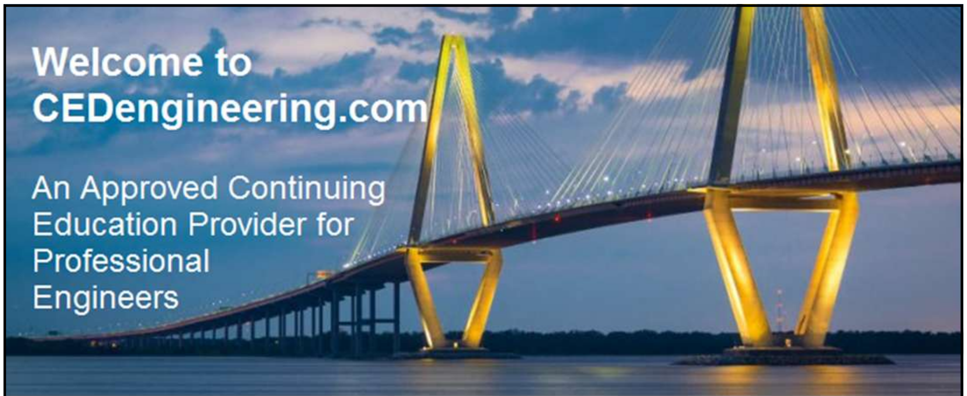

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SOIL SURVEY MANUAL

Course No: L03-303 - Course Credit: 3 PDH

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Hosted by:

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LEARNING OBJECTIVES

1. To understand soil structure and internal ped and void surface features, including how they influence soil behavior and interpretation.
2. To identify concentrations, pedogenic carbonates, and redoximorphic features, and explain their significance in soil formation and environmental conditions.
3. To examine soil consistence and its role in determining soil strength, stability, and response to external forces.
4. To analyze the presence and characteristics of roots, pores, and soil fauna, and their contribution to soil structure and biological activity.
5. To explore selected chemical properties of soils and their impact on soil functionality and land use.
6. To understand soil water and soil temperature dynamics and their influence on soil processes, plant growth, and environmental interactions.

EXAMINATION AND DESCRIPTION OF SOIL PROFILES

Soil Structure

- Soil structure refers to units composed of primary particles.
- Cohesion within these units is greater than the adhesion among units.
- As a consequence, the soil mass under stress tends to rupture along predetermined planes or zones.
- These planes or zones form the boundary of the structural units.
- Compositional differences of the fabric matrix appear to exert weak or no control over where the bounding surfaces occur.
- If compositional differences control the bounding surfaces of the body, then the term "concentration" is used.
- The term "structural unit" is used for any repetitive soil body that is commonly bounded by planes or zones of weakness that are not an apparent consequence of compositional differences.

- A structural unit that is the consequence of soil development is called a ped.
- The surfaces of peds persist through cycles of wetting and drying in place.
- Commonly, the surface of the ped and its interior have different composition or organization, or both, because of soil development.
- In contrast to peds, soil-forming processes exert weak or no control on the boundaries of earthy clods.
- Clods commonly form in the surface layer due to the rearrangement of primary particles to a denser configuration through plowing or other mechanical disturbance.

- The same terms and criteria used to describe structured soils should be used to describe the shape, grade, and size of clods.
- Commonly, clods have a blocky shape and are large enough to affect tilth adversely.
- Although the descriptive terms are used for both structural units and clods, this does not infer that clods are the result of pedogenic processes like structural units are.
- To avoid misunderstanding, the word “clods” is substituted for “structure” in written descriptions (e.g., strong, coarse, angular blocky clods).

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

- Some soils have simple structure, where each unit is an entity without component smaller units.
- Others have compound structure, where large units are composed of smaller units separated by persistent planes of weakness.
- In soils that have structure, the shape, size, and grade (distinctness) of the units are described.
- Field terminology for soil structure has separate sets of terms designating each of the three properties that, when used in combination, form the names for structure.
- For example, "strong fine granular structure" is used to describe a soil that separates almost entirely into discrete units that are loosely packed, roughly spherical, and mostly between 1 and 2 mm in diameter.
- The designation of structure by grade, size, and shape can be modified with other appropriate terms to describe other characteristics, e.g., "moderate medium lenticular structure with peds tilted about 15 degrees from horizontal (upslope)."
- Surface characteristics of units are described separately.

Shape

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

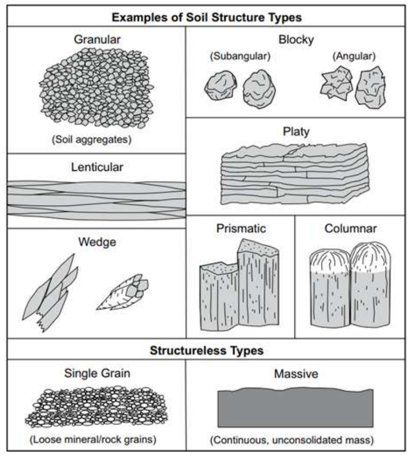


Figure 1: Examples of soil structure types.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Platy.
  - The units are flat and platelike.
  - They are generally oriented horizontally.
- Prismatic.
  - The individual units are bounded by flat to rounded vertical faces.
  - Units are distinctly longer vertically, and the faces are typically casts or molds of adjoining units.
  - Vertices are angular or subrounded; the tops of the prisms are somewhat indistinct and normally flat.

- The figure here shows a soil profile with prismatic structure in the subsoil.

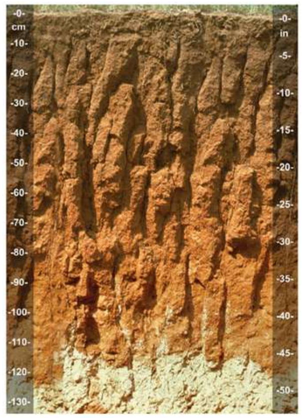


Figure 2: Prismatic soil structure.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Columnar.
  - The units are similar to prisms and bounded by flat or slightly rounded vertical faces.
  - The tops of columns, in contrast to those of prisms, are very distinct and normally rounded.
- Blocky.
  - The units are blocklike or polyhedral.
  - They are bounded by flat or slightly rounded surfaces that are casts of the faces of surrounding peds.
  - Typically, blocky structural units are nearly equidimensional but grade to prisms and plates.
  - The structure is described as angular blocky if the faces intersect at relatively sharp angles and as subangular blocky if the faces are a mixture of rounded and plane faces and the corners are mostly rounded.

