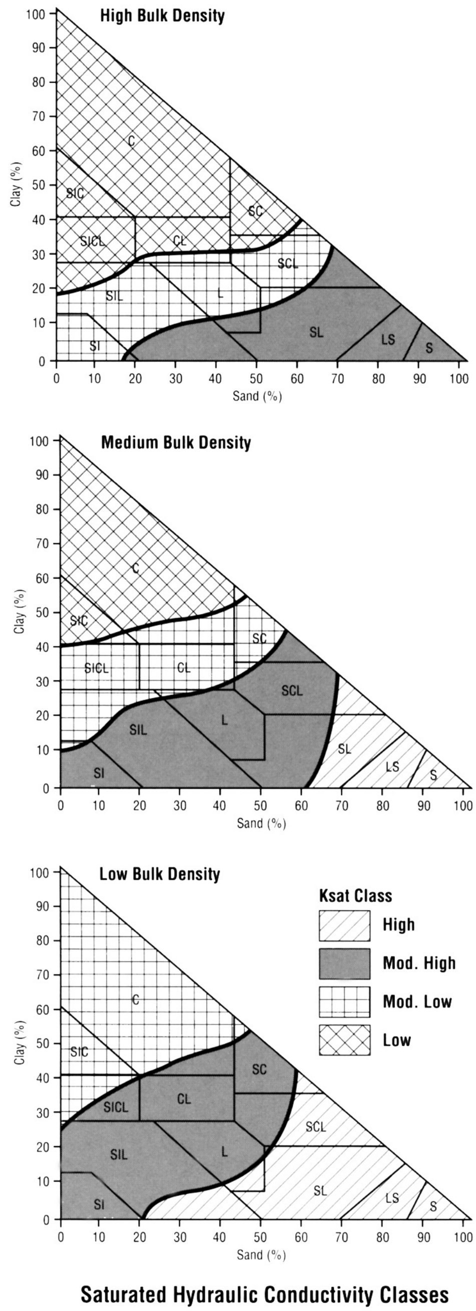
Figure 3-12 can be used to help determine which triangle in figure 3-11 to use. In each of the triangles, interpolation of the iso-bulk density lines yields a bulk density value for the particular soil texture. The triangle that provides the value closest to the measured or estimated bulk density determines the corresponding triangle in figure 3-11 that should be used.

FIGURE 3-11



Saturated hydraulic conductivity classes (Rawls and Brakensiek, 1983). A clay loam with a bulk density of 1.40 g/cc and 35 percent both sand and clay falls in the medium bulk density class.

FIGURE 3-12



Bulk density and texture relationships.

The hydraulic conductivity of a particular soil horizon is estimated by finding the triangle (fig. 3-11), based on texture and bulk density, to which the horizon belongs. The bulk density class to which the horizon belongs in Fig. 3-11 determines the triangle to be used in Fig. 3-12. The K_{sat} class can be determined immediately from the shading of the triangle. 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. The values 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 always best to make several measurements at the site.

The K_{sat} values given by the above procedure may need to be adjusted based on other known soil properties. Currently, there is little information available to provide adequate guidelines for adjusting the estimated K_{sat}. The soil scientist must use best judgement based on experience and the observed behavior of the particular soil.

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 hydraulic conductivity classification for 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 usually given.

Infiltration

Infiltration is the process of downward water entry into the soil. The values are usually sensitive to near surface conditions as well as to the antecedent water state. Hence, they are subject to significant change with soil use and management and time.

Infiltration stages.—Three stages of infiltration may be recognized—preponded, transient ponded, and steady ponded. *Preponded infiltration* pertains to downward water entry into the soil under conditions that free water is absent on the land surface. The rate of water addition determines the rate of water entry. If rainfall intensity increases twofold, then the infiltration increases twofold. In this stage, surface-connected macropores are relatively ineffective in transporting water downward. No runoff occurs during this 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 control over the infiltration shifts from the rate of water addition to characteristics of the soil. Surface-connected nonmatrix and subsurface-initiated cracks then become effective 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 stages of *ponded infiltration*, the rate of water entry usually 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 would be closed, if reversible. The suction gradient would be small and the driving force reduced to near that of the gravitational gradient. Assuming the absence of ice and of zones of free water within moderate depths and that surface or near surface features (crust, for example) do not control infiltration, the minimum saturated hydraulic conductivity within a depth of 1/2 to 1 meter should be a useful predictor of steady ponded infiltration rate.

Minimum Annual Steady Ponded Infiltration.—The steady ponded infiltration rate while the soil is in the wettest state that regularly occurs while not frozen is called the *minimum annual steady ponded infiltration rate*. The quantity is subject to reduction because of the presence of free water at shallow depths if this is a predictable feature of the soil. Allowance for the effect of free water differentiates the quantity from minimum saturated hydraulic conductivity for the upper meter of the soil. The minimum annual steady ponded infiltration rate has application for prediction of runoff at the wettest times of the year when the runoff potential should be the highest.

Hydrologic soil groups.—Hydrologic soil groups are employed in the computation of runoff by the Curve Number method. Minimum annual steady ponded infiltration rate for a bare ground surface determines the hydrologic soil groups. Table 3-9 contains criteria for class placement.

Table 3-9. Criteria for placement of hydrologic soil groups

Hydrologic Soil Group	Criteria[a]
A	Saturated hydraulic conductivity is *very high* or in the upper half of high and internal free water occurrence is *very deep*
B	Saturated hydraulic conductivity is in the lower half of *high* or in the upper half of *moderately high* and free water occurrence is *deep* or *very deep*.
C	Saturated hydraulic conductivity is in the lower half of *moderately high* or in the upper half of *moderately* low and internal free water occurrence is deeper than *shallow*.
D	Saturated hydraulic conductivity is below the upper half of *moderately low*, and/or internal free water occurrence is *shallow* or *very shallow* and *transitory* through *permanent*.

[a]The criteria are guidelines only. They are based on the assumption that the minimum saturated hydraulic conductivity occurs within the uppermost 0.5 m. If the minimum occurs between 0.5 and 1 m, then saturated hydraulic conductivity for the purpose of placement is increased one class. If the minimum occurs below 1 m, then the value for the soil is based on values above 1 m using the rules as previously given.

The Green-Ampt model is an example of a 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) to describe 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 is available 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 with the bulk density and for all horizons with the water state. It is, therefore, sensitive to soil use which may affect both bulk density of surficial horizons and the antecedent water state. The value of S, the effective suction head at the wetting front, is determined largely by the 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 should approach the value of the hydraulic conductivity for the satiated condition.

Surface Runoff

Surface runoff refers to the loss of water from an area by flow over the land surface. Surface runoff differs from subsurface flow or interflow that results when infiltrated water encounters a zone with lower perviousness than the soil above. The water accumulates above this less pervious zone and may move laterally if conditions are favorable for the occurrence of free water.

Index Surface Runoff Classes.—Historically, a set of runoff classes have been employed "as determined by the characteristics of soil slope, climate, and cover" (Soil Survey Staff, 1951). Table 3-10 contains a set of classes that parallel the sense of how the previous runoff classes were applied but with some changes in the written definitions. The current concept is referred to as index surface runoff. The concept indicates relative runoff for very specific conditions. The soil surface is assumed to be bare and surface water retention due to irregularities in the ground surface is low. Steady ponded infiltration rate is the applicable infiltration stage. Ice is assumed to be absent unless otherwise indicated. Finally, both the maximum bulk density in the upper 25 cm and the bulk density of the uppermost few centimeters are assumed within the limits specified for the mapping concept.

The concept assumes a standard storm or amount of water addition from snowmelt of 50 mm in a 24-hour period with no more than 25 mm in any single 1-hour period. Additionally, a standardized antecedent water state condition prior to the water addition is assumed: the soil is conceived to be *very moist* or *wet* to the base of the soil, to 1/2 m, or through the horizon or layer with minimum saturated hydraulic conductivity within 1 meter, whichever is the greatest depth. If the minimum saturated hydraulic conductivity of the soil occurs below 1 meter, it is disregarded and the minimum "to and including 1 m" is employed. For soils with seasonal *shallow* or *very shallow* free water, *very low* saturated hydraulic conductivity is assumed in the application of the guidelines in table 3-10.

Table 3-10. Index surface runoff classes based on slope gradient and saturated hydraulic conductivity

Slope Gradient	Saturated Hydraulic Conductivity Class [a, b]					
Pct.	*Very High*	*High*	*Mod. High*	*Mod. Low*	*Low*	*Very Low*
Concave [c]	N	N	N	N	N	N
<1	N	N	N	L	M	H
1 to 5	N	LV	L	M	H	HV
5 to 10	LV	L	M	H	HV	HV
10 to 20	LV	L	M	H	HV	HV
≥20	L	M	H	HV	HV	HV

[a]Abbreviations: Negligible-N; Very Low-LV; Low-L; Medium- M; High-H; and Very High-HV.

[b]Consult Table 3-7 for definitions. Assumes that the lowest value for the soil occurs above 1/2 m. If the lowest value occurs 1/2 to 1 m, then reduce runoff by one class (medium to slow, for example). If it occurs >1 m, then use the lowest saturated hydraulic conductivity < 1 m.

[c]Areas from which no or very little water escapes by flow over the ground surface.

Class placement (table 3-10) depends only on slope and on saturated hydraulic conductivity. Table 3-10 is based on the minimum saturated hydraulic conductivity for the soil at or above 1/2 m. If the minimum for the soil occurs between 1/2 and 1 m, the runoff should be reduced by one class (from *medium* to *low*, for example). If the lowest saturated hydraulic conductivity occurs at 1 m or deeper, the lowest value to 1 m depth should be employed rather than the lowest value for the soil.

Hydrologic models.—The set of index surface runoff classes are relative and not quantitative. Actual runoff estimates require quite different approaches. To make quantitative surface runoff estimates requires application of a hydrologic model to a watershed. Most hydrologic models involve a balancing between precipitation and infiltration rates with runoff being the difference after a correction for retention of water on the land surface and on vegetation. In the more rigorous models, the infiltration is predicted from soil physical quantities and estimates of infiltration, evapotranspiration, and deep percolation are used to predict continuously the soil water state.

An empirical model in current use is based on an analysis of a large number of runoff events for watersheds (Soil Conservation Service, 1972). A family of curves was formulated from these data to show the relationship between cumulative daily runoff and cumulative daily rainfall. Each of the family of curves is numbered&151;hence the name, Curve Number Model. The curves that describe the runoff-precipitation relationship are affected by the sum of the removals from the rainfall by infiltration, by retention on vegetation, and by storage in depressions on the land surface. If no removal of the added water has occurred, then the relationship between daily runoff and daily rainfall is a straight line at 45 degrees. As the removal increases, the departure from a 45 degree line increases. The specific curve to employ is determined by evaluation of these factors: the assumed ground surface conditions as determined by the vegetation and cultural practices, the hydrologic soil group (table 3-9), and the water storage capacity. The first factor is evaluated from land use, vegetation, and land treatment or farming practices. The second is an assessment commonly made for a soil series. The third factor is evaluated from the rainfall-evaporation balance for several days preceding the precipitation event.

Soil Temperature

Soil temperature exerts a strong influence on biological activities. It also influences the rates of chemical and physical processes within the soil. 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, growth of roots of most plants is negligible. In areas where soils have permanently frozen layers near the surface, however, even large roots of adapted plants are present immediately above the frozen layer late in the summer. Most plants grow best within a restricted range of soil and air temperature. Knowledge of soil and air temperature is essential in understanding soil-plant relationships. Temperature changes with time, as does the soil-water state. 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 and 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, but 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 from layer to layer at a given site at a given time; yet, if the average annual temperatures at different depths in the same pedon are compared, they usually do not differ. Mean annual 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 as seasons change in the middle and high latitudes. Mean seasonal temperatures can be used to characterize soil temperature. Seasonal temperature differences decrease and the seasonal cycles lag progressively as depth increases.

For soils that freeze in winter, soil temperature is influenced by the release of heat when water changes from the liquid to the solid form. This releases about 80 calories per gram of water. The 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 may 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; soil color; aspect and gradient of slope; elevation; and ground water. All of these factors may be described in a soil survey if they are significant.

Estimating Soil Temperature

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 representative of the soil to be characterized. 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 usually gives a close estimate of mean annual soil temperature. Mean annual soil temperature can also be estimated closely 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 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 subject to minor variation caused by differences in 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.

Designations for Horizons and Other Layers

Soils vary widely in the degree to which horizons are expressed. Relatively fresh geologic formations, such as fresh alluvium, sand dunes, or blankets of volcanic ash, may have no recognizable genetic horizons, although they may have distinct layers that reflect different modes of deposition. As soil formation proceeds, horizons may be detected in their early stages only by very careful examination. As age increases, horizons generally are more easily identified in the field. 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.

Layers of different kinds are identified by 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 investigator's interpretations of genetic relationships among the layers within a soil. Layers need not be identified by symbols for a good description; yet, the usefulness of soil descriptions is greatly enhanced by the proper use of designations.

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 among taxa. Changes implied by genetic horizon designations may not be large enough to justify recognition of diagnostic criteria. For example, a designation of Bt does not always indicate an argillic horizon. Furthermore, the diagnostic horizons may not be coextensive with genetic horizons.

Three kinds of symbols are used in various combinations to designate horizons and layers. These are capital letters, lower case letters, and Arabic numerals. Capital letters are used to designate the master horizons and layers; lower case letters are used as suffixes to indicate specific characteristics of master horizons and layers; and Arabic numerals are used both as suffixes to indicate vertical subdivisions within a horizon or layer and as prefixes to indicate discontinuities.

Master Horizons and Layers

The capital letters O, A, E, B, C, and R represent the master horizons and layers of soils. The capital letters are the base symbols to which other characters are added to complete the designations. Most horizons and layers are given a single capital letter symbol; some require two.

O horizons or layers: *Layers dominated by organic material. Some are saturated with water for long periods or were once saturated but are now artificially drained; others have never been saturated.*

Some O layers consist of undecomposed or partially decomposed litter, such as leaves, needles, twigs, moss, and lichens, that has been deposited on the surface; they may be on top of either mineral or organic soils. Other O layers, are organic materials that were deposited under saturated conditions and have decomposed to varying stages (Soil Survey Staff, 1975). The mineral fraction of such material is only a small percentage of the volume of the material and generally is much less than half of the weight. Some soils consist entirely of material designated as O horizons or layers.

An O layer may be on the surface of a mineral soil or at any depth beneath the surface, if it is buried. 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 much organic matter.

A horizons: *Mineral horizons that formed at the surface or below an O horizon, that exhibit obliteration of all or much of the original rock structure, and that show one or more of the following: (1) an accumulation of humified organic matter intimately mixed with the mineral fraction and not dominated by properties characteristic of E or B horizons (defined below) 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 an A horizon. In some places, as in warm arid climates, the undisturbed surface horizon is less dark than the adjacent underlying horizon and contains only small amounts of organic matter. It has a morphology distinct from the C layer, although the mineral fraction is unaltered or only slightly altered by weathering. Such a horizon is designated A because it is at the surface; however, recent alluvial or eolian deposits that retain rock structure[7] are not considered to be an A horizon unless cultivated.

E horizons: *Mineral horizons in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles. These horizons exhibit obliteration of all or much of the original rock structure.*

An E horizon is usually, but not necessarily, lighter in color than an underlying B horizon. In some soils the color 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 has less organic matter than the A horizon. An E horizon is most commonly differentiated from an underlying B horizon in the same sequum by color of higher value, by lower chroma or both, by coarser texture, or by a combination of these properties. An E horizon is commonly near the surface below an O or A horizon and above a B horizon, but the symbol E can be used for eluvial horizons within or between parts of the B horizon or for those that extend to depths greater than normal observation if the horizon has resulted from soil genesis.

B horizons: *Horizons that formed below an A, E,, or O horizon and are dominated by obliteration of all or much of the original rock structure and show one or more of the following:*

(1) *illuvial concentration of silicate clay, iron, aluminum, humus, carbonates, gypsum, or silica, alone or in combination;*
(2) *evidence of removal of carbonates;*
(3) *residual concentration of sesquioxides;*
(4) *coatings of sesquioxides that make the horizon 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 granular, blocky, or prismatic structure if volume changes accompany changes in moisture content; or*
(6) *brittleness.*

All kinds of B horizons are subsurface horizons or were originally. Included as B horizons where contiguous to another genetic horizon are layers of illuvial concentration of carbonates,

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[7] Rock structure includes fine stratification in unconsolidated, or pseudomorphs, of weathered minerals that retain their positions relative to each other and to unweathered minerals in saprolite from consolidated rocks.

gypsum, or silica that are the result of pedogenic processes (these layers may or may not be cemented) and brittle layers that have other evidence of alteration, such as prismatic structure or illuvial accumulation of clay.