Figure 3: Peds with angular blocky structure.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Granular.
  - The units are approximately spherical or polyhedral.
  - They are bounded by curved or very irregular faces that are not casts of adjoining peds.
- Wedge.
  - The units are approximately elliptical with interlocking lenses that terminate in acute angles.
  - They are commonly bounded by small slickensides.
- Lenticular.
  - The units are overlapping lenses parallel to the soil surface.
  - They are thickest in the middle and thin towards the edges.
  - Lenticular structure is commonly associated with moist soils, texture classes high in silt or very fine sand (e.g., silt loam), and high potential for frost action.

Size

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

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

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

Table 1: Size Class Terms for Peds with Various Soil Structure Types.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Grade

- Grade indicates the distinctness of units.
- Criteria for grade classes are the ease of separation into discrete units and the proportion of units that hold together when the soil is handled.
- Three classes are used:
- Weak.
  - The units are barely observable in place.
  - When they are gently disturbed, the disturbed soil material parts into a mixture of whole and broken units, the majority of which exhibit no planes of weakness.
  - Faces that indicate persistence through wet-dry cycles are evident if the soil is handled carefully.
  - Distinguishing structureless soils from those with weak structure can be difficult.
  - Weakly expressed structural units in virtually all soil materials have surfaces that differ in some way from the interiors.

- Moderate.
  - The units are well formed and evident in undisturbed soil.
  - When disturbed, the soil material parts into a mixture of mostly whole units, some broken units, and material that is not in units.
  - Peds part from adjoining peds to reveal nearly entire faces that have properties distinct from those of fractured surfaces.
- Strong.
  - The units are distinct in undisturbed soil.
  - They separate cleanly when the soil is disturbed.
  - When removed, the soil material separates mainly into whole units.
  - Peds have distinctive surface properties.

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

Compound Structure

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

Extra-Structural Cracks

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

Importance

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

Kinds of Cracks

- Cracks are characterized as either crust-related or trans-horizon.
- Crust-related cracks are shallow cracks that initiate at the surface and are restricted to a surface crust layer.
- They form primarily from raindrop impact and soil puddling followed by drying and consolidation.
- Trans-horizon cracks commonly extend across more than one horizon.
- They may extend upward to the soil surface and downward to significant depth.
- These cracks are commonly associated with soils that have a high content of smectitic clay minerals.
- They open as the soil dries out and close upon rewetting.
- Less commonly, some trans-horizon cracks form upon dewatering and subsequent consolidation of poorly drained sediments with high n value (fluid materials), e.g., upon drainage of some soils that are classified as Hydraquents.
- Once formed, these cracks do not open and close seasonally but rather remain open permanently.

Crust-related cracks.

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

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

Trans-horizon cracks.

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

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

Figure 4: Large reversible trans-horizon cracks extend from the soil surface deep into the subsoil of this clayey soil, which is classified as a Vertisol.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Descriptions of Cracks

- Descriptions of cracks include:
  - Relative frequency: Average number of cracks per square meter.
  - Depth: Average depth of penetration.
  - Kind: Reversible crust-related, irreversible crust-related, reversible trans-horizon, or irreversible trans-horizon.
- If the cracks do not extend to the surface, this should be noted.
- Examples of crack descriptions: "On average, five reversible trans-horizon cracks per square meter extend from the surface to about 50 cm" and "on average, five reversible trans-horizon cracks per square meter beginning below 18 cm extend to about 50 cm."

Internal Ped and Void Surface Features

- Features formed by pedogenic processes commonly occur on or beneath ped or void surfaces.
- Such features include: (1) coats of various substances covering part or all of surfaces, (2) material concentrated on surfaces due to preferential removal of finer material, (3) stress formations in which thin layers at the surfaces have undergone particle reorientation or packing by stress and/or shear, and (4) material infused beneath surfaces (termed a "hypocoat").
- All these features differ from the adjacent material in composition, orientation, and/or packing.
- Hypocoats commonly result from oxidation and reduction processes and are generally described as redoximorphic features (discussed below).
- Description of surface features may include kind, location, amount, and distinctness.
- Color, texture, and other characteristics may also be described, especially if the features contrast strongly with characteristics of adjacent material.

Kinds

- Surface features are distinguished by differences in texture, color, packing, particle orientation, or reaction to selected tests.
- If a feature is distinctly different from the adjacent material but its kind cannot be determined, it is still described.
- Clay films.
    - Thin layers of oriented, translocated clay; also called clay skins or argillans.
- Clay bridges.
    - Illuvial clay linking together adjacent mineral grains.

Figure 5: Shiny clay films coat the surface of this ped.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Figure 6: Sand grains (visible as individual quartz grains) coated and bridged with illuvial clay (smooth yellowish color).
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Sand or silt coats.
  - Sand or silt grains adhering to a ped, void, or crack surface.
  - The grains may be derived from material originally in a horizon from which finer particles have been removed.
  - These coats are also referred to as skeletans.
  - Sand or silt coats may also form by translocation and deposition of sand or silt from upper horizons or via oxidation-reduction reactions that preferentially remove iron and/or manganese and, in some cases, clay.
  - Coats inferred to form from oxidation-reduction reactions are described as redoximorphic features.
- Other coats.
  - Coats composed of iron, aluminum, or manganese oxides; organic matter; salts; or carbonates.
  - They are described by properties that can be observed in the field.
  - Laboratory analyses may be needed for verification.