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

C horizons or layers: *Horizons or layers, excluding hard bedrock, that are little affected by pedogenic processes and lack properties of O, A, E, or B horizons. The material of C layers 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 are sediment, saprolite, unconsolidated bedrock, and other geologic materials that commonly are uncemented (table 3-14) and exhibit low or moderate excavation difficulty (table 3-21). Some soils form in material that is already highly weathered. If such material does not meet the requirements of A, E, or B horizons, it is designated C. Changes not considered pedogenic are those not related to overlying horizons. Layers that have accumulations of silica, carbonates, or gypsum or more soluble salts are included in C horizons, even if indurated (table 3-14). If the indurated layers are obviously affected by pedogenic processes, they are a B horizon.

R layers: *Hard Bbedrock*

Granite, basalt, quartzite and indurated limestone or sandstone are examples of bedrock that are designated R. These layers are cemented and excavation difficulty exceeds moderate. 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 contain cracks that generally are too few and too small to allow roots to penetrate at intervals of less than 10 cm. The cracks may be coated or filled with clay or other material.

Transitional and Combination Horizons

Horizons dominated by properties of one master horizon but having subordinate properties of another. Two capital letter symbols are used, as AB, EB, BE, or BC. The master horizon symbol that is given first designates the kind of 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 than like the B.

In some cases, a horizon can be designated as transitional even if one of the master horizons to which it is apparently transitional is not present. A BE horizon may be recognized in a truncated soil if its properties are similar to those of a BE horizon in a soil in 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 is transitional to assumed parent material.

Horizons in which distinct parts have recognizable properties of the two kinds of master horizons indicated by the capital letters. The two capital letters are separated by a virgule (/), as

E/B, B/E, or B/C. Most of the individual parts of one of the components are surrounded by the other.

The designation may be used even though horizons similar to one or both of the components are not present, if the separate components can be recognized. The first symbol is that of the horizon that makes up the greater volume.

Single sets of designators do not cover all situations; therefore, some improvising may be necessary. For example, Alfic Udipsamments have lamellae that are separated from each other by eluvial layers. Because it is generally not practical to describe each lamellae and eluvial layer as a separate horizon, the horizons are combined but the components are described separately. One horizon would then contain several lamellae and eluvial layers and might be designated as an E and Bt horizon. The complete horizon sequence for this soil could be: Ap-Bw-E and Bt1-E and Bt2-C. r material.

Subordinate Distinctions Within Master Horizons and Layers

Lower case letters are used as suffixes to designate specific kinds of master horizons and layers. The word "accumulation" is used in many of the definitions in the sense that the horizon must have more of the material in question than is presumed to have been present in the parent material. The symbols and their meanings are as follows:

a *Highly decomposed organic material*
This symbol is used with "O" to indicate the most highly decomposed of the organic materials. The rubbed fiber content is less than about 17 percent of the volume.

b *Buried genetic horizon*
This symbol is used in mineral soils to indicate identifiable buried horizons with major genetic features that were formed 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 soil. The symbol is not used in organic soils or to separate an organic layer from a mineral layer.

c *Concretions or nodules*
This symbol is used to indicate a significant accumulation of concretions or of nodules. Cementation is required. The cementing agent is not specified except it cannot be silica. This symbol is not used if concretions or nodules are dolomite or calcite or more soluble salts, but it is used if the nodules or concretions are enriched in minerals that contain iron, aluminum, manganese, or titanium.

d *Physical root restriction*
This symbol is used to indicate root restricting layers in naturally occurring or manmade unconsolidated sediments or materials such as dense basal till, plow pans, and other mechanically compacted zones.

e *Organic material of intermediate decomposition*
This symbol is used with "O" to indicate organic materials of intermediate decomposition. Rubbed fiber content is 17 to 40 percent of the volume.

f *Frozen soil*
This symbol is used to indicate that the horizon or layer contains permanent ice. Symbol is not used for seasonally frozen layers or for "dry permafrost" (material that is colder than O° C but does not contain ice).

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

h *Illuvial accumulation of organic matter*
This symbol used with "B" to indicate the accumulation of illuvial, amorphous, dispersible organic matter-sesquioxides complexes. The sesquioxide component coats sand and silt particles. In some horizons, coatings have coalesced, filled pores, and cemented the horizon. The symbol "h" is also used in combination with "s" as "Bhs" if the amount of sesquioxide component is significant but value and chroma of the horizon are 3 or less.

i *Slightly decomposed organic material*
This symbol is used with "O" to indicate the least decomposed of the organic materials. Rubbed fiber content is more than about 40 percent of the volume.

k Accumulation of carbonates
This symbol is used to indicate the accumulation of alkaline earth carbonates, commonly calcium carbonate.

m *Cementation or induration*
This symbol is used to indicate continuous or nearly continuous cementation. The symbol is used only for horizons that are more than 90 percent cemented, although they may be fractured. The layer is physically root restrictive. The single predominant or codominant cementing agent may be indicated by using defined letter suffixes, singly or in pairs. If the horizon is cemented by carbonates, "km" is used; by silica, "qm"; by iron, "sm"; by gypsum, "ym"; by both lime and silica, "kqm"; by salts more soluble than gypsum, "zm."

n *Accumulation of sodium*
This symbol is used to indicate an accumulation of exchangeable sodium.

o *Residual accumulation of sesquioxides*
This symbol is used to indicate residual accumulation of sesquioxides.

p *Tillage or other disturbance*
This symbol is used to indicate a disturbance of the surface layer by mechanical means, pasturing, or similar uses. A disturbed organic horizon is designated Op. A disturbed mineral horizon is designated Ap even though clearly once an E, B, or C horizon.

q *Accumulation of silica*
This symbol is used to indicate an accumulation of secondary silica.

r *Weathered or soft bedrock*
This symbol is used with "C" to indicate root restrictive layers of soft bedrock or saprolite, such as weathered igneous rock; partly consolidated soft sandstone; siltstone; and shale. Excavation difficulty is low or moderate.

s *Illuvial accumulation of sesquioxides and organic matter*
This symbol is used with "B" to indicate the accumulation of illuvial, amorphous, dispersible organic matter-sesquioxide complexes if both the organic matter and sesquioxide components are significant and the value and chroma of the horizon is more than 3. The symbol is also used in combination with "h" as "Bhs" if both the organic matter and sesquioxide components are significant and the value and chroma are 3 or less.

ss *Presence of slickensides*
This symbol is used to indicate the presence of 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 is used to indicate an accumulation of silicate clay that has formed and subsequently translocated within the horizon or has been moved into the horizon by illuviation, or both. At least some part should show evidence of clay accumulation in the form of coatings on surfaces of peds or in pores, or as lamellae, or bridges between mineral grains.

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 that hardens irreversibly when exposed to the atmosphere and to repeated wetting and drying.

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

x *Fragipan character*
This symbol is used to indicate genetically developed layers that have a combination of firmness, brittleness, very coarse prisms with few to many bleached vertical faces, and commonly higher bulk density than adjacent layers. Some part is physically root restrictive.

y *Accumulation of gypsum*
This symbol is used to indicate the accumulation of gypsum.

z *Accumulation of salts more soluble than gypsum*
This symbol is used to indicate an accumulation of salts more soluble than gypsum.

Conventions for using letter suffixes.—Many master horizons and layers that are symbolized by a single capital letter will have one or more lower case letter suffixes. The following rules apply:

Letter suffixes should immediately follow the capital letter.

More than three suffixes are rarely used.

When more than one suffix is needed, the following letters, if used, are written first: a, e, h, i, r, s, t, and w. Except for the Bhs or Crt[8] horizons, none of these letters are used in combination in a single horizon.

If more than one suffix is needed and the horizon is not buried, these symbols, if used, are written last: c, d, f, g, m, v, and x. Some examples: Btg, Bkm, and Bsm.

If a horizon is buried, the suffix "b" is written last. Suffix "b" is used only for buried mineral soils.

A B horizon that has significant accumulation of clay and also shows evidence of development of color or structure, or both, is designated Bt ("t" has precedence over "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 accumulation or sesquioxides carries the appropriate symbol—g, k, n, q, y, z, or o. If illuvial clay is also present, "t" precedes the other symbol: Btg.

Suffixes "h," "s," and "w" are not normally used with g, k, n, q, y, z, or o.

Vertical subdivision.—Commonly a horizon or layer designated by a single letter or a combination of letters needs to be subdivided. The Arabic numerals used for this purpose always follow all letters. Within a C, for example, successive layers could be C1, C2, C3, and so on; or, if the lower part is gleyed and the upper part is not, the designations could be C1-C2-Cg1-Cg2 or C-Cg1-Cg2-R.

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[8] Indicates weathered bedrock or saprolite in which clay films are present.

These conventions apply whatever the purpose of subdivision. In many soils, horizons that would be identified by one unique set of letters are subdivided on the basis of evident morphological features, such as structure, color, or texture. These divisions are numbered consecutively. The numbering starts with 1 at whatever level in the profile any element of the letter symbol changes. Thus Bt1-Bt2-Btk1-Btk2 is used, not Bt1-Bt2-Btk3-Btk4. The numbering of vertical subdivisions within a horizon is not interrupted at a discontinuity (indicated by a numerical prefix) if the same letter combination is used in both materials: Bs1-Bs2-2Bs3-2Bs4 is used, not Bs1-Bs2-2Bs1-2Bs2.

Sometimes, thick layers are subdivided during sampling for laboratory analyses even though differences in morphology are not evident in the field. These layers need to be identified. This is done by following the convention of using Arabic numerals to identify the subdivision. The Arabic numerals would follow the letter designations and be a part of the horizon designation. For example, four layers of a Bt2 horizon sampled by 10-cm increments would be designated Bt21, Bt22, Bt23, and Bt24. The Bt2 horizon is subdivided for sampling purposes only.

Discontinuities.—In mineral soils Arabic numerals are used as prefixes to indicate discontinuities. Wherever needed, they are used preceding A, E, B, C, and R. These prefixes are distinct from Arabic numerals used as suffixes to denote vertical subdivisions.

A discontinuity is a significant change in particle-size distribution or mineralogy that indicates a difference in the material from which the horizons formed and/or a significant difference in age, unless that difference in age is indicated by the suffix "b." Symbols to identify discontinuities are used only when they will contribute substantially to the reader's understanding of relationships among horizons. Stratification common to soils formed in alluvium is not designated as discontinuity, unless particle size distribution differs markedly (strongly contrasting particle-size class, as defined by Soil Taxonomy) from layer to layer even though genetic horizons have formed in the contrasting layers.

Where a soil has formed entirely in one kind of material, a prefix is omitted from the symbol; the whole profile is material 1. Similarly, the uppermost material in a profile having two or more contrasting materials is understood to be material 1, but the number is omitted. Numbering starts with the second layer of contrasting material, which is designated "2." Underlying contrasting layers are numbered consecutively. Even though a layer below material 2 is similar to material 1, it is designated "3" in the sequence. The numbers indicate a change in the material, not the type of material. Where two or more consecutive horizons formed in one kind of material, the same prefix number is applied to all of the horizon designations in that material: Ap-E-Bt1-2Bt2-2Bt3-2BC. The number of suffixes designating subdivisions of the Bt horizon continue in consecutive order across the discontinuity.

If an R layer is below a soil that formed in residuum and the material of the R layer is judged to be like that from which the material of the soil weathered, the Arabic number prefix is not used. If it is thought that the R layer would not produce material like that in the solum, the number prefix is used, as in A-Bt-C-2R or A-Bt-2R. If part of the solum formed in residuum, "R" is given the appropriate prefix: Ap-Bt1-2Bt2-2Bt3-2C1-2C2-2R.

Buried horizons (designated "b") are special problems. A buried horizon is obviously not in the same deposit as horizons in the overlying deposit. Some buried horizons, however, formed in material lithologically like that of the overlying deposit. A prefix is not used to distinguish material of such buried horizons. If the material in which a horizon of a buried soil formed is lithologically unlike that of the overlying material, the discontinuity is designated by number prefixes and the symbol for a buried horizon is used as well: Ap-Bt1-Bt2-BC-C-2ABb-2Btb1-2Btb2-2C.

In organic soils, discontinuities between different kinds of layers are not identified. In most cases, the differences are shown by the letter suffix designations if the different layers are organic or by the master symbol if the different layers are mineral.

Use of the prime.—Identical letter and numerical designations may be appropriate for two or more horizons separated by at least one horizon or layer of a different kind in the same pedon. The sequence A-E-Bt-E-Btx-C is an example: the soil has two E horizons. To make communication easier, the prime is used with the master horizon symbol of the lower of two horizons having identical designations: A-E-Bt-E'-Btx-C. The prime is applied to the capital letter designation and any lower-case symbols follow it: B't. The prime is not used unless all letters of the designations of two different layers are identical. Rarely, three layers have identical letter symbols; a double prime can be used: E".

The same principle applies in designating layers of organic soils. The prime is used only to distinguish two or more horizons that have identical symbols: Oi-C-O'i-C' or Oi-C-Oe-C'. The prime is added to the lower C layer to differentiate it from the upper.

Sample Horizons and Sequences

The following examples illustrate some common horizon and layer sequences of important soils and the use of Arabic numerals to identify their subdivisions. The examples were selected from soil descriptions on file and modified to reflect present conventions.

Mineral soils:

Typic Hapludoll: A1-A2-Bw-BC-C
Typic Haploboroll: Ap-A-Bw-Bk-Bky1-Bky2-C
Cumulic Haploboroll: Ap-A-Bw1-Bw2-BC-Ab-Bwb1-Bwb2-2C
Typic Argialboll: Ap-A-E-Bt1-Bt2-BC-C
Typic Argiaquoll: A-AB-BA-Btg-BCg-Cg
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-A3-2Bt1-2Bt2-2Bt3-2BC-2C
Glossoboric Hapludalf: Ap-E-B/E-Bt1-Bt2-C
Typic Paleudult: A-E-Bt1-Bt2-B/E-B't1-B't2-B't3
Typic Hapludult: 0i-A1-A2-BA-Bt1-Bt2-BC-C
Arenic Plinthic Paleudult: Ap-E-Bt-Btc-Btv1-Btv2-BC-C
Typic Haplargid: A-Bt-Bk1-Bk2-C
Entic Durorthid: A-Bw-Bq-Bqm-2Ab-2Btkb-3Byb-3Bqmb-3Bqkb
Typic Dystrochrept: Ap-Bw1-Bw2-C-R
Typic Fragiochrept: Ap-Bw-E-Bx1-Bx2-C
Typic Haplaquept: Ap-AB-Bg1-Bg2-BCg-Cg

Typic Udifluvent: Ap-C-Ab-C'

Typic Haplustert: Ap-A-AC-C1-C2

Organic soils:

Typic Medisaprist: Op-Oa1-Oa2-Oa3-C

Typic Sphagnofibrist: Oi1-Oi2-Oi3-Oe

Limnic Borofibrist: Oi-C-O'i1-O'i2-C'-Oe-C'

Lithic Cryofolist: Oi-Oa-R

Cyclic and Intermittent Horizons and Layers

A 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. At one place the aggregate horizon thickness may be only 50 cm; two meters away, the same horizons may be more than 125 cm thick. The cycle is repeated, commonly with considerable variation in both depth and horizontal interval, but still with some degree of regularity. If 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 would appear wedge-shaped.

A profile of a soil having an intermittent horizon shows that the horizon extends horizontally for some distance, ends, and reappears again some distance away. A B horizon interrupted at intervals by upward extensions of bedrock into the A horizon is an example. The distance between places where the horizon is absent is commonly variable, yet it has some degree of regularity. The distances range from less than one meter to several meters.

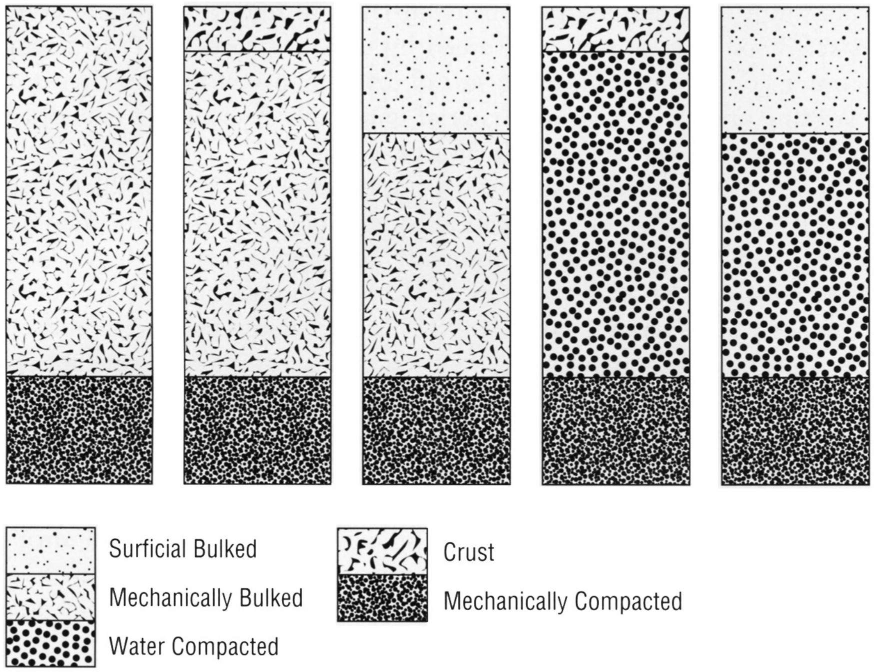
Obviously, a soil profile at one place could be unlike a profile only a few meters away for soils with cyclic or intermittent horizons or layers. The order of the variations of these soils are given in soil descriptions.

Descriptions of the order of horizontal variation within a pedon include the kind of variation, the spacing of cycles or interruptions, and the amplitude of depth variation of cyclic horizons.

Near Surface Subzones

The morphology of the uppermost few centimeters is subject in many soils to strong control by antecedent weather and by soil use. A soil may be freshly tilled today and have a loose surface. Tomorrow it may have a strong crust because of a heavy rain. Or, in one place soil may be highly compacted by livestock and have a firm near surface even though over most of its extent the same uppermost few centimeters are little disturbed and very friable. There is a need for a set of terms to describe subzones of the near surface and, in particular, the near surface of tilled soils. Five subzones of the near surface are recognized (fig. 3-13).

FIGURE 3-13



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

The *mechanically bulked* subzone has undergone through mechanical manipulation a reduction in bulk density and an increase in discreteness of structural units, if present. Usually the mechanical manipulation is the consequence of tillage operations. Rupture resistance of the mass overall, inclusive of a number of structural units, is *loose* or *very friable* and *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 < 20 mm across, is moderate or strong. Strain that results from contraction on drying of individual structural units may not extend among structural units. Hence, internally initiated desiccation cracks may be weak or absent even though the soil material in a consolidated condition has considerable potential extensibility. Cracks may be present, however, if they are initiated deeper in the soil.

The *mechanically compacted* subzone has been subject to compaction, usually in tillage operations but possibly 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 extensibility and drying has been sufficient. In some soils this subzone restricts root growth. The suffix "d" may be used if compaction results in a strong plow pan.

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 for the same soil material if mechanically bulked. Structure generally would be weak or the condition would be massive. Mechanical continuity of the fabric is sufficient that strain which originates on drying propagates appreciable distances. As a consequence, if extensibility is sufficient, cracks develop on drying. In many soils, over time the water-compacted subzone replaces the mechanically bulked subzone. The replacement can occur in a single year if the subzone is subject to periodic occurrence of free water with intervening periods when *slightly moist* or *dry*. The presence of a water-compacted subzone and the absence of the mechanically bulked subzone is an important consequence of no-till farming systems.

The *surficial bulked* subzone occurs in the very near surface. Continuity of the fabric is low. Cracks are not initiated in this subzone, although they may be present if initiated in underlying more compacted soil. The subzone is formed by various processes. Frost action under conditions where the soil is drier than wet is a mechanism. Wetting and drying of soil material with high extensibility is another origin; certain Vertisols are illustrative.

Crust is a surficial subzone, usually less than 50 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 and freeze-thaw cycles are mechanisms leading to reconstitution. Crusting related to *raindrop-impact* and *freeze-thaw* are recognized.

A *fluventic* zone may be formed by local transport and deposition of soil material in tilled fields. Such a feature has weaker mechanical continuity than a crust. The rupture resistance is lower, and the reduction in infiltration may be less than for crusts of similar texture. A raindrop-impact crust may occur on a fluventic zone.

Crusts and a fluventic zone may be described in terms of thickness in millimeters, structure and other aspects of the fabric, and by consistence, including rupture resistance while dry and micropenetration resistance while wet. Thickness pertains to the zone where reconstitution of the fabric has been pronounced. Also, the distance between *surface-initiated cracks* 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 that shows little or no reconstitution is not part of the crust and does not contribute to the thickness.

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

The distinction between a bulked and compacted state for soil material with appreciable extensibility is made in part on the 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 would be propagated over distances greater than the horizontal dimensions of the larger structural units. Many soils have low extensibility because of texture, clay mineralogy, or both. For these soils, the expression of cracks cannot be used to distinguish between a bulked and 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 to which the actual degree of compaction is compared. 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 followed by drying 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 involves 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 employed.

Boundaries of Horizons and Layers

A boundary is a surface or 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 in 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:

Abrupt: Less than 2 cm thick

Clear: 2 to 5 cm thick

Gradual: 5 to 15 cm thick

Diffuse: More than 15 cm thick

Abrupt soil boundaries, such as those between the E and Bt horizons in 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 most difficult to locate and require time-consuming comparisons of small specimens of soil from various parts of the profile until the midpoint of the transitional zone is determined. 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. Even though soil layers are commonly seen in vertical section, they are three-dimensional. Topography of boundaries is described with the following terms:

Smooth:	The boundary is a plane with few or no irregularities.
Wavy:	The boundary has undulations in which depressions are wider then 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.

Root Restricting Depth

The root restricting depth is where root penetration would be strongly inhibited because of physical (including soil temperature) and/or chemical characteristics. Restriction means the incapability to support more than a few *fine* or *very fine* roots if depth from the soil surface and water state, other than the occurrence of frozen water, are not limiting. For cotton or soybeans and possibly other crops with less abundant roots than the grasses, 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 evaluation should be for the specific plants that are important to the use of the soil. These plants should be indicated. The root-restriction depth may differ depending on the plant considered.

Root-depth observations preferably should be used to make the generalization. If these are not available—and often they are not because roots do not extend to the depth of concern—then inferences may be made from morphology. Some guidelines follow for physical restriction. Chemical restrictions, such as high extractable aluminum and/or low extractable calcium, are not considered here. These are generally not determinable by field examination alone.

Physical root restriction is assumed at contact to rock, whether hard or soft. Further, certain pedogenic horizons, such as *fragipans*, infer root restriction. A change in particle size distribution alone, as for example loamy sand over gravel, is not always a basis for physical root restriction.

A common indication of physical root restriction is a combination of structure and consistence which together suggest 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. Root restriction is inferred for a continuously *cemented* zone of any thickness; or a zone >10-cm thick that when *very moist* or *wet* is *massive*, *platy*, or has *weak* structure of any type for a vertical repeat distance of >10 cm and while *very moist* or *wet* is *very firm* (*firm*, if sandy), *extremely firm*, or has a *large* penetration resistance.

Classes of root-restricting depth:

Very shallow:	< 25 cm
Shallow:	25-50 cm
Moderately deep:	50-100 cm
Deep:	100-150 cm
Very deep:	>150 cm

Particle Size Distribution

This section discusses particle distribution. The finer sizes are called *fine earth* (smaller than 2 mm diameter) as distinct from *rock fragments* (pebbles, cobbles, stones, and boulders). Particle-size distribution of fine earth or less than 2 mm is determined in the field mainly by feel. The content of rock fragments is determined by estimating the proportion of the soil volume that they occupy.

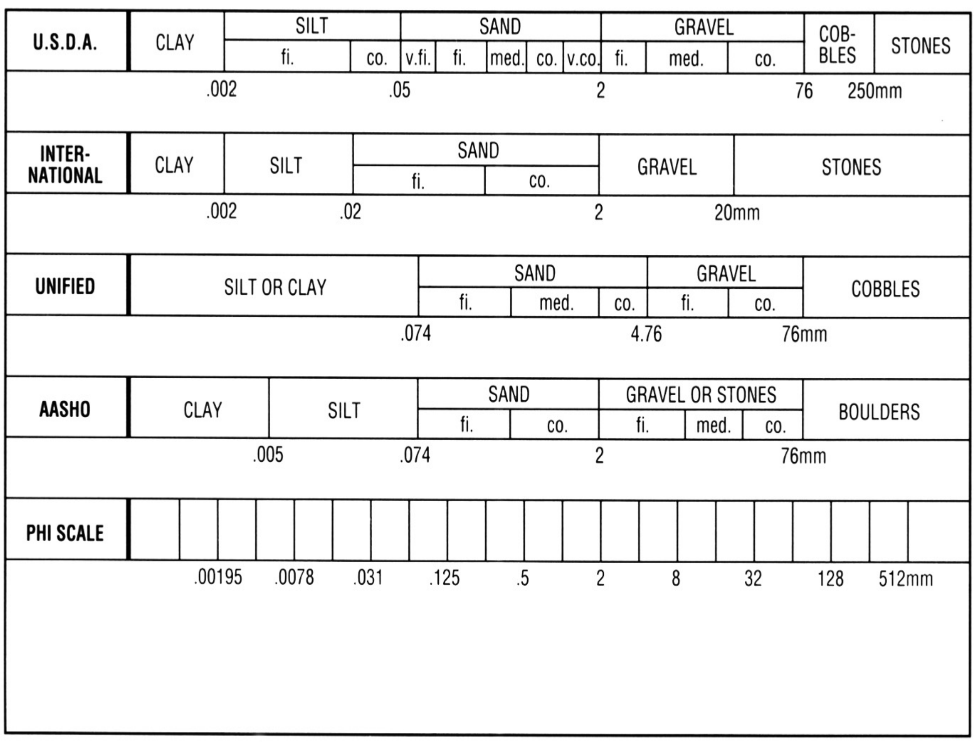
Soil Separates

The United States Department of Agriculture uses the following size separates for the <2 mm mineral material:

Very coarse sand:	2.0-1.0 mm
Coarse sand:	1.0-0.5 mm
Medium sand:	0.5-0.25 mm
Fine sand:	0.25-0.10 mm
Very fine sand:	0.10-0.05 mm
Silt:	0.05-0.002 mm
Clay:	< 0.002 mm

Figure 3-14 compares the USDA system with others.

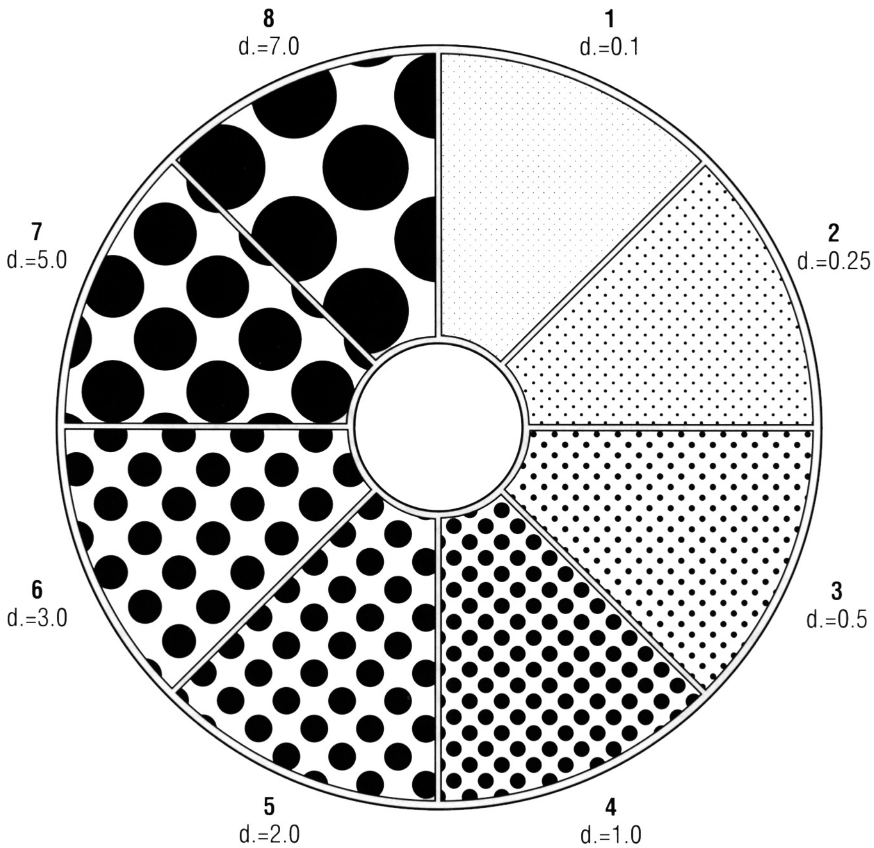
FIGURE 3-14



Relationships among particle size classes of 5 different systems.

Figure 3-15 illustrates classes of soil particles larger than silt.

FIGURE 3-15



Sizes of particles of indicated diameters (d) in millimeters.

Soil Texture

Soil texture refers to the weight proportion of the separates for particles less than 2 mm as determined from a laboratory particle-size distribution. Field estimates should be checked against laboratory determinations and the field criteria should be adjusted as necessary. Some soils are not dispersed completely in the standard particle size analysis. For these, the field texture is referred to as *apparent* because it is not an estimate of the results of a laboratory operation. Apparent field texture is a tactile evaluation only with no inference as to laboratory test results. Field criteria for estimating soil texture must be chosen to fit the soils of the area. Sand particles feel gritty and can be seen individually with the naked eye. Silt particles cannot be seen individually without magnification; they have a smooth feel to the fingers when dry or wet. In some places, clay soils are sticky; in others they are not. Soils dominated by montmorillonite clays, for example, feel different from soils that contain similar amounts of micaceous or kaolintic clay. Even locally, the relationships that are useful for judging texture of one kind of soil may not apply as well to another kind.

The texture classes (fig. 3-16) are sand, 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 subdivided into 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 the soil texture classes follow:

Sands.—More than 85 percent sand, the percentage of silt plus 1.5 times the percentage of clay is less than 15.

Coarse sand. A total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sand. 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.

Fine sand. 50 percent or more fine sand; or a total of less than 25 percent very coarse, coarse, and medium sand and less than 50 percent very fine sand.

Very fine sand. 50 percent or more very fine sand.

FIGURE 3-16

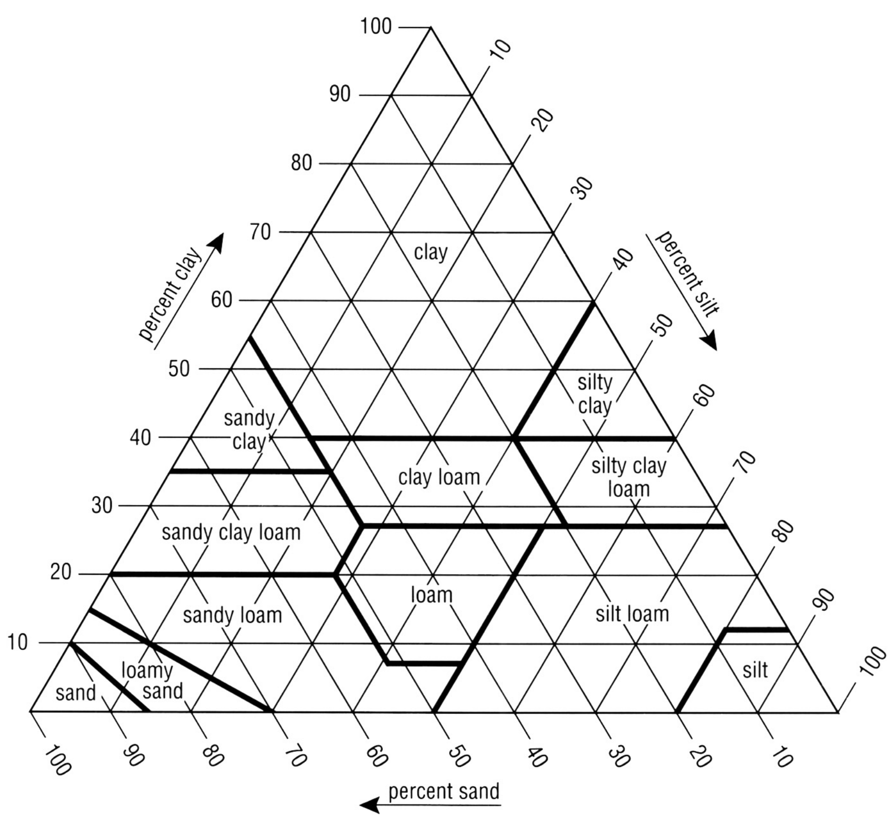


Chart showing the percentages of clay, silt, and sand in the basic textural classes.

Loamy sands.—Between 70 and 91 percent sand and 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. 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. A total of 25 percent or more very coarse, coarse, and medium sand and 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.

Loamy fine sand. 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. 50 percent or more very fine sand.

Sandy loams.—7 to 20 percent clay, more than 52 percent sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or less than 7 percent clay, less than 50 percent silt, and more than 43 percent sand.

Coarse sandy loam. A total of 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sandy loam. 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 and less than 30 percent fine sand and less than 30 percent very fine sand; or 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.