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

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

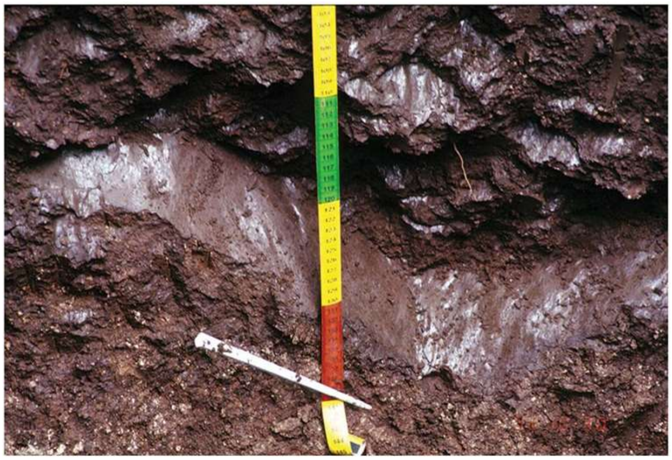


Figure 7: Prominent slickensides in the Bss horizon of a Vertisol.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Location

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

Amount

- The percentage of the total surface area occupied by a particular surface feature over the extent of the horizon or layer is described.
- Amount can be characterized using the following classes:
  - Very few; less than 5 percent
  - Few; 5 to less than 25 percent
  - Common; 25 to less than 50 percent
  - Many; 50 to less than 90 percent
  - Very many; 90 percent or more
- These classes are also used to describe the amount of bridges connecting particles.
- This amount is based on the percentage of particles of a designated size that are joined to adjacent particles of similar size by bridges at contact points.

Distinctness

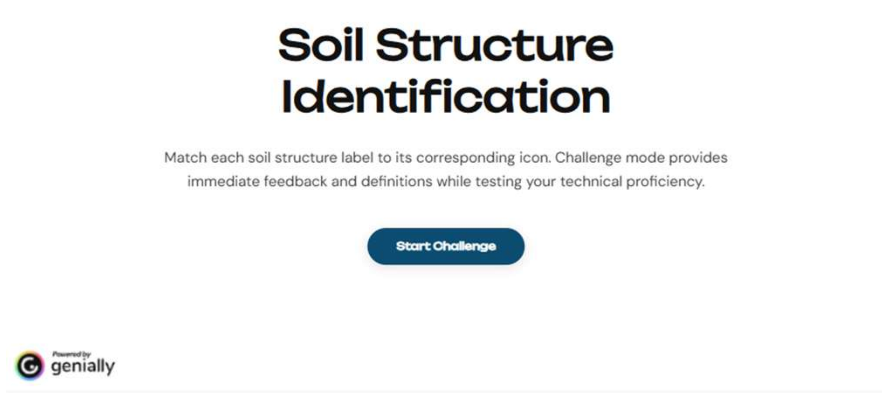
- Distinctness refers to the ease and degree of certainty with which a surface feature can be identified.
- It is related to thickness, color contrast with the adjacent material, and other properties.
- However, it is not itself a measure of any one of them (e.g., some thick coats are faint and some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

EXAMINATION AND DESCRIPTION OF SOIL PROFILES (CONT'D)

- The classes of distinctness are:
- Faint.
  - Feature is evident only on close examination with 10X magnification and cannot be identified positively in all places without greater magnification.
  - The contrast with the adjacent material in color, texture, and other properties is minimal.
- Distinct.
  - Feature can be detected without magnification, although magnification or tests may be needed for verification.
  - The feature contrasts enough with the adjacent material that differences in color, texture, or other properties are evident.
- Prominent.
  - Feature is conspicuous without magnification when compared to a surface broken through the soil.
  - Color, texture, or other property or a combination of properties contrasts sharply with properties of the adjacent material, or the feature is thick enough to be conspicuous.

EXAMINATION AND DESCRIPTION OF SOIL PROFILES (CONT'D)

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



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Concentrations

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

Kinds

- Masses are non-cemented concentrations that commonly cannot be removed from the soil as a discrete unit.
    - Masses may consist of, but are not limited to, calcium carbonate, fine crystals of gypsum or soluble salts, or iron and manganese oxides.
    - In most cases, masses form in place.
- Plinthite consists of reddish, iron-enriched bodies that have a low content of organic matter.
    - In contrast to most other masses, plinthite bodies are coherent enough to be separated readily from the surrounding soil.

Figure 8: Masses of secondary calcium carbonate (white bodies below a depth of about 60 cm) in the calcic horizon of an Aridisol.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

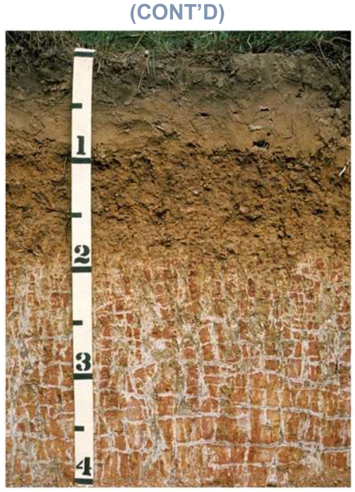


Figure 9: A soil in which a reticulately mottled zone with plinthite (darkest red colors) is below a depth of about 2 feet.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Upon repeated wet-dry cycles, plinthite may irreversibly harden and convert to indurated ironstone.
- Plinthite bodies commonly occur as discrete nodules or plates.
- The plates are oriented horizontally.
- The nodules occur above, and the plates within, the upper part of the reticulately mottled horizon.
- The plates generally have a uniformly reddish color and have sharp boundaries with the surrounding brown or gray material.
- The part of the iron-rich body that is not plinthite normally stains the fingers if rubbed while wet, but the plinthite center does not.
- Plinthite has a harsh, dry feel when rubbed, even if wet.
- Horizons containing plinthite are more difficult to penetrate with an auger than adjacent horizons at the same water state and with the same clay content.
- Plinthite generally becomes less cemented after prolonged submergence in water.
- An air-dried sample can be dispersed by normal procedures for particle-size distribution.