Fine sandy loam. 30 percent or more fine sand and less than 30 percent very fine sand; or a total of 15 to 30 percent very coarse, coarse, and medium sand; or a total of more than 40 percent fine and very fine sand, one half or more of which is fine sand, and a total of 15 percent or less very coarse, coarse, and medium sand.

Very fine sandy loam. 30 percent or more very fine sand and a total of less than 15 percent very coarse, coarse, and medium sand; or more than 40 percent fine and very fine sand, more than one half of which is very fine sand, and total of less than 15 percent very coarse, coarse, and medium sand.

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

Silt loam. 50 percent or more silt and 12 to 27 percent clay, or 50 to 80 percent silt and less than 12 percent clay.

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

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

Clay loam. 27 to 40 percent clay and more than 20 to 46 percent sand.

Silty clay loam. 27 to 40 percent clay and 20 percent or less sand.

Sandy clay. 35 percent or more clay and 45 percent or more sand.

Silty clay. 40 percent or more clay and 40 percent or more silt.

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

The texture triangle (fig. 3-16) is used to resolve problems related to word definitions, which are somewhat complicated. The eight distinctions in the sand and loamy sand groups provide refinement 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.

Groupings of soil texture classes.—The need for fine distinctions in the texture of the soil layers results in a large number of classes of soil texture. Often it is convenient to speak generally of broad groups or classes of texture. An outline of soil texture groups, in three classes and in five, follows. In some areas where soils are high in silt, a fourth general class, silty soils, may be used for silt and silt loam.

General terms [9]	*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 soils:	
Fine-textured	Sandy clay, silty clay, clay

[9] These are loamy, and clayey texture groups, not the sandy, loamy, and clayey particle-size classes defined in Soil Taxonomy.

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 a proportional amount of organic carbon, between 12 and 18 percent, if the clay content is between 0 and 60 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. A special effort is made to identify and estimate the volume occupied by *sphagnum* fibers, which have extraordinary high water retention characteristics. 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 2 cm 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.

Muck (sapric) is well-decomposed, organic soil material. *Peat* (fibric) is relatively undecomposed, organic material in which the original fibers constitute almost all of the material. *Mucky peat* (hemic) is material intermediate between muck and peat.

Rock Fragments

Rock fragments are unattached pieces of rock 2 mm in diameter or larger that are *strongly cemented* or more resistant to rupture. Rock fragments include all sizes that have horizontal dimensions less than the size of a pedon.

Rock fragments are described by size, shape, and, for some, the kind of rock. The classes are *pebbles, cobbles, channers, flagstones, stones,* and *boulders* (table 3-11). If a size or range of sizes predominates, the class is modified, as for example: "fine pebbles," "cobbles 100 to 150 mm in diameter," "channers 25 to 50 mm in length."

Gravel is a collection of pebbles that have diameters ranging from 2 to 75 mm. The term is applied to the collection of pebbles in a soil layer with no implication of geological formalization. The terms "pebble" and "cobble" are usually restricted to rounded or subrounded fragments; however, they can be used to describe angular fragments if they are not flat. Words like chert, limestone, and shale refer to a kind of rock, not a piece of rock. The composition of the fragments can be given: "chert pebbles," "limestone channers." The upper size of gravel is 3 inches (75 mm). 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 "3/4 inch" screen (19.05 mm) used in engineering.

The 75 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 (channers) and 380 mm (flagstones) limits for thin, flat fragments 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.

Rock Fragments in the Soil

Historically, the total volume of rock fragments of all sizes has been used to form classes. The interpretations program imposes requirements that cannot be met by grouping all sizes of rock fragments together. Furthermore, the interpretations program requires weight rather than volume estimates. For interpretations, the weight percent >250, 75-250, 5-75 and 2-5 mm are required; the first two are on a whole soil basis, and the latter two are on a <75 mm basis. For the >250 and 75-250 mm, weighing is generally impracticable. Volume percentage estimates would be made from areal percentage measurements by point-count or line-intersect methods. Length of the transect or area of the exposure should be 50 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 <75 mm weight, measurements are feasible but may require 50-60 kg of sample if appreciable rock fragments near 75 mm are present. An alternative is to obtain volume estimates for the 20-75 mm and weight estimates for the <20 mm. This is favored because of the difficulty in visual evaluation of the 2 to 5 mm size separations. The weight percentages of 5-20 and 2-5 mm may be converted to volume estimates and placed on a <75 mm base by computation. The adjectival form of a class name of rock fragments (table 3-11) is used as a modifier of the textural class name: "gravelly loam," "stony loam."

Table 3-11. Terms for rock fragments

Shape and size[1]	Noun	Adjective
Spherical, cubelike, or equiaxial:		
2-75 mm diameter	Pebbles	Gravelly
2-5 mm diameter	Fine	Fine gravelly
5-20 mm diameter	Medium	Medium gravelly
20-75 mm diameter	Coarse	Coarse gravelly
75-250 mm diameter	Cobbles	Cobbly.
250-600 mm diameter	Stones	Stony.
≥600 mm diameter	Boulders	Bouldery.
Flat:		
2-150 mm long	Channers	Channery.
150-380 mm long	Flagstones	Flaggy.
380-600 mm long	Stones	Stony.
≥600 mm long	Boulders	Bouldery.

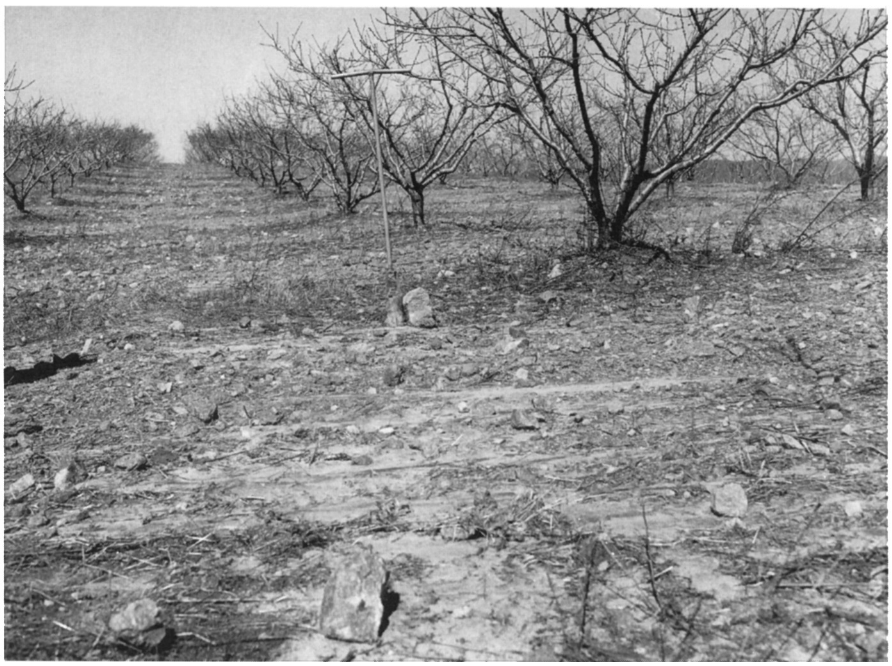
[1]The roundness of the fragments may be indicated as angular (strongly developed faces with sharp edges), irregular (prominent flat faces with incipient rounding or corners), subrounded (detectable flat faces with well-rounded corners), and rounded (flat faces absent or nearly absent with all corners.

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

Less than 15 percent: No adjectival or modifying terms are used in writing for contrast with soils having less than 15 percent pebbles, cobbles, or flagstones. The adjective "slightly" may be used, however, to recognize those soils used for special purposes.

15 to 35 percent: The adjectival term of the dominant kind of rock fragment is used as a modifier of the textural term: "gravelly loam," "channery loam," "cobbly loam" (fig. 3-17).

FIGURE 3-17



A soil with cobbly horizon. Both angular cobbles and angular pebbles are present, but the cobbles dominate in the limitations they impose. Rock fragments occupy

35 to 60 percent: The adjectival term of the dominant kind of rock fragment is used with the word "very" as a modifier of the textural term: "very gravelly loam," "very flaggy loam" (fig. 3-18).

More than 60 percent: If enough fine earth is present to determine the textural class (approximately 10 percent or more by volume) the adjectival term of the dominant kind of rock fragment is used with the word "extremely" as a modifier of the textural term: "extremely gravelly loam," "extremely bouldery loam." If there is too little fine earth to determine the textural class (less than about 10 percent by volume) the term "gravel," "cobbles," "stones," or "boulders" is used as appropriate.

The class limits apply to the volume of the layer occupied by all pieces of rock larger than 2 mm. The soil generally contains fragments smaller or larger than those identified in the term. For example, a stony loam usually contains pebbles, but "gravelly" is not mentioned 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.

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

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.

FIGURE 3-18

A soil with a very cobbly surface horizon. Rock fragments occupy about 40 percent of the plowed layer and are concentrated on the surface.

Rock Fragments at the Surface

The treatment of gravel, cobbles and channers (2-250 mm) differs from that for stones and boulders (>250 mm).[10] The reason for the difference is that an important aspect of the description of the 2-250 mm is the areal percent cover on the ground surface afforded by the rock fragments. For the >250 mm, the percent of cover is not of itself as important as the interference with mechanical manipulation of the soil. A very small areal percentage of large rock fragments, insignificant for erosion protection, may interfere with tillage.

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

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[10] These terms are defined in table 3-11.

The number, size, and spacing of stones and boulders (>250 mm) on the surface of a soil, including both those that lie on the surface and those that are partly within the soil but protrude above ground, have important effects on soil use and management. The class limits that follow are given in terms of the approximate amount of stones and boulders at the surface.

Class 1. Stones or boulders cover about 0.01 to 0.1 percent of the surface. Stones of the smallest sizes are at least 8 m apart; boulders of the smallest sizes are at least 20 m apart (fig. 3-19).

Class 2. Stones or boulders cover about 0.1 to 3 percent of the surface. Stones of the smallest sizes are not less than 1 m apart; boulders of the smallest size are no less than 3 m apart.

Class 3. Stones or boulders cover about 3 to 15 percent of the surface. Stones of the smallest size are as little as 0.5 m apart; boulders of the smallest size are as little as 1 m apart (fig. 3-21).

Class 4. Stones or boulders cover about 15 to 50 percent of the surface. Stones of the smallest size are as little as 0.3 m apart; boulders of the smallest size are as little as 0.5 m apart. In most places it is possible to step from stone to stone or jump from boulder to boulder without touching the soil (fig. 3-22).

Class 5. Stones or boulders appear to be nearly continuous and cover 50 to 90 percent of the surface. Stones of the smallest size are less than 0.03 m apart; boulders of the smallest size are less than 0.05 m apart. Classifiable soil is among the rock fragments, and plants can grow if not otherwise limited (fig. 3-23).

These limits are intended only as guides to amounts that may mark critical limitations for major kinds of land use. Table 3-12 is a summary of the classes.

Table 3-12. Classes of surface stones and boulders in terms of cover and spacing

Class	Percentage	Distance in meters between stones			
		0.25 m[1]	0.6 m	1.2 m	Name
1	0.01-0.1	≥8	≥20	≥37	Stony or bouldery
2	0.1-3.0	1-8	3-20	6-37	Very stony or very
3	3.0-15	0.5-1	1-3	2-6	Extremely stony or
4	15-50	0.3-0.5	0.5-1	1-2	Rubbly
5	50-90	<0.3	<0.5	<1	Very Rubbly

[1] 0.38 m if flat.

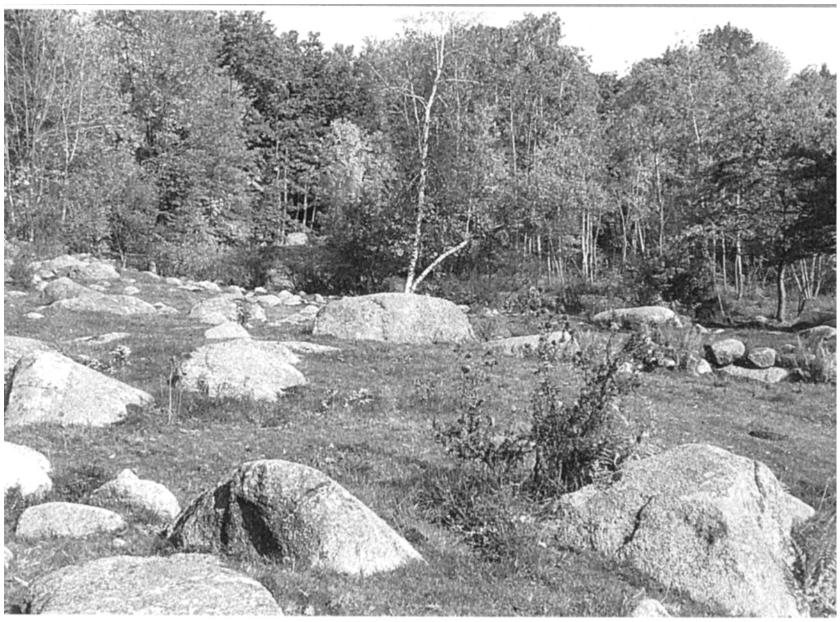
FIGURE 3-19

An area of bouldery soil (class 1).

FIGURE 3-20

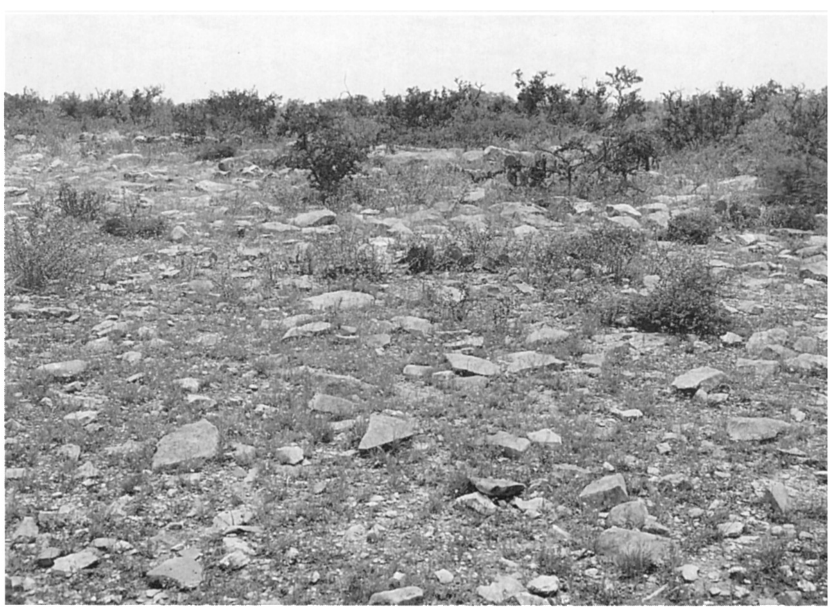
An area of very bouldery soil (class 2).

FIGURE 3-21



An area of extremely bouldery soil (class 3).

FIGURE 3-22



An area of rubbly soil (class 4).

FIGURE 3-23

An area of very rubbly soil (class 5).

Soil Color

Elements of soil color descriptions are the color name, the Munsell notation, the water state, and the physical state: "brown (10YR 5/3), dry, crushed, and smoothed."

Physical state is recorded as broken, rubbed, crushed, or crushed and smoothed. The term "crushed" usually applies to dry samples and "rubbed" to moist samples. If unspecified, the surface is broken. The color of the soil is recorded for a surface broken through a ped if a ped can be broken as a unit.

The color value of most soil material becomes 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 as color determinations of wet soil may be in error because of the light reflection of water films. In a humid region, the moist state generally is considered 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 usually described first. Both moist and dry colors are particularly valuable for the immediate surface and tilled horizons in order to assess reflectance.

Munsell notation is obtained by comparison with a Munsell system color chart. The most commonly used chart includes only about one fifth of the entire range of hues.[11] It consists of about 250 different colored papers, or chips, systematically arranged on hue cards according to their Munsell notations. Figure 3-24 illustrates the arrangements of color chips on a Munsell color card.

The Munsell color system uses three elements of color—*hue, value,* and *chroma*—to make up a color notation. The notation is recorded in the form: hue, value/chroma—for example, 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 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 3-25. Each of the 10 major hues is divided into four segments of equal visual steps, which are designated by numerical values applied as prefixes to the symbol for the hue name.[12] In figure 3-25, 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.

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 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 or chromatic 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 3-24 shows this arrangement vertically on the card for the hue of 10YR.

Chroma is the relative purity or strength of the spectral color. Chroma 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 a chroma of /8 as the strongest expression of color used for soils. Figure 3-24 illustrates that color chips are arranged horizontally by increasing chroma from left to right on the color card.

The complete color notation can be visualized from figure 3-24. Pale brown, for example, is designated 10YR 6/3. Very dark brown is designated 10YR 2/2. All of the colors on the chart have hue of 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; the strongest expression of chroma is at the right.

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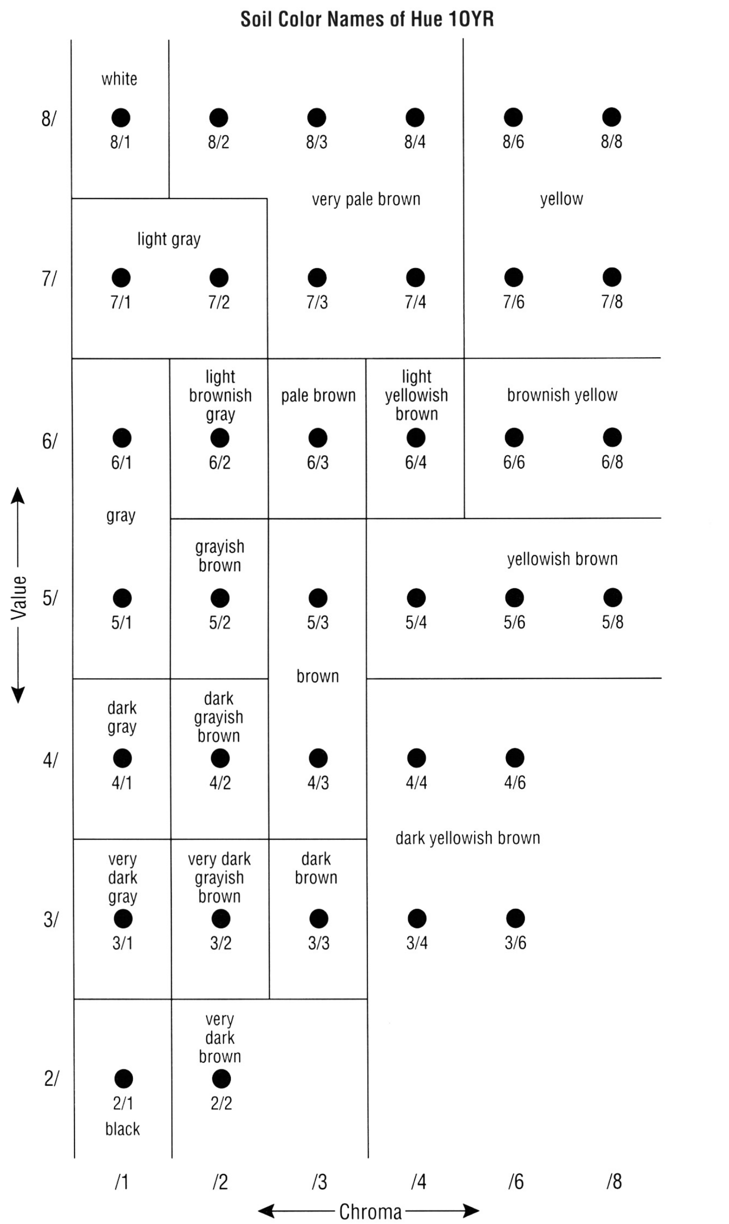
[11] The appropriate color chips, separate or mounted by hue on special cards for a loose leaf notebook, may be obtained from the Munsell Company.

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

FIGURE 3-24

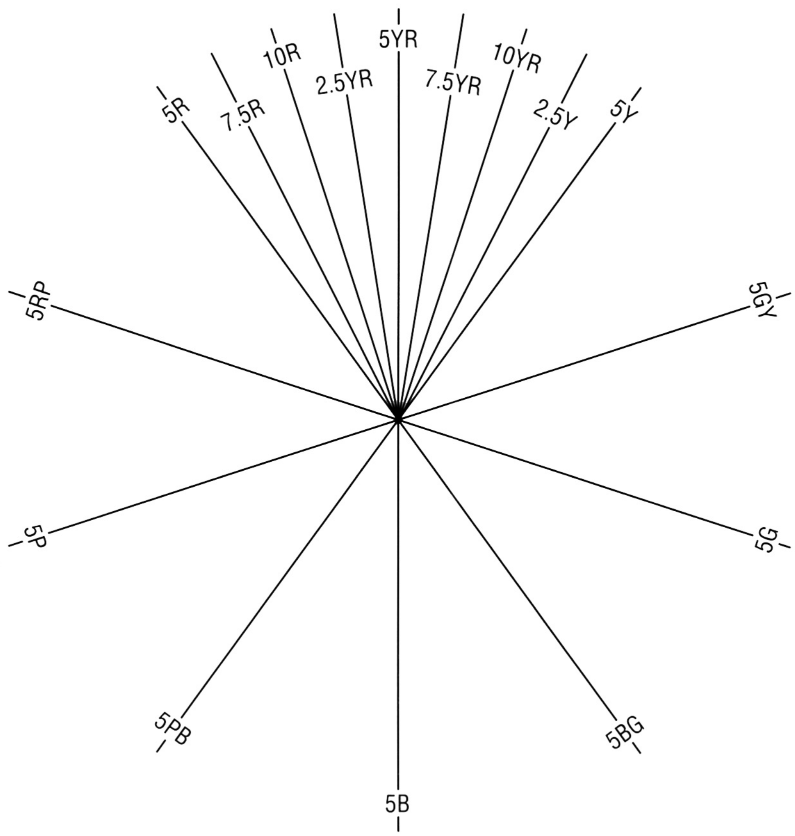


The arrangement of color chips according to value and chroma on the soil-color card of 10YR hue.

At the extreme left of the card are symbols such as N 6/. These are colors of zero chroma which are totally achromatic—neutral color. They have no hue and no chroma but range in value from black (N 2/) 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," for the hue is hardly perceptible at such low chroma.

Conditions for measuring color.—The quality and intensity of the light affect the amount and quality of the light reflected from the sample to the eye. The moisture content of the sample

FIGURE 3-25



A schematic diagram of relationships among the five principal and five intermediate hues of the Munsell Color System and subdivisions within the part used for most soil colors.

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 is 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 used must be as near the white light of midday as possible. With practice, compensation can be made for the differences unless the light is so subdued that the distinctions between color chips are not apparent. 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 nearly as possible at a right angle. For crushed samples, the surface is smoothed; the state is recorded as "dry, crushed, and smoothed."

Recording Guidelines

Uncertainty.—Under field conditions, measurements of color are reproducible by different individuals within 2.5 units of hue (one card) and 1 unit of value and chroma. Notations are made to the nearest whole unit of value and chroma.

Before 1989, the cards for hues of 2.5YR, 7.5YR, and 2.5Y did not include chips for colors having chroma of 3. These colors are encountered frequently in some soils and can be estimated reliably by interpolation between adjacent chips of the same hue. Chips for chromas of 5 and 7 are not provided on any of the standard color cards. Determinations are usually not precise enough to justify interpolation between chromas of 4 and 6 or 6 and 8. Color should never be extrapolated beyond the highest chip. It should also be rounded to the nearest chip.

For many purposes, the differences between colors of some adjacent color chips have little significance. For such purposes, color notations have been grouped, and the groups have been named (fig. 3-24).

Dominant Color

The dominant color is the color that occupies the greatest volume of the layer. Dominant color (or colors) is always given first among those of a multicolored layer. It is judged on the basis of colors of a broken sample. For only two colors, the dominant color makes up more than 50 percent of the volume. For three or more colors, the dominant color makes up more of the volume of the layer 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. It 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 are about equal 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.

Mottling

Mottling refers to repetitive color changes that cannot be associated with compositional properties of the soil. Redoximorphic features are a type of mottling that is associated with wetness. A color pattern that can be related to proximity to a ped surface or other organizational or compositional feature is not mottling. Mottle description follows the dominant color. Mottles are described by quantity, size, contrast, color, and other attributes in that order.

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

few: less than 2 percent,

common: 2 to 20 percent, and

many: more than 20 percent.

The notations must clearly indicate to which colors the terms for quantity apply. For example, "common grayish brown and yellowish brown mottles" could mean that each 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 read "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. Three size classes are used:

fine: smaller than 5 mm,

medium: 5 to 15 mm, and

coarse: larger than 15 mm.

Contrast refers to the degree of visual distinction that is evident between associated colors:

Faint: Evident only on close examination. Faint mottles commonly have the same hue as the color to which they are compared and differ by no more than 1 unit of chroma or 2 units of value. Some faint mottles of similar but low chroma and value differ by 2.5 units (one card) of hue.

Distinct: Readily seen but contrast only moderately with the color to which they are compared. Distinct mottles commonly have the same hue as the color to which they are compared but differ by 2 to 4 units of chroma or 3 to 4 units of value; or differ from the color to which they are compared by 2.5 units (one card) of hue but by no more than 1 unit of chroma or 2 units of value.

Prominent: Contrast strongly with the color to which they are compared. Prominent mottles are commonly the most obvious color feature of the section described. Prominent mottles that have medium chroma and value commonly differ from the color to which they are compared by at least 5 units (two pages) of hue if chroma and value are the same; at least 4 units of value or chroma if the hue is the same; or at least 1 unit of chroma or 2 units of value if hue differs by 2.5 units (one card).

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 commonly involving several colors.

Shape, location, and character of boundaries of mottles are indicated as needed. *Shape* is described by common words such as streaks, bands, tongues, tubes, and spots. *Location* of mottles as related to structure of the soil may be significant. *Boundaries* may be described as *sharp* (color gradation is not discernable with the naked eye), *clear* (color grades over less than 2 mm), or *diffuse* (color grades over more than 2 mm).

Moisture state and physical state of the dominant color are presumed to apply to the mottles unless the description states otherwise. An example, for which a standard moist broken state of the sample has been specified, might read "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 at other moisture states. The color of mottles commonly is given only for the standard state unless special significance can be attached to colors at another state.

A nearly equal mixture of two colors for a moist broken standard state can be written "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, "common medium faint dark grayish brown (10YR 4/2) mottles, grayish brown (10YR 5/2) dry" can be added.

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

Color Patterns

Color, including mottling, may be described separately for any feature that may merit a separate description, such as peds, concretions, nodules, cemented bodies, filled animal burrows, and the like. Color patterns that exhibit a spatial relationship to composition changes or to features such as nodules or surfaces of structural units may be useful to record because of the inferences that may be drawn about genesis and soil behavior. Colors may be given for extensions of material from another soil layer. The fine tubular color patterns that extend vertically below the A horizon of some wet soils, for example, were determined by the environment adjacent to roots that once occupied the tubules. The rim of bright color within an outer layer of lighter color at the surface of some peds relate to water movement into and out of the peds and to oxidation-reduction relationships.

Ground surface color.—The color value of the immediate ground surface may differ markedly from that of the surface horizon. For example, raindrop impact may have removed clay-size material from the surface of sand and silt which results in a surficial millimeter or so of increased color value. 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. Color information is, therefore, desirable for the actual ground surface inclusive of the vegetation as well as the soil material. Surface color influences reflectivity of light, therefore, the capacity to absorb and release radiant energy.

Surface soil colors commonly range widely at a site, and it may be necessary to array mentally the color values and their areal proportion for the ground surface, whether rock fragments, dead vegetation, or fine earth. Then a single color value is selected 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. Estimation of the areal proportion of components is discussed in the section on ground cover.

Soil Structure

Soil structure refers to units composed of primary particles. The cohesion within these units is greater than the adhesion among units. As a consequence, under stress, the soil mass tends to rupture along predetermined planes or zones. These planes or zones, in turn, form the boundary. 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 employed. 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 differ as to composition or organization, or both, because of soil development. Earthy *clods* and *fragments* stand in contrast to peds, for which soil forming processes exert weak or no control on the boundaries. Some clods, adjacent to the surface of the body, exhibit some rearrangement of primary particles to a denser configuration through mechanical means. The same terms and criteria used to describe structured soils should be used to describe the shape, grade, and size of clods. Structure is not inferred by using the terms interchangeably. A size sufficient to affect tilth adversely must be considered. The distinction between clods and fragments rests on the degree of consolidation by mechanical means. Soil fragments include (1) units of undisturbed soil with bounding planes of weakness that are formed on drying without application of external force and which do not appear to have predetermined bounding planes, (2) units of soil disturbed by mechanical means but without significant rearrangement to a denser configuration, and (3) pieces of soil bounded by planes of weakness caused by pressure exerted during examination with size and shape highly dependent on the manner of manipulation.

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 by tapping a spade containing a slice of soil against a hard surface or dropping a large fragment on the ground. When structureless soils are ruptured, soil fragments, single grains, or both result. Structureless soil material may be either single grain or massive. Soil material of single grains lacks structure. In addition, it is loose. On rupture, more than 50 percent of the mass consists of discrete mineral particles.

Some soils have *simple structure*, each unit being an entity without component smaller units. Others have *compound structure*, in which 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 consists of separate sets of terms designating each of the three properties, which by combination form the names for structure.

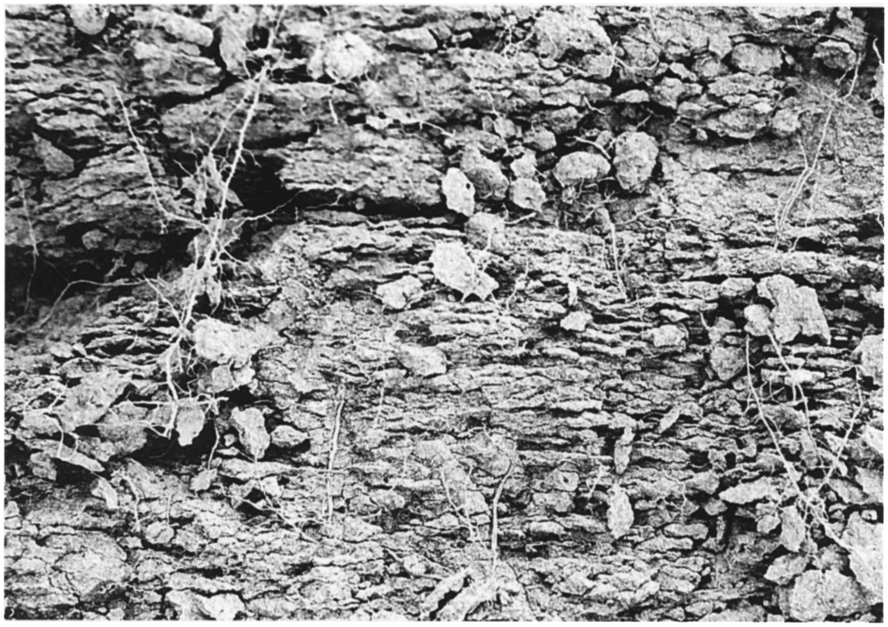
Shape.—Several basic shapes of structural units are recognized in soils. Supplemental statements about the variations in shape of individual peds are needed in detailed descriptions of some soils. The following terms describe the basic shapes and related arrangements:

platy: The units are flat and platelike. They are generally oriented horizontally. Platy structure is illustrated in figure 3-26. A special form, lenticular platy structure, is recognized for plates that are thickest in the middle and thin toward the edges.

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. Prismatic structure is illustrated in figure 3-27.

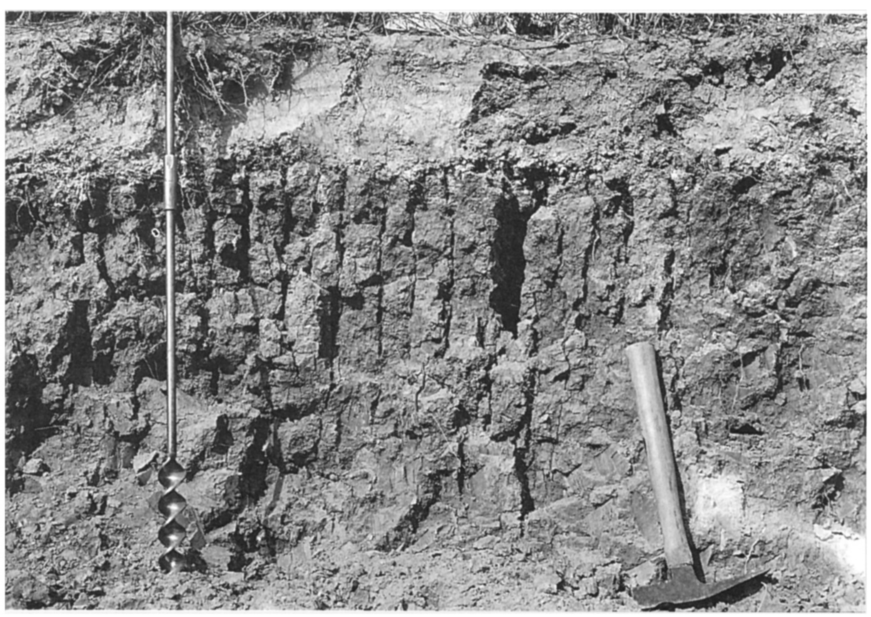
columnar: The units are similar to prisms and are bounded by flat or slightly rounded vertical faces. The tops of columns, in contrast to those of prisms, are very distinct and normally rounded, as illustrated in figure 3-28.