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

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

- Crystals are macro-crystalline forms of relatively soluble salts that form in place.
  - They may occur singly or in cluster.
  - Gypsum, calcite, halite, and other salt crystals are common in arid and semiarid soils.
  - Crystals composition should be denoted if known.
- Finely disseminated materials are small precipitates dispersed throughout the matrix.
  - The material is not observable with the naked eye but can be detected by chemical reactions (e.g., effervescence of calcium carbonate with dilute HCl).
  - An example is calcium carbonate that has accrued due to dust fall and its subsequent dissolution and reprecipitation throughout the matrix of a horizon.
- Biological concentrations are discreet bodies accumulated by biological process.
  - Examples include fecal pellets and wormcasts.
- Inherited minerals consist of distinct, observable mineral particles in the soil that formed from geologic rather than pedogenic processes.
  - Mica flakes and glauconite pellets are examples.

Figure 10: A cluster of gympsum crystals (selenite) in an Aridisol.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Describing Concentrations Within the Soil

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

- Amount or quantity of concentrations refers to the relative volume of a horizon or other specified unit occupied by the bodies.
- The classes are the same as those used for quantity of redoximorphic features and mottles:
  - Few; less than 2 percent
  - Common; 2 to less than 20 percent
  - Many; 20 percent or more

- Size may be measured directly or designated by a class.
- The dimension to which size-class limits apply depends on the shape of the body described.
- If the body is nearly uniform, the shortest dimension is measured, such as the effective diameter of a cylinder or the thickness of a plate.
- For irregular bodies, the longest dimension is measured (if needed, more measurements can be given for clarification).
- The classes are the same as those used for mottles and redoximorphic features:
  - Fine; less than 2 mm
  - Medium; 2 to less than 5 mm
  - Coarse; 5 to less than 20 mm
  - Very coarse; 20 to less than 76 mm
  - Extremely coarse; 76 mm or more

- Shape of concentrations varies according to kinds of concentrations and commonly within a concentration.
- Shape terms are generally not used to describe crystals, however, because the crystal type itself implies its shape.
- The terms for concentration shape are:
  - Cubic: Roughly equidimensional, blocklike structures.
  - Cylindrical: Cylindrical or tubular shape; one dimension is greater than the other two.
  - Dendritic: Branched, elongated, tubular forms.
  - Irregular: Concentrations characterized by nonrepeating spacing or shape, but not elongated (as a dendritic form).
  - Lenticular: Roughly disk-shaped forms, thickest in the middle and thinning toward the edges.
  - Pendular: Coatings or nodules formed on the undersides of rock fragments.
  - Platy: Shaped like a plate; one dimension is much smaller than the other two.
  - Reticulate: Crudely interlocking structures (common with some plinthite concentrations).
  - Rosettelike: Interlocking blade-like structures forming a petal-like structure.
  - Spherical: Approximately equidimensional and well rounded.
  - Threadlike: Thin, elongated filament-like structures (but not dendritic).

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

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

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

Pedogenic Carbonates

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

Forms of Carbonate Accumulation

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

- With time, carbonate crystals accumulate within the soil fabric and are visible as:
  - Filaments.
    - Threadlike concentrations of carbonate typically < 1 mm in diameter and a few centimeters long.
  - Root casts.
    - Branching (and commonly tubular) forms of carbonate accumulation (carbonate pseudomorphs of roots).
  - Bands.
    - Sheet-like deposits of carbonate typically ranging from about 1 to several millimeters thick.
    - They form along the bedding planes of finely stratified parent material and are separated by soil with little or no macroscopic carbonate.

- Joint fillings.
  - Vertical bands of carbonate in the fracture planes of large prisms in soil.
  - Joint fillings, in profile, range from less than 1 to a few centimeters in width.
- Coatings.
  - Deposits of carbonate on the surfaces of rock fragments and sand grains.
  - They may be continuous or discontinuous and have a rupture resistance ranging from non-cemented to extremely weakly cemented.
- Pendants.
  - Deposits of laminar carbonate coatings on rock that are very weakly cemented to indurated.
  - They are more common on the bottom of rocks than on the top.
  - They commonly have stalactite-like protrusions radiating perpendicularly away from the rock fragment.

- Masses.
  - Bodies of carbonate accumulation of various shapes that are non-cemented or extremely weakly cemented and cannot be removed as discrete units from soil.
- Nodules.
  - Rounded bodies of carbonate accumulation that are very weakly cemented to indurated and can be removed as discrete units from soil.
- Concretions.
  - Rounded bodies of carbonate accumulation that are very weakly cemented to indurated.
  - They have spherically concentric layers surrounding a nucleus.

- Cylindroids.
  - Cylindrical bodies of carbonate accumulations that are very weakly cemented to indurated.
  - Many are cicada casts impregnated with calcium carbonate while others developed in soil material filling former root channels or small krotovinas.
  - Cylindroids are typically less than 2.5 cm thick.
  - They are typically vertical but may also be diagonal or horizontal.
- Beds.
  - Carbonate accumulations along bedding planes of parent material that are similar to bands but differ in size (ranging from a few centimeters to a meter or more thick).
  - They range from non-cemented to indurated, occur below the main zone of pedogenic horizons, and preserve the original sedimentary structure.

- Plugged horizons.
  - Pedogenic carbonate accumulations that occur at the soil-horizon-landscape scale, which is larger than the soil-profile scale, at which filaments, nodules, and other carbonate forms occur.
  - They are characterized by laterally continuous pedogenic carbonate that has engulfed soil particles, filled most or all pores, and obliterated the original sedimentary structure.
  - Most plugged horizons are strongly cemented to indurated, although some are non-cemented.
- Laminar horizons.
  - Smooth, strongly cemented to indurated deposits of carbonate that develop on top of plugged horizons (or shallow bedrock).
  - They have a fabric that contains much more carbonate than the underlying plugged horizon and essentially no allogenic skeletal grains.

- Laminae.
  - Thin (less than 1 mm to a few millimeters) individual layers of carbonate comprising the laminar horizon.
  - They typically parallel one another, but one set may truncate another set at various angles.
- Pisoliths.
  - Subangular to spheroidal carbonate masses (2 to more than 100 mm in diameter) that form within highly developed petrocalcic horizons.
  - They are characterized by concentric banding and an internal structure of disrupted laminae or by disrupted concentric banding that may or may not have detrital material at the core.
- Ooliths.
  - Spheroidal carbonate masses (less than 2 mm in diameter) that form within highly developed petrocalcic horizons.
  - They have an internal structure of laminae that may or may not have detrital material at the core.