FIGURE 3-26



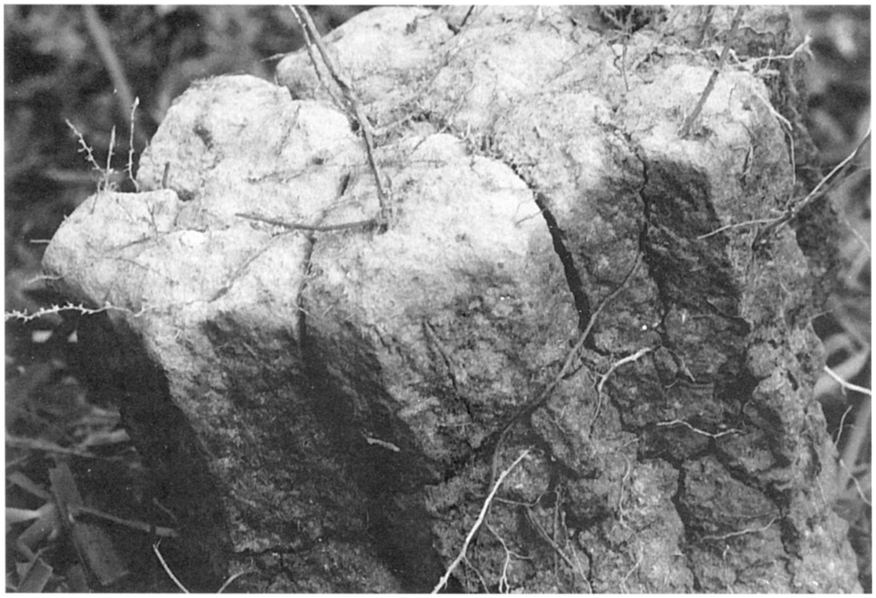
Strong thin platy structure

FIGURE 3-27



Strong medium platy structure. The prisms are 35 to 45 mm across.

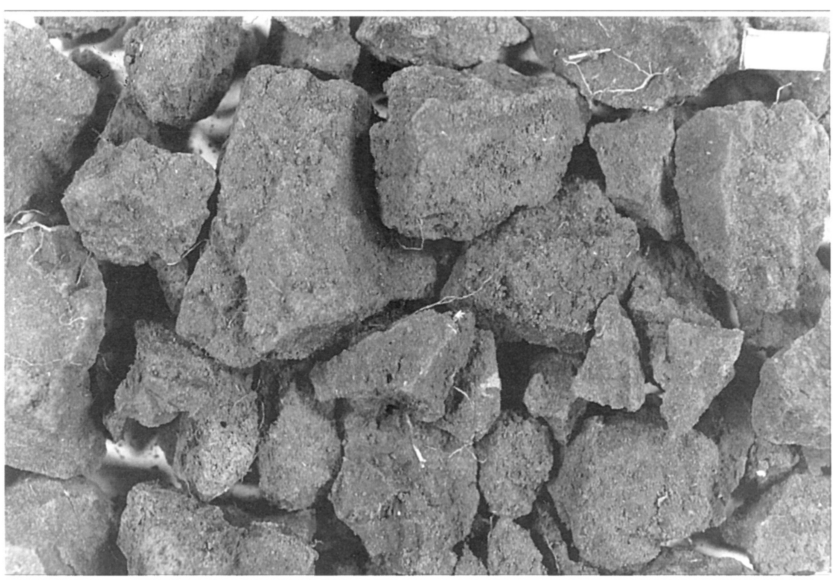
FIGURE 3-28



A cluster of strong medium columnar peds. The cluster is about 135 mm across.

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 to plates. The structure is described as angular blocky if the faces intersect at relatively sharp angles; as subangular blocky if the faces are a mixture of rounded and plane faces and the corners are mostly rounded. Figure 3-29 illustrates angular blocky units.

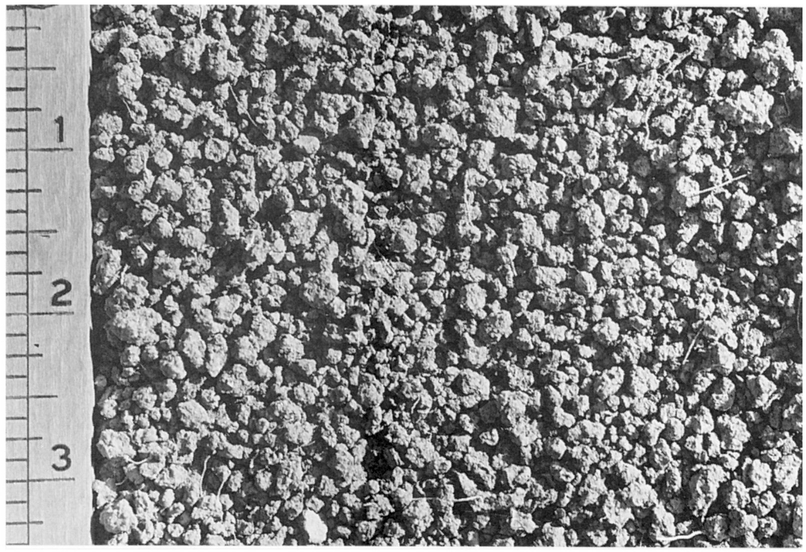
FIGURE 3-29



Strong medium and coarse blocky peds.

granular: The units are approximately spherical or polyhedral and are bounded by curved or very irregular faces that are not casts of adjoining peds. Granular units are illustrated in figure 3-30.

FIGURE 3-30



Strong fine and medium granular peds.

Size.—Five classes are employed: very fine, fine, medium, coarse, and very coarse. The size limits of the classes differ according to the shape of the units. The size limit classes are given in table 3-13. The size limits refer to the smallest dimension of plates, prisms, and columns. If the units are more than twice the minimum size of "very coarse," the actual size is given: "prisms 30 to 40 cm across."

Grade.—Grade describes the distinctness of units. Criteria 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 gently disturbed, the soil material parts into a mixture of whole and broken units and much material that exhibits no planes of weakness. Faces that indicate persistence through wet-dry-wet cycles are evident if the soil is handled carefully. Distinguishing structurelessness from weak structure is sometimes 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.

Table 3-13. Size classes of soil structure

	Shape of structure			
Size Classes	***Platy*** [1] mm	***Prismatic and Columnar*** mm	***Blocky*** mm	***Granular*** mm
1	<1	<10	<5	<1
2	1-2	10-20	5-10	1-2
3	2-5	20-50	10-20	2-5
4	5-10	50-100	20-50	5-10
5	>10	>100	>50	>10

[1] In describing plates, "thin" is used instead of "fine" and "thick" instead of "coarse."

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 they may 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.

The three terms for soil structure are combined in the order (1) grade, (2) size, (3) shape. "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 when necessary to describe other characteristics. Surface characteristics of units are described separately. Special structural units, such as the wedge-shaped units of Vertisols, are described in appropriate terms.

Compound Structure

Smaller structural units may be held together to form larger units. Grade, size, and shape are given for both and the relationship of one set to the other is indicated: "strong medium blocks within moderate coarse prisms," or "moderate coarse prismatic structure parting to strong medium blocky."

Extra-Structural Cracks

Cracks are macroscopic vertical planar voids with a width much smaller than length and depth. A crack represents the release of strain that is a consequence of drying. In many soils, cracks bound individual structural units. These cracks are repetitive and usually quite narrow. Their presence is part of the concept of the structure. The cracks to be discussed are the result of localized stress release which forms planar voids that are wider than the repetitive planar voids between structural units or which occur in massive or weakly structured material at relatively wide intervals. These cracks may be coextensive with crack space between structural units. If they are coextensive, the width exceeds that of the associated structural cracks. The areal percentage of such cracks, either on a vertical exposure or on the ground surface, may be measured by line-intercept methods. For taxonomic purposes, the width and depth of cracks has importance. Four kinds of extra-structural cracks may be recognized:

Surface-initiated reversible 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.

Surface-initiated irreversible cracks form on near-surface water reduction from exceptionally high water content related to freeze-thaw action and other processes. The cracks do not close completely when rewet and extend through the crust formed by frost action. They act to increase ponded infiltration rates.

Subsurface-initiated reversible cracks form as a result of appreciable reduction in water content from "field capacity" in horizons or layers with considerable extensibility. They close in a matter 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 (mechanically bulked subzones (fig. 3-13, for example)). Such cracks importantly influence ponded infiltration rates and evaporation directly from the soil.

Subsurface-initiated irreversible cracks are the "permanent" cracks of the USDA soil taxonomy system (see figure 3-31). They have a similar origin to surface-initiated irreversible cracks, although quite different agencies are involved.

The foregoing genetic definition of cracks does not directly relate to prediction of infiltration. For such predictions, the surface connectiveness of the cracks and their depth must be specified. *Surface-connected cracks* occur at the ground surface or are covered by up to 10-15 cm of soil material that would permit the accumulation of free water at the plane that marks the top of the crack under conditions that may occur in most years. If the antecedent water state of the overlying zone were *very moist*, free water from 25 mm of rainfall in one hour should reach the top of the cracks. Usually the zone would have *very high* or *high* saturated hydraulic conductivity. Such subzones may exhibit structure or be single grain. The structure units range widely in size. The common characteristic is that the consistent units of the mass as a whole are highly discrete and the porosity of the interstices among the structural units is high. If not too thick, the *mechanically bulked* subzone of tilled surface horizons would be such a zone.

FIGURE 3-31

Natural fragments formed by cracking of a massive soil as it contracted upon drying.

A crack depth index value may be obtained by insertion of a blunt wire, approximately 2 mm in diameter.[13] *Penetrant cracks* are 15 cm or more in depth as measured by wire insertion. Cracks that are both *penetrant* and *surface connected* are described as *penetrant surface connected*. Penetrant surface-connected cracks act to increase transient ponded infiltration. Prominence of the penetrant surface-connected cracks would depend on the linear distance of such cracks per unit area of ground surface. The linear distance may be allowed to decrease as crack depths increase. No classes are provided.

Internal Surface Features

Surface features include (1) coats of a variety of substances unlike the adjacent soil material and covering part or all of surfaces, (2) material concentrated on surfaces by the removal of other material, and (3) stress formations in which thin layers at the surfaces have undergone reorientation or packing by stress or shear. All differ from the adjacent material in composition, orientation, or packing.

Descriptions of surface features may include kind, location, amount, continuity, distinctness, and thickness of the features. In addition, color, texture, and other characteristics that apply may be described, especially if they contrast with the characteristics of the adjacent material.

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

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[13] Crack depth by wire insertion may yield shallower depths than is measured by pouring loose sand into the crack and excavating after wetting and the crack has closed. The latter method, however, is only suitable for detailed examination; whereas, wire insertion is relatively rapid and can be completed in a single observation.

Clay films (synonymous with clay skins) are thin layers of oriented, translocated clay.

Clay bridges link together adjacent mineral grains.

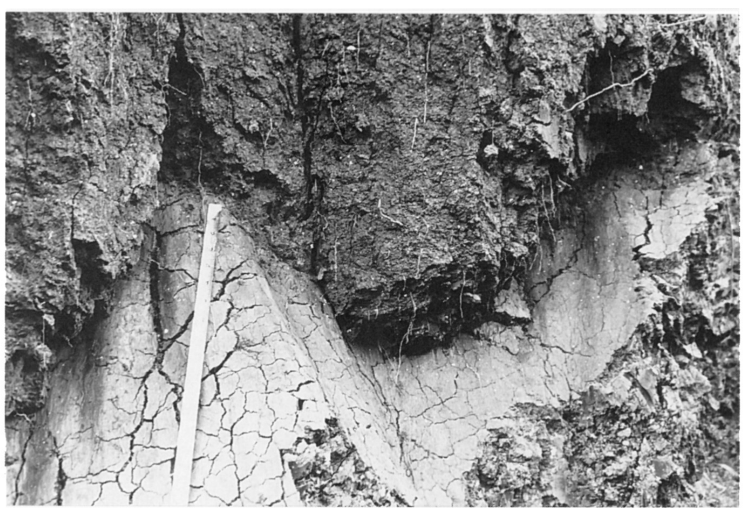
Sand or silt coats are sand or silt grains adhering to a surface. Some sand and silt coats are concentrations of the sand and silt originally in the horizon from which finer particles have been removed. Some sand and silt coats are material that has been moved from horizons above and deposited on surfaces. In some coats the grains are almost free of finer material; in others, the grains themselves are coated. If known, the composition of the coat is noted.

Other coats are described by properties that can be observed in the field. The coats are composed variously of iron, aluminum or manganese oxides, organic matter, salts, or carbonates. Laboratory analyses may be needed for a positive identification.

Stress surfaces (pressure faces) are smoothed or smeared surfaces. They are formed through rearrangement as a result of shear forces. They may persist through successive drying and wetting cycles.

Slickensides (fig. 3-32) are stress surfaces that are polished and striated and usually have dimensions exceeding 5 cm. They are produced by relatively large volumes of soil sliding over another. They are common below 50 cm in swelling clays which are subject to large changes in water state.

FIGURE 3-32



Intersecting slickensides in the Bss horizon of a Udic Haplustert. The cracking is due to drying after exposure.

Location.—The various surface features may be on some or all structural units, channels, pores, primary particles or grains, soil fragments, rock fragments, nodules, or concretions. The kind and orientation of surface on which features are observed is always given. For example, if clay films are on vertical but not horizontal faces of peds, this fact should be recorded.

Amount.—The percentage of the total surface area of the kind of surface considered occupied by a particular surface feature over the extent of the horizon or layer is described. Amount can be characterized by the following classes:

very few:	Occupies < 5 percent.
few:	Occupies 5 to 25 percent.
common:	Occupies 25 to 50 percent.
many:	Occupies > 50 percent.

The same classes are used to describe the amount of "bridges" connecting particles. The amount is judged on the basis of the percentage of particles of the size designated 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. Distinctness is related to thickness, color contrast with the adjacent material, and other properties. It is, however, not itself a measure of any one of them. Some thick coats, for example, are faint; some thin ones are prominent. The distinctness of some surface features changes markedly as water state changes. Three classes are used.

Faint. 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 small.

Distinct. Can be detected without magnification, although magnification or tests may be needed for positive identification. The feature contrasts enough with the adjacent material to make a difference in color, texture, or other properties evident.

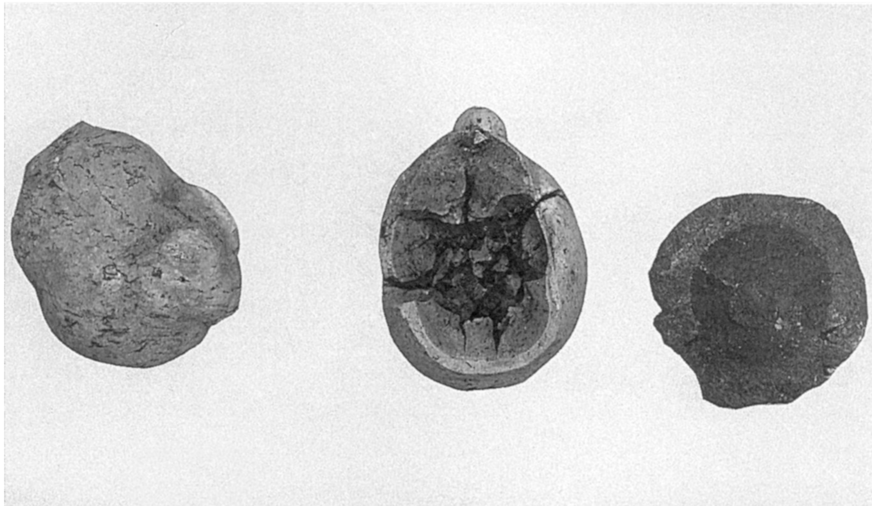
Prominent. Conspicuous without magnification when compared with a surface broken through the soil. Color, texture, or some other property or combination of properties contrasts sharply with properties of the adjacent material or the feature is thick enough to be conspicuous.

The order of description is usually amount, distinctness, color, texture, kind, and location. Two examples: "few distinct grayish brown (10YR 5/2) clay films on vertical faces of peds"; "many distinct brown clay bridges between mineral grains." Only properties are listed that add to the understanding of the soil. If texture of the surface feature is obvious, as in most stress surfaces, repeating texture adds nothing. Kind and location are essential if the feature is mentioned at all. The conventions do not characterize the volume of the surface features. If volume is important, it is estimated separately.