Stages of Carbonate Accumulation

- Pedogenic carbonate that forms in soils in arid and semiarid climates is closely linked to age (i.e., progressively older geomorphic surfaces have soils with commensurately greater amounts of carbonate).
- Gile et al. described carbonate accumulation through four successive morphogenic stages with a distinction between gravelly and nongravelly soils.
- Soils that form in gravelly parent materials progress from pebble coatings (Stage I) to interpebble fillings (Stage II), a plugged horizon (Stage III), and eventually a laminar horizon atop the plugged horizon (Stage IV).
- Soils that form in nongravelly parent materials progress from filaments (Stage I) to nodules (Stage II), a plugged horizon (Stage III), and eventually a laminar horizon atop the plugged horizon (Stage IV).

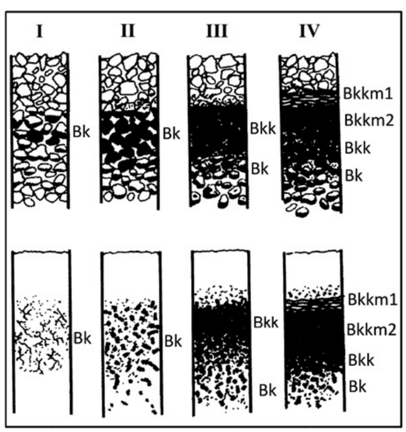


Figure 11: Schematic diagram of diagnostic carbonate morphology for the four main stages of carbonate accumulation in two morphogenetic sequences.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Bachman and Machette and Machette recognized two additional stages.
- Stage V is characterized by laminae less than 1 cm thick and may contain pisoliths as well as vertical faces and fractures coated with laminated carbonate.
- Stage VI is characterized by multiple generations of recemented laminae, breccia, and pisoliths.
- The time required to reach a certain morphogenetic stage depends on soil particle size and quantity of carbonate inputs.
- Gravelly soils pass through the stages more quickly than nongravelly soils because they have less surface area and less total pore space.
- Pedogenic carbonate that forms above the phreatic zone by means of capillary rise does not necessarily proceed through the morphogenetic stages.

Redoximorphic Features

- Redoximorphic features (RMF) include color patterns, mineral concentrations, and a reduced (in respect to iron) soil state that form via coupled oxidation/reduction reactions involving iron and manganese under anaerobic soil conditions.
- Saturation or near saturation limits oxygen diffusion in soil.
- Microbial activity consumes existing oxygen, and an anaerobic condition results.
- Under anaerobic conditions, certain microbes utilize chemical species other than oxygen as the terminal electron acceptor for carbon metabolism.
- Such microbially mediated redox processes follow a sequence based on electrochemical or redox potential, which is a measure of anaerobic intensity.
- The metabolic energy gain for an organism is the energy difference between reduced carbon and the specific electron acceptor.
- The oxidant with the highest redox potential is utilized first, followed by the oxidant with the next highest potential.
- $O_2 > NO_3^{2-} > Mn\ (VI) > Fe\ (III) > SO_4^{2-} > CO_2 > H^+$

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

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

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

Describing Redoximorphic Features

- Because RMF have a strong relationship to soil wetness, they are typically described separately from other color variations or concentrations.
- Mottles (color variations not due to iron loss or accrual, such as variegated weathered rock) are described with soil color.
- The characteristics routinely described for RMF include quantity, size, contrast, color, kind, and location.
- If important, the moisture state, shape, hardness, and boundary can also be described.
- Guidelines for describing color and the associated moisture state are the same as those for recording color.
- Terms for describing quantity, size, contrast, color, and location of RMF are the same as those for describing concentrations within the soil.

Redox Concentrations

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

- Redox concentrations have the following forms:
  - Masses.
    - Non-cemented bodies or localized regions of enhanced pigmentation due to Fe and/or Mn accretion.
    - Masses that occur as coatings or thin matrix impregnations along pores (such as root channels) are referred to as pore linings.
  - Nodules or concretions.
    - Cemented bodies of iron-manganese oxides that formed through successive wet-dry cycles.

Figure 12: Redoximorphic features that consist of a redox concentration, as an iron mass (reddish area along ped surface) and an iron depletion (light-colored area surrounding the root channel in ped interior).

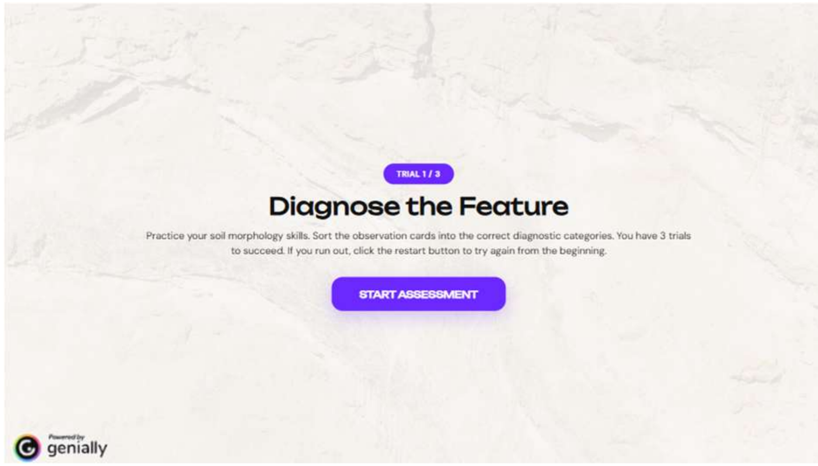
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Redox Depletions

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

- Redox depletions occur in the following forms:
  - Iron depletions.
    - Localized zones that have lost iron and/or manganese pigment due to oxidation or reduction reactions under anaerobic conditions but that have a clay content similar to that of the adjacent matrix.
  - Clay depletions.
    - Localized zones that have lost iron, manganese, and clay.
    - These features are commonly referred to assilt coatings or skeletans.
    - Silt coatings may form by eluvial processes rather than from oxidation and reduction.
    - Soil features of inferred eluvial origin (for example, albic materials, silt coatings, and skeletans) are not considered or described as a redox depletion.