Concentrations

The features discussed here are identifiable bodies within the soil that were formed by pedogenesis. Some of these bodies are thin and sheetlike; some are nearly equidimensional; others have irregular shapes. They may contrast sharply with the surrounding material in

FIGURE 3-32



Nodules and concretions: an unbroken nodule at the left, a broken concretion at the right, a hollow nodule in the middle.

strength, composition, or internal organization. Alternatively, the differences from the surrounding material may be slight. Soft rock fragments which have rock structure but are *weakly cemented* or *noncemented* are not considered concentrations. They are excluded on the basis of inference as to a geological as opposed to a pedological origin.

Masses are noncemented concentrations of substances that commonly cannot be removed from the soil as a discrete unit. Most accumulations consist of calcium carbonate, fine crystals of gypsum or more soluble salts, or iron and manganese oxides. Except for very unusual conditions, masses have formed in place.

Plinthite consists of reddish, iron-enriched bodies that are low in organic matter and are coherent enough to be separated readily from the surrounding soil. Plinthite commonly occurs within and above reticulately mottled horizons. Plinthite 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 the natural setting. The bodies are commonly about 5 to 20 mm across their smallest dimension. Plinthite bodies are *firm* or *very firm* when moist, *hard* or *very hard* when air dry, and become *moderately cemented* on repetitive wetting and drying. They 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 when rubbed while wet, but the plinthite center does not. It has a harsh, dry feel when rubbed, even if wet. Horizons containing plinthite are more difficult to penetrate with an auger than adjacent horizons at the same water state and clay content but which do not contain plinthite. Plinthite generally becomes less cemented after prolonged submergence in water. An air dry sample can be dispersed by normal procedures for particle-size distribution.

Nodules and *concretions* are cemented bodies that can be removed from the soil intact. Composition ranges from material dominantly like that of the surrounding soil to nearly pure chemical substances entirely different from the surrounding material. Their form is apparently not governed by crystal forms based on examination at a magnification of 10X as is the case for crystals and clusters of crystals. It is impossible to be sure if some certain nodules and concretions formed where they are observed or were transported.

Concretions are distinguished from nodules on the basis of internal organization. Concretions have crude internal symmetry organized around a point, a line, or a plane. Nodules lack evident, orderly, internal organization. A typical example of a concretion organized around a point is illustrated in figure 3-33. The internal structure typically takes the form of concentric layers that are clearly visible to the naked eye. A coat or a very thin outer layer of an otherwise undifferentiated body does not indicate a concretion.

Crystals are considered to have been formed in place. They may occur singly or in clusters. Crystals of gypsum, calcite, halite, and other pure compounds are common in some soils. These are described as crystals or clusters of crystals, and their composition is given if known.

Ironstone is an in-place concentration of iron oxides that is at least *weakly cemented*. Ironstone nodules are commonly found in layers above plinthite. These ironstone nodules are apparently plinthite that has cemented irreversibly as a result of repeated wetting and drying. Commonly, the center of iron-rich bodies cements upon repeated wetting and drying but the periphery does not.

Describing Concentrations Within the Soil

Any of a large number of attributes of concentrations within the soil may be important; the most common are number or amount, size, shape, consistence, color composition, kind, and location. Not all of these attributes are necessarily described. The order as listed above is convenient for describing them, as for example: "many, fine, irregular, hard, light gray, carbonate nodules distributed uniformly through the horizon." The conventions for describing kind have been indicated in this section. Descriptions of 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 used for quantity of mottles are also used for these features.

Size may be measured directly or given by the classes listed below. The dimension to which size-class limits apply depends on the shape of the body described. If the body 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 irregular bodies, size refers to the longest dimension unless that creates an erroneous impression; measurements can be given if needed.

The following size classes are used:

fine	< 2 mm
medium	2 - 5 mm
coarse	5 - 20 mm
very coarse	20 - 76 mm
extremely coarse	> 76 mm

Shape of concentrations is variable both among kinds of concentrations and commonly within a concentration. The following terms are suggested:

rounded: Approximately equidimensional, a few sharp corners, and at least approximately regular.

cylindrical: At least crudely cylindrical or tubular; one dimension is much greater than the other two.

platelike: Shaped crudely like a plate; one dimension is very much smaller than the other two. The term "platelike" is used to avoid confusion with platy structure.

irregular: Characterized by branching, convoluted, or mycelial form.

The terms listed apply to all concentrations. Individual crystals of a particular mineral usually implies a shape.

Composition of bodies is described if known and if important for understanding their nature or the nature of the soil in which they are observed. 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 that are composed dominantly of a single substance and those that are composed of earthy material impregnated by various substances. For many bodies, the chemical composition cannot be determined with certainty in the field. The following set of terms, however, is useful for describing composition.

If the substance dominates the body, then the body is described as a substance body. If the substance impregnates other material, the body is described as a body of substance accumulation.

Carbonates and iron are common substances that dominate or impregnate nodular or concretionary bodies. Discrete nodules of clay are found in some soils; argillaceous impregnations are less common. Materials dominated by manganese are rare, but manganese is conspicuous in some nodules that are high in iron and mistakenly called "manganese nodules."

Consistence

Soil consistence in the general sense refers to "attributes of soil material as expressed in degree of cohesion and adhesion or in resistance to deformation on rupture." As employed 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 should be applied which may be useful.

A word may be in order about the similar term, consistency. Consistency was used originally in soil engineering for a set of classes of resistance to penetration by thumb or thumbnail (test designation D 2488, ASTM, 1984). The term has been generalized to cover about the same concept as "consistence." The set of tests specified, however, is different from those given here.

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. Previously class sets were given for "dry" and "moist" consistence of the soil material as observed in the field. "Wet" consistence was evaluated for puddled soil material. Here the terms used for "moist" consistence previously are applied to the wet state as well. The previous term "wet consistence" is dropped. Stickiness, plasticity, and toughness of the puddled soil material are independent tests.

For determinations on the natural fabric, variability among specimens is likely to be large. Multiple measurements may be necessary. Recording of median values is suggested in order to reduce the influence of the extremes measured.

Rupture Resistance Blocklike Specimens

Table 3-14 contains the classes of resistance to rupture and the means of determination for specimens that are block-like. Different class sets are provided for moderately dry and very dry soil material, and for slightly dry and wetter soil material. Unless specified otherwise, 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. The placements do not pertain to the soil material at the field water state.

The blocklike specimen should be 25-30 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 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 over a 1-second period. 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 that is testable with the fingers. A bathroom scale may be used for the higher rupture resistance.

Specimens of standard size and shape are not always available. Blocks of specimens that are smaller than 25-30 mm on edge may be tested. The force withstood may be assumed to decrease as the reciprocal of the dimension along which the stress is applied. If a block specimen with a length of 10 mm along the direction the force is applied were to be ruptured, the force should be one-third that for an identical specimen 30 mm on edge. If the specimen is smaller than the standard size, the evaluated rupture resistance should be recorded and the dimensions of the specimen along the axis the stress is applied should be indicated.

Soil structure complicates the evaluation of rupture resistance. If a specimen of standard size can be obtained, report the rupture resistance of the standard specimen and other individual constituent structural units as desired. Usually the constituent structural units must exceed about

5 mm in the direction the stress is applied; expression must exceed weak for the rupture resistance to be evaluated.

If structure size and expression are such that a specimen of standard size cannot be obtained, then the soil material overall is loose. Structural unit resistance to rupture may be determined if the size is large enough (exceed about 5 mm in the direction stress is applied) for a test to be performed.

Table 3-14. Rupture resistance classes for blocklike specimens

Classes			Test Description	
Moderately dry and very dry	***Slightly dry and wetter***	***Air dried, submerged***	***Operation***	***Stress Applied***[a]
Loose	Loose	Not applicable	Specimen not obtainable	
Soft	Very friable	Uncemented	Fails under very slight force applied slowly between thumb and forefinger	< 8N
Slightly hard	Friable	Extremely weakly cemented	Fails under slight force applied slowly between thumb and forefinger	8-20N
Moderately hard	Firm	Very weakly cemented	Fails under moderate force applied slowly between thumb and forefinger	20-40N
Hard	Very firm	Weakly cemented	Fails under strong force applied slowly between thumb and forefinger (80 N about maximum force that can be applied).	40-80N
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.	80-160N
Extremely hard	Slightly rigid	Strongly cemented	Cannot be failed in hands but can be underfoot by full body weight (ca 800 N) applied slowly.	160-800N
Rigid	Rigid	Very strongly cemented	Cannot be failed underfoot by full body weight but can be by <3 J blow.	800N-3J
Very rigid	Very rigid	Indurated	Cannot be failed by blow of <3 J.	$\geq$3 J

[a]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 Plate-Shaped Specimens

Tests are described that are applicable to plate-shaped specimens where the length and width are several times more than the thickness. Test procedures were developed for surface crusts but are applicable to plate-shaped bodies at greater depth in the soil. An alternative method of directly measuring plate-shaped specimens is to break them into a crudely blocked form. If the dimensions of the resulting block specimens are smaller than 25-30 mm on edge, it would be assumed that the measured rupture resistance is lower by 25.

Rupture Resistance by Crushing.—This test was designed primarily for air dry surface crust, but it may be used for other soil features. The morphological description of surface crust is discussed earlier in this chapter. The specimen should be 10 to 15 mm on edge and 5 mm thick or the thickness of occurrence if less than 5 mm. If surface crust, the thickness is inclusive of the crust proper and the adhering soil material beneath. The specimens are small to make the test applicable to crusts with closely spaced cracks. The specimen is grasped on edge between extended thumb and first finger. Force is applied along the longer of the two principal dimensions. Table 3-15 contains a set of classes. Compression to failure should be over about one second. A scale may be used to both rupture the specimens directly and develop the finger tactile sense. Force is applied with the first finger through a bar 5 mm across on the scale to create a similar bearing area to that of the plate-like specimen. The specimen is compressed between thumb and first finger while simultaneously exerting the same felt pressure on the scale with the first finger 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 with the two larger surfaces parallel and flat. The specimen is placed with a larger face downward on a nonresilient surface and force is applied through the 6 mm diameter penetrometer tip until rupture occurs.

Table 3-15. Rupture resistance classes applied to crushing plate-shaped specimens

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

For plate-shaped bodies that are durable enough to withstand handling, such as fragments of fissile sedimentary rock, a modulus of rupture estimation is an appropriate test (Reeve, 1965). In practice, modulus of rupture tests commonly would be used to acquire a tactile sense which then would be used directly in the field. Insufficient experience has been obtained to provide classes.

The tests to follow are hand-held tests. The configuration of the tests do not conform rigorously to the requirements for measurement of modulus of rupture. Furthermore, the amount of force applied may be only roughly approximated. For these reasons, the test results are only a crude measure of the modulus of rupture.

In one test, a specimen is held in contact with a small diameter cylindrical shaft (pencil, nail, and so on) placed near the center of the specimen. Stress is applied by pressing in opposite directions with the two first fingers and the thumbs until rupture occurs. The equation for the modulus of rupture in MPa is:

$$S = \frac{(0.15\,FL)}{bd^2}$$

where F is the force in newtons, L is the distance between the shaft and the inside edge of the area over which the force is applied on either side of the shaft with the fingers, b is the width of the specimen (in centimeters), and d is the depth or thickness in the direction of the load (in centimeters). The force application is based on the tactile sense and hence is approximate.

In the other approach, the specimen is grasped firmly at one end with pliers and force is applied downward at an established distance (to the nearest 1 cm) from the edge of the pliers. The area over which the force is applied should be small. The flat-end rod penetrometer described in the section on micropenetration resistance works well. A chisel point may be mounted over the tip. Modulus of rupture, S, expressed in megapascals (MPa), is calculated by:

$$S = \frac{(0.6FL)}{bd^2}$$

where F is the force in newtons, L is the distance between the end of the jaws of the pliers and the inside edge of the area where the force is applied, b is width, and d is the thickness. The dimensions are all in centimeters. Length and width are estimated to 1 cm and thickness to 1 mm.

Plasticity

Plasticity (table 3-16) is the degree to which puddled soil material is permanently deformed without rupturing by force applied continuously in any direction. Plasticity is determined on material smaller than 2 mm.

The determination is made on thoroughly puddled soil material at a water content where maximum plasticity is expressed. This water content is above the plastic limit, but it is less than the water content at which maximum stickiness is expressed. The water content is adjusted by adding water or removing it during hand manipulation. The closely related plastic limit that is used in engineering classifications is the water content for < 0.4 mm material at which a roll of 3 mm in diameter which had been formed at a higher water content breaks apart (method D 4318 in ASTM, 1984).

Table 3-16. Plasticity classes

Classes	Test description
Non-plastic	A roll 4 cm long and 6 mm thick that supports its own weight held on end cannot be formed.
Slightly plastic	A roll 4 cm long and 6 mm thick can be formed and, if held on end, will support its own weight. A roll 4 mm thick will not support its own weight.
Moderately plastic	A roll 4 cm long and 4 mm thick can be formed and will support its own weight, but a roll 2 mm thick will not support its own weight.
Very plastic	A roll 4 cm long and 2 mm thick can be formed and will support its own weight.

Toughness

Toughness is related to plasticity. Table 3-17 contains a set of classes. 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, 1984).

Table 3-17. Toughness classes

Classes	Criteria
Low	Can reduce the specimen diameter at or near the plastic limit to 3 mm by exertion of < 8N
Medium	Requires 8-20 N to reduce the specimen diameter at or near the plastic limit to 3 mm.
High	Requires > 20 N to reduce the specimen diameter at or near the plastic limit to 3 mm.

Stickiness

Stickiness refers to the capacity of a soil to adhere to other objects. Table 3-18 contains a set of classes. 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 while manipulation is continued between thumb and forefinger until maximum stickiness is reached.

Table 3-18. Stickiness classes

Classes	Test Description
Non-sticky	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 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 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 usually is highly dependent on water state. To evaluate the manner of failure, a roughly cubical specimen 25-30 mm on edge is pressed between extended forefinger and thumb and/or a handful of soil material is squeezed in the hand. Table 3-19 contains sets of classes and related operations. Some soil materials although wet are brittle; some may be compressed markedly without cracks appearing; others, if wet, behave like liquids; and still others smear if stressed under shear to failure.

Soil in the *slightly moist* or *dry states*, if coherent, is nearly always brittle and probably would not exhibit smeariness; consequently, manner of failure is probably only useful for *moderately moist* or wetter soil material.

Table 3-19. Manner of failure classes

Classes	Operation	Test Description Characteristics
Brittle	Gradually increasing compressive pressure applied to a 25-30mm specimen held between extended thumb and forefinger	Specimen retains its size and shape (no deformation) until it ruptures abruptly into subunits or fragments.
Semideformable	Same	Deformation occurs prior to rupture. Cracks develop and specimen ruptures before compression to half its original thickness.
Deformable*	Same	Specimen can be compressed to half its original thick- ness without rupture. Radial cracks may appear and extend inward less than half the radius normal compression.
Nonfluid	A handful of soil material is squeezed in the hand.	None flows through the fingers after exerting full compression.
Slightly fluid*	Same	After exerting full compression, some flows through the fingers, but most remains in the palm of the hand.
Moderately fluid*	Same	After exerting full pressure, most flows through the fingers; a small residue remains in the palm of the hand.
Very fluid*	Same	Under very gentle pressure most flows through the fingers like a slightly viscous fluid; very little or no residue remains.
Non-smeary	Gradually increasing pressure 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	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	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	At failure, the specimen suddenly changes 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 n-value
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 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.

The classes in table 3-20 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). 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 probably more descriptive of the fine earth fabric.

Table 3-20. Penetration resistance classes

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

A standard instrument is the pocket penetrometer shown in Bradford (1986). 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 here. Penetration resistance is expressed in units of pressure. The preferred unit is the megapascal; the symbol is MPa. For the 6.4-mm diameter tip, the measured force in kilograms is 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 enter the set of classes in table 3-20. 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 (1982). One has a base area of 1.3 cm^2; the other, 3.2 cm^2. Insertion should be to where the base of the cone is flush with the soil surface. Insertion times of 2 seconds and 4 seconds, respectively, should be used for the smaller and the larger cones. A relationship between the cone tips and the specified rod with a flat end must be established before table 3-20 can be used to enter cone measurements.

Determination of penetration resistance while the soil layer is at or near its maximum water content is a useful strategy for 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 may need modification for particular plants and soils. First, 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. Secondly, between 2 and 1 MPa, root restriction may be assumed to decrease roughly linearly. Finally, below 1 MPa, root restriction may be assumed to be small.

Excavation Difficulty

Excavation of soil is a very common activity. Table 3-21 lists classes for recording the difficulty of making an excavation. The classes may be employed to describe horizons, layers, or pedons on a one-time observation or over time. In most instances, excavation difficulty is related to and controlled by a water state.

Table 3-21. Excavation difficulty classes

Classes	Test description
Low	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 (50-80 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 tractor (50-80 hp).