  - Reduced matrix.
    - A soil horizon, layer, or zone that is reduced in respect to iron.
    - It has an in situ matrix chroma < 2 and/or a hue of 5GY, 5G, or 5BG that reflects the presence of Fe(II).
    - The color of a soil sample becomes visibly redder or brighter (oxidizes) when exposed to air.
    - The color change typically occurs within 30 minutes.
    - A 0.2% solution of alpha,alpha-dipyridyl dissolved in 1N ammonium acetate (NH4 OAc) pH 7 can verify the presence of Fe+2 in the field.



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Consistence

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

- Consistence is not synonymous with consistency.
- Originally, consistency was used in soil engineering to define degree of resistance to penetration by thumb or thumbnail.
- The engineering term was generalized for use in soil survey and called "consistence."
- The set of tests to determine consistency, however, is different from those for consistence.
- Consistence is highly dependent on the soil water state and the description has little meaning unless the water state class is specified or is implied by the test.

EXAMINATION AND DESCRIPTION OF SOIL PROFILES (CONT'D)

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- For rupture resistance, separate class terms are provided for tests on dry soil (moderately dry or very dry soil water states) and moist soil (slightly dry through satiated soil moisture states).
- To determine cementation class, the sample is air dried, then submerged in water for at least 1 hour, and checked for slaking.
- Stickiness, plasticity, and toughness tests are performed on puddled soil material.
- Stickiness determinations are made at the highest moisture content, when the sample is most sticky.
- Tests for manner of failure are best performed on moderately moist or wetter samples.
- Penetration resistance depends strongly on moisture state, which should always be noted.

- The class definitions for rupture resistance and toughness include both qualitative descriptions as well as quantitative limits for the stress or force applied to the sample.
- Since the perception of the relative amount of force required to cause a sample to fail varies by individual, one should learn what the various classes of applied force feel like personally.
- The tactile sense of the class limits may be learned by applying force to top-loading scales and sensing the pressure through the tips of the fingers or through the ball of the foot.
- Postal scales may be used for the resistance range testable with the fingers.
- A bathroom scale may be used for higher rupture resistance.

- To calculate force in newtons, multiply kg by 10, or pounds by 4.54.
- One joule is equal to the energy delivered by dropping a 1-kg weight from a height of 10 cm.
- The 3 joules class limit is approximately equivalent to dropping a 2-pound weight from a height of 1 foot.
- An easy to develop training tool for calibrating one's fingers to estimate applied force is to record the force required to compress springs with varying degrees of resistance using scales as described above.
- A set of small springs that approximate the class limits for rupture resistance classes can then be used as "known samples" for estimating rupture resistance and toughness classes.
- For determinations on the natural fabric, variability among specimens is likely to be large.
- Multiple measurements may be necessary. Recording median values helps reduce the influence of the extremes measured.

Rupture Resistance for Blocklike Specimens

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

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

Table 2: Rupture Resistance Classes for Blocklike Specimens.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

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

Table 2: Rupture Resistance Classes for Blocklike Specimens.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

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

$$\text{Adjusted stress value} = [(28\ \text{mm}/\text{actual cube length mm})^2 \times \text{observed stress (N) at failure}]$$

- For the 10-mm specimen in the example above, [(28/10)2 x 4 N] equals an adjusted stress of about 31 N.
- According to table 2, the rupture resistance class is firm.
- Soil structure complicates the evaluation of rupture resistance.
- If a specimen of standard size can be obtained, rupture resistance of the standard specimen is reported.
- Other individual constituent structural units can also be described.

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

Rupture Resistance for Plate-Shaped Specimens

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

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

Table 3: Rupture Resistance Classes Applied to Crushing Plate-Shaped Specimens.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- For calibration of finger force applied with the quantitative class limits, a scale may be used to both rupture the specimens directly and develop the finger tactile sense.
- Force is applied with the forefinger through a bar 5 mm across on the scale to create a similar bearing area to that of the plate-shaped specimen.
- The specimen is compressed between the thumb and forefinger of one hand while simultaneously the same felt pressure is exerted on the scale with the forefinger of the other hand.
- The scale is read at the failure of the specimen.
- For specimens that cannot be broken between thumb and forefinger, the resistance to rupture may be evaluated using a small penetrometer.
- The specimen is formed by orienting the two larger surfaces parallel to one another and then creating a flat surface.
- It is placed with one of the larger faces downward on a nonresilient surface.
- Force is applied through the 6-mm-diameter penetrometer tip until rupture occurs.

Plasticity

- Plasticity is the degree to which puddled soil material is permanently deformed without rupturing by force applied continuously in any direction.
- The table here lists the classes and their criteria.

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

Table 4: Plasticity Classes.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- Plasticity is determined on material smaller than 2 mm.
- The determination is made using thoroughly puddled soil material at a water content where maximum plasticity is expressed.
- This water content is above the plastic limit but less than the water content at which maximum stickiness is expressed.
- The water content is adjusted by adding or removing water during hand manipulation.
- The plastic limit used in engineering classifications, which is closely related, indicates the water content at which a roll that consists of < 0.4 mm material, is 3 mm in diameter, and was formed at a higher water content breaks apart.

Toughness

- Toughness is related to plasticity.
- The table here lists the classes and their criteria.
- The classes are based on the relative force necessary to form, with the fingers, a roll 3 mm in diameter of < 2 mm soil material at a water content near the plastic limit.

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

Table 5: Toughness Classes.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Stickiness

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

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

Table 6: Stickiness Classes.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Manner of Failure

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

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

Table 7: Manner of Failure Classes.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

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

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

Table 7: Manner of Failure Classes.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Penetration Resistance

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

Figure 13: A field test on a soil with a moderately fluid manner of failure class.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- The classes in the table here 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.
- Three generalized classes and seven more narrowly defined classes are used.
- Orientation of the axis of insertion should be specified.
- A correction should be made for the weight of the penetrometer if the axis of insertion is vertical and the resistance is small.
- If rock fragments are present, the lower values measured are typically more descriptive of the fine-earth fabric.

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

Table 8: Penetration Resistance Classes.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- The pocket penetrometer, shown in Bradford (1986), is the standard instrument.
- Penetrometers with the same 6.4-mm-diameter flat-end tip and a dial reading device are available.
- The resistance can be read with less variability using the dial device.
- The scale on the barrel of the pocket penetrometers should be converted to units of force.
- The supplied scale on such instruments commonly is based on a regression between penetration resistance and unconfined, compressive strength measurements and has no application in the context used here.
- Penetration resistance is expressed in units of pressure.
- The preferred unit is the megapascal (MPa).
- For the 6.4-mm-diameter tip, the measured force in kilograms is multiplied by 0.31 to obtain the pressure in megapascals.
- To extend the range of the instrument, weaker and stronger springs may be substituted.
- Values in megapascals obtained with any diameter of flat-end rod are used to determine the class.

- In addition to the flat-end tip, cone-shaped tips may be mounted on the penetrometers with flat ends as well as other penetrometers.
- Two 30-degree cone penetrometer tips are specified by the American Society of Agricultural Engineers.
- One has a base area of 1.3 cm^2 and the other of 3.2 cm^2.
- The tips should be inserted where the base of the cone is flush with the soil surface. Insertion times of 2 seconds and 4 seconds should be used for the smaller and larger cones, respectively.
- A relationship between the cone tips and the specified rod with a flat end must be established before cone measurements.
- Table 8 can be modified to use the corresponding cone measurements.

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

Excavation Difficulty

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

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

Table 9: Excavation Difficulty Classes.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Roots

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

Quantity of Roots

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

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

- The quantity classes are:
  - Few less than 1 per unit area
    - Very few less than 0.2 per unit area
    - Moderately few 0.2 to less than 1 per unit area
  - Common 1 to less than 5 per unit area
  - Many 5 or more per unit area

Size Classes of Roots

- Roots are described in terms of a specified diameter size.
- The size classes are:
  - Very fine; less than 1 mm
  - Fine; 1 to less than 2 mm
  - Medium; 2 to less than 5 mm
  - Coarse; 5 less than 10 mm
  - Very coarse; 10 mm or larger

Location of Roots

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

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

- For annual plants, the time of the root observation may be indicated.
- Root traces (channels left by roots that have died) and the dead roots themselves can be clues to soil properties that change with time.
- The rate of root decay depends on the species, root size, and the soil moisture and temperature regimes.
- Local experience can determine the time after maturity or harvest that the root distribution is affected by decay.

- Root traces in deep layers may persist for years.
- Many of these traces have organic coatings or linings.
- If they occur below the normal rooting depth of annual crops, they were left by deeper-rooted plants, perhaps native perennials.
- The presence of dead roots below the current rooting depth may indicate a change in the soil water regime.
- The roots may have grown normally for a few years, then died when the soils were saturated for a long period.

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

Pores

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

Kinds of Pores

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

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

- Non-matrix pores may be formed by roots, animals, compressed air, and other agents.
- The size distribution of these pores typically is not associated with the particle-size distribution and the related matrix pore-size distribution.
- For water movement at low suction and conditions of satiation, the non-matrix and interstructural porosity have particular importance.
- Non-matrix pores are described by quantity, size, shape, and vertical continuity,generally in that order.
- Quantity classes pertain to numbers per unit area,1 cm^2 for very fine and fine pores, 1 dm^2 for medium and coarse, and 1 m^2 for very coarse.

Quantity Classes of Pores

- The pore quantity classes are:
  - Few; less than 1 per unit area
  - Common; 1 to less than 5 per unit area
  - Many; 5 or more per unit area

Size Classes of Pores

- Pores are described relative to a specified diameter size.
- The five pore size classes are:
  - Very fine; less than 1 mm
  - Fine; 1 to less than 2 mm
  - Medium; 2 to less than 5 mm
  - Coarse; 5 to less than 10 mm
  - Very coarse; 10 mm or more

Shape Classes of Pores

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

Continuity Classes of Pores

- Vertical continuity involves assessment of the average vertical distance through which the minimum pore diameter exceeds 0.5 mm when the soil layer is moderately moist or wetter.
- Three classes are used:
  - Low; less than 1 cm
  - Moderate; 1 to less than 10 cm
  - High; 10 cm or more

- Additionally, the designation "continuous" is used if the non-matrix pores extend through the thickness of the horizon or layer.
- Vertical continuity has extreme importance in assessing the capacity of the soil layer to transmit free water vertically.
- Special aspects are noted, such as orientation in an unusual direction, concentration in one part of a layer, or conditions where tubular pores are plugged with clay at both ends.
- Some examples of descriptions of pores are "many fine tubular pores," "few fine tubular pores and many medium tubular pores with moderate vertical continuity," and "many medium vesicular pores in a horizontal band about 1 cm wide at the bottom of the horizon."

Animals

- The mixing, changing, and moving of soil material by animals is a major factor affecting properties of some soils.
- The features resulting from animal activity reflect mainly mixing or transport of material from one part of the soil to another or to the surface.
- The original material may be substantially modified physically or chemically.
- The features that animals produce on the land surface may be described.
- Termite mounds, ant hills, heaps of excavated earth beside burrows, the openings of burrows, paths, feeding grounds, earthworm castings, other castings, and other traces on the surface are easily observed and described.
- Simple measurements and estimates (such as the number of structures per unit area, proportionate area occupied, and volume of above-ground structures) give quantitative values that can be used to calculate the extent of activity and even the number of organisms.