Roots

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

Quantity of roots is described in terms of numbers of each size per unit area. The class placement for quantity of roots pertains to an area in a horizontal plane unless otherwise stated. This unit area changes with root size as follows: 1 cm2 for very fine and fine, 1 dm2 for medium and coarse, and 1 m2 for very coarse (figs. 3-34 and 3-35). The quantity classes are:

Few:	< 1 per unit area
Very few:	< 0.2 per unit area
Moderately few:	.2- 1 per unit area
Common:	1- 5 per unit area
Many:	>5 per unit area

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

Very fine:	< 1 mm
Fine:	1- 2 mm
Medium:	2- 5 mm
Coarse:	5- 10 mm
Very coarse:	> 10 mm

It is desirable to have class separation at an 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. A difficulty is that species differ in the efficiency of their roots. Soybeans and cotton are several fold more efficient than the grasses, and there are undoubtedly other differences among specific groups. The abundance 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 moderately few-very few separation is where soybeans and cotton would have insufficient numbers.

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 follow parting planes between structural units.

Quantity, size, and location is a convenient order: "Many very fine and common fine roots" implies that roots are uniformly distributed, since location is not given. This contrasts to examples that provide locational information such as "common very fine and common fine roots concentrated along vertical faces of structural units" or "common very fine roots inside peds, many medium roots between structural units."

FIGURE 3-34

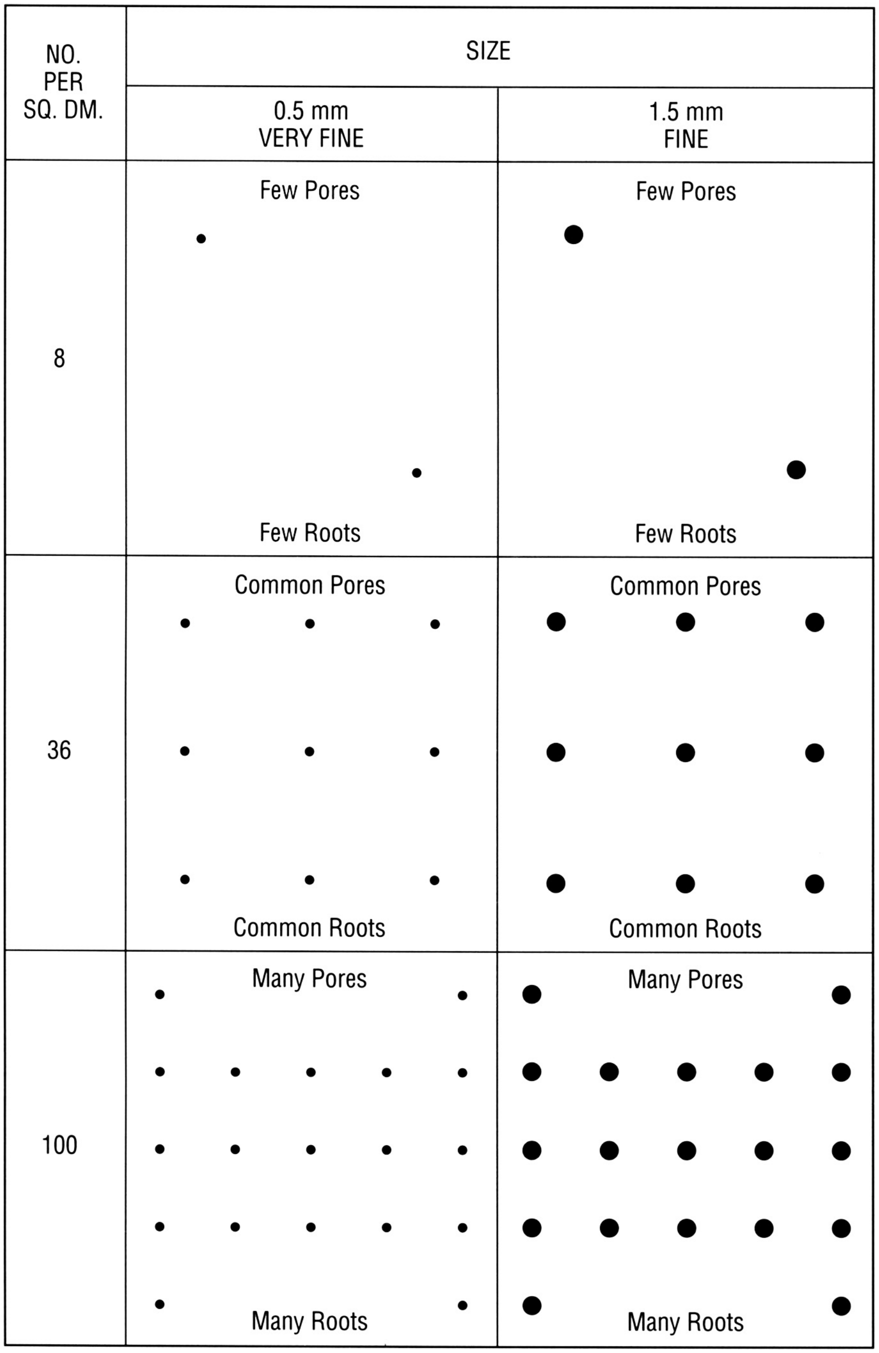


Diagram illustrating the visual impressions of abundance classes of Very Fine and Fine Roots and Pores in relation to size.

FIGURE 3-35

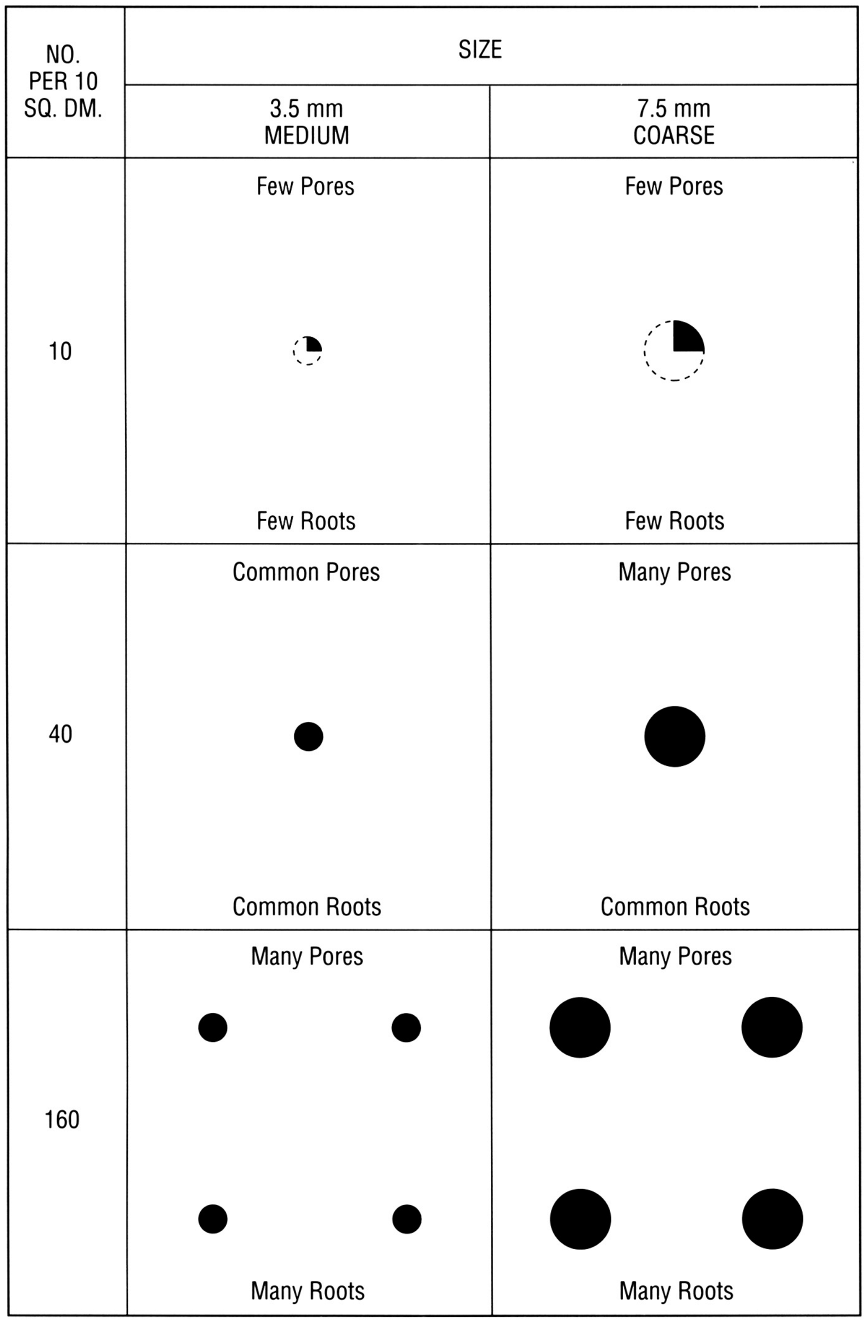


Diagram illustrating the visual impressions of abundance classes of Medium and Coarse Roots and Pores in relation to size.

In some soils, the pattern or root growth may not correspond to soil horizons or layers; therefore, a summary statement of root development by increments of 15 cm or 30 cm or some other convenient thickness is often 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 be similar throughout the A horizon, different in the E horizon, and still different in the B horizon but similar throughout the B. Root distribution in the example can then 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 are sometimes 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 must dictate 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. They may occur below the normal rooting depth of annual crops. This suggests that they were left by deeper rooted plants, perhaps native perennials. The presence of dead roots below the current depth of rooting may indicate a change in the soil water regime. The roots may have grown normally for a few years, then killed 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 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. If annual plants are involved, the generalization should be for near physiological maturity.

Pores

Pore space is a general term for voids in the soil material. The term includes matrix, nonmatrix, and interstructural pore space. *Matrix* pores are formed by the agencies that control the packing of the primary soil particles. These pores are usually smaller than nonmatrix pores. Additionally, their aggregate volume and size would change markedly with water state for soil horizons or layers with high extensibility. *Nonmatrix pores* are relatively large voids that are expected to be present when the soil is *moderately moist* or wetter, as well as under drier states. The voids are not bounded by the planes that delimit structural units. *Interstructural pores*, in turn, are delimited by structural units. Inferences as to the interstructural porosity may be obtained from the structure description. Commonly, interstructural pores are at least crudely planar.

Nonmatrix pores may be formed by roots, animals, action of compressed air, and other agents. The size of the distribution of nonmatrix pores usually bears no relationship to the particle size distribution and the related matrix pore size distribution. For water movement at low suction and conditions of satiation, the nonmatrix and interstructural porosity have particular importance.

Nonmatrix pores are described by quantity, size, shape, and vertical continuity—generally in that order. Quantity classes pertain to numbers per unit area—1 cm2 for very fine and fine pores, 1 dm2 for medium and coarse pores, and 1 m2 for very coarse. The quantity classes are:

Few:	< 1 per unit area
Common:	1- 5 per unit area
Many:	>5 per unit area

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

Very fine:	< 0.5 mm
Fine:	1- 2 mm
Medium:	2 - 5 mm
Coarse:	5 - 10 mm
Very coarse:	> 10 mm

Most nonmatrix pores are either vesicular (approximately spherical or elliptical), or tubular (approximately cylindrical and elongated). Some are irregularly shaped.

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 10 cm; and *high*—10 cm or more. Additionally, the designation *continuous* is used if the nonmatrix 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 such special conditions as tubular pores that 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," "many medium vesicular pores in a horizontal band about 1-cm wide at the bottom of the horizon."

Animals

Mixing, changing, and moving of soil material by animals is a major factor affecting properties of some soils. The features left by the work of some animals 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 (fig. 3-36).

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 or other castings, and other traces on the surface are easily observed and

FIGURE 3-35

Cicada casts at about 0.4 actual size. The photograph is a close-up view of an indurated horizon about 35 cm thick. Cicada casts in varying stages of induration are common in some soils of semi-arid climates.

described. Simple measurements and estimates—such as the number of structures per unit area, proportionate area occupied, 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.

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. No special conventions are provided. 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.

Krotovinas are irregular tubular streaks within one layer 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.

Selected Chemical Properties

This section discusses selected chemical properties that are important for describing and identifying soils.

Reaction

The numerical designation of reaction is expressed as pH. With this notation, pH 7 is neutral. Values lower than 7 indicate acidity; values higher, indicate alkalinity. Most soils range in pH from slightly less than 2.0 to slightly more than 11.0, although sulfuric acid forms and pH may decrease to below 2.0 when some naturally wet soils that contain sulfides are drained.

The descriptive terms to use for ranges in pH are as follows:

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

Both colorimetric and electrometric methods are used for measuring pH. Colorimetric methods are simple and inexpensive. Reliable portable pH meters are available.

Carbonates of Divalent Cations

Cold 2.87N (about a 1:10 dilution of concentrated HCl) hydrochloric acid is used to test for carbonates in the field. The amount and expression of effervescence is affected by size distribution and mineralogy as well as the amount of carbonates. Consequently, effervescence cannot be used to estimate the amount of carbonate. Four classes of effervescence are used:

Very slightly effervescent:	few bubbles seen
Slightly effervescent:	bubbles readily seen
Strongly effervescent:	bubbles form low foam
Violently effervescent:	thick foam forms quickly

Calcium carbonate effervesces when treated with cold dilute hydrochloric acid. Effervescence is not always observable for sandy soils. Dolomite reacts to cold dilute acid slightly or not at all and may be overlooked. Dolomite can be detected by heating the sample, by using more concentrated acid, and by grinding the sample. The effervescence of powdered dolomite with cold dilute acid is slow and frothy and the sample must be allowed to react for a few minutes.

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 of a saturation extract method is the standard measure of salinity. Electrical conductivity is related to the amount of salts more soluble than gypsum in the soil, but it may include a small contribution (up to 2 dS/m) from dissolved gypsum.

The standard international unit of measure is decisiemens per meter (dS/m) corrected to a temperature of 25 °C. Millimhos per centimeter (mmhos/cm) means the same as dS/m and may still be used. If it has been measured, the electrical conductivity is reported in soil descriptions. The following classes of salinity are used if the electrical conductivity has not been determined, but salinity is inferred:

Class		**Electrical conductivity dS/m (mmhos/cm)**
0	Non saline	0-2
1	Very slightly saline	2-4
2	Slightly saline	4-8
3	Moderately saline	8-16
4	Strongly saline	≥16

Sodicity

The sodium adsorption ratio (SAR) is the standard measure of the sodicity of a soil. 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 exchangeable sodium percentage, which equals exchangeable sodium (meq/100 g soil) divided by the cation exchange capacity (meq/100 g soil) times 100, was the primary measure of sodicity. 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 sodium affects the soil's 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) usually decreases as a soil is leached, but the amount of change depends in part on the composition of the water used for leaching and, therefore, cannot be predicted with certainty. If the initial SAR is greater than 10 and the initial electrical conductivity is more than 20 dS/m and information is needed as to whether the soil will be sodic following leaching, the SAR is determined on another sample after first leaching with the intended irrigation water. For the land reclamation of soils with an electrical conductivity of more than 20 dS/m, the SAR is used that is determined after leaching with distilled water to an electrical conductivity of about 4 dS/m.

Sulfates

Gypsum (calcium sulfate) can be inherited from the parent material, or it can precipitate from supersaturated solutions in the soil or in the substratum. Gypsum can alleviate the effects of sodium, making possible 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; frequent releveling may be required. Gypsum is soluble in water. The electrical conductivity of a distilled water solution with gypsum is about 2dS/m. In the absence of other salts, a salinity hazard does not exist except for such sensitive plants as strawberries and some ornamentals. Gypsum and other sulfates may cause damage to concrete.

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

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

Sulfides

Sulfides, mainly iron sulfide, are in some soils of tidal marshes and in some sedimentary rocks. When these materials are exposed, as 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 fish in nearby waters. The solutions produced are extremely acid and are highly corrosive to exposed metal and concrete. Soils and rock suspected of potential sulfur acidity are 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 such soils, the total amounts of both calcium carbonate and sulfides must be known.

No reliable field methods are available for determining the amount of sulfides in marshes. The sulfide odor of marshes is not a reliable indicator of the presence of oxidizable sulfides; however, there are situations in which odor is a reliable estimate. Drained or excavated marsh soils that contain large amounts of sulfides commonly have yellow efflorescences of the mineral jarosite on the exteriors of clods.

Two field tests are commonly used to detect excess oxidizable sulfides (Soil Survey Staff, 1975). In one test, pH is measured before and after the soil is incubated 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 drive off the excess peroxide. Then, pH is measured. If the decrease in pH is large, sulfides are probably present. A meter is preferred for measuring pH because of the possibility of oxidation of indicator dyes. Special dyes suitable for this test are available.

If the field tests for oxidizable sulfides are positive, laboratory determinations of sulfur content may be required for precise interpretations.