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

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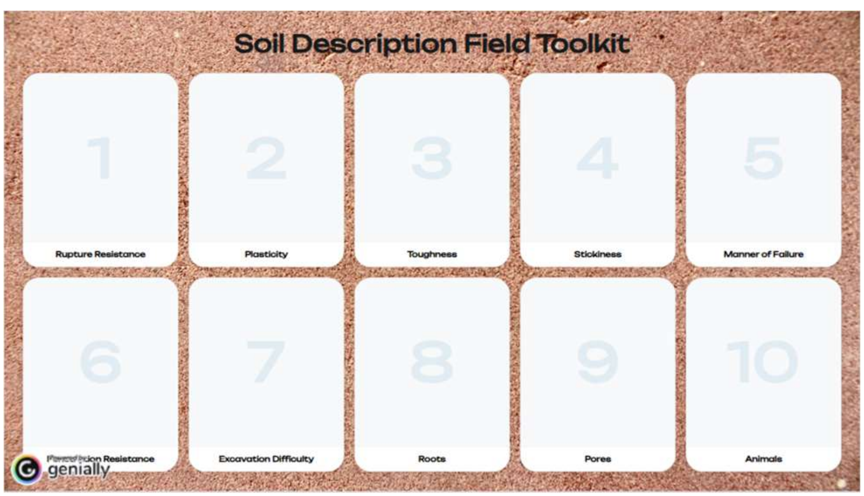
- Krotovinas are irregular tubular streaks in a layer that consists of material transported from another layer.
- They are caused by the filling of tunnels made by burrowing animals in one layer with material from outside the layer.
- In a profile, they appear as rounded or elliptical volumes of various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

Description of Animal-Related Features

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



Selected Chemical Properties

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

Reaction

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

- The standard field pH measurement is performed with a 1:1 soil:water mixture so that comparisons of pH readings are on an equivalent basis.
- A more dilute sample (for example, a 1:5 soil:water mixture) generally has a higher pH, and less dilute samples generally have lower pH.
- While the standard for measuring pH in the field is a 1:1 soil:water mixture, other methods of measuring pH are also used in soil survey for specific purposes, especially those required for some taxonomic criteria in Soil Taxonomy.

- They include:
    - 0.01 M $CaCl_2$.
        - This method has the advantage of dampening seasonal variation in pH.
        - It is used for some taxonomic family-level criteria.
    - 1N KCl.
        - This method is used to infer aluminum saturation levels in some great groups of Oxisols (e.g., Acrudox).
        - If the criteria are met, aluminum toxicity may be a concern.
    - 1M NaF.
        - This method is used to infer the presence of short-range order minerals.
        - It is used in the criteria for the isotic mineralogy class.

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

- Reaction Class Terms
- Reaction class terms are commonly used to communicate information about soil pH.
- The terms are given in the table here.

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

Table 10: Reaction Class Terms and Their Ranges in pH.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Carbonates of Divalent Cations

- A solution of cold, 1-normal hydrochloric acid (1N HCl) is used to test for the presence of free carbonates in the field.
- The proper concentration is made by combining 1 part concentrated HCl (37%) with 11 parts distilled water.
- Add acid to water, not water to acid.
- Care must be taken when handling concentrated HCl as it can cause severe skin burns.
- The application of a few drops of HCl to a sample containing carbonates results in the evolution of CO2 gas, which forms bubbles (effervescence).
- The amount and expression of effervescence is affected by size distribution of the carbonates and their mineralogy as well as the overall amount of carbonates present.
- Consequently, effervescence is a qualitative test and cannot be used to estimate the quantitative amount of carbonate.

Effervescence Class Terms

- The five classes of effervescence and their criteria are shown in the table here.

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

Table 11: Effervescence Class Terms.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

Calcium Carbonate Equivalent

- Calcium carbonate equivalent refers to the amounts of CaCO3 in soil.
- Other names include soil carbonate, soil inorganic carbon, pedogenic carbonate, caliche, nari, tosca, croute calcaire, kankar, and soil lime.
- The most common mineral form is calcite.
- Aquantitative field test for measuring the soil carbonate uses a simple volume calcimeter.
- For this procedure, a small sample (commonly 0.33 g) is placed in a syringe.
- A 10 percent HCl solution is placed in a second syringe which is connected to the first syringe by a rubber tube.
- The HCl solution is injected into the syringe containing the soil sample and the evolution of CO2 gas is recorded and adjusted to compensate for temperature and elevation.
- Soil carbonate is recorded to the nearest whole number.

Manganese Oxides

- Hydrogen peroxide (H_2O_2, 3-4% solution, commonly available in pharmacies) can be used to test for the presence of manganese oxides (MnO_2, a kind of redoximorphic concentration).
- The effervescence classes used for carbonates are also used for describing the presence of manganese oxides.
- The effervescence class and reagent are recorded, e.g., “violently effervescent in 3% H_2O_2.”
- It should be noted that organic matter also reacts to hydrogen peroxide.
- This reaction is typically slow, while MnO_2 reacts quickly.
- Hydrogen peroxide is also used for a color change test to detect the presence of reduced monosulfides (e.g., FeS) in subaqueous soils.

Salinity and Sodicity

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

Salinity

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

- The preparation of a saturation paste extract is most commonly performed in the laboratory rather than in the field.
- Pocket electrical conductivity meters can be used in the field for measuring electrical conductivity of soil:water solutions of various ratios (e.g., 1:1, 1:2, 1:5, etc.).
- The EC values recorded reflect the concentration of the mixture.
- Lower readings are associated with higher amounts of water relative to soil.
- Electrical conductivity measured this way should be denoted with the soil:water ratio (e.g., EC1:1, EC1:5).

- There is no universal correction factor to equate these results to the standard saturation paste extract method performed in the laboratory.
- General correlations between field-measured EC using a soil:water solution and laboratory-measured ECe for the same samples may be possible for soils in a localized geographic area having similar salt chemistry and other properties and similar environmental conditions.
- Additional samples having only field-measured EC may then be estimated as to their expected ECe values for classification purposes and assignment to salinity classes.
- Care must be taken to not extend the relationship beyond the area for which it was established.

- The 1:5 soil:water mixture (by volume) is commonly used as a field test for measuring EC of subaqueous soil samples.
- These results are recorded as described above (e.g., $EC_{1:5}$ 10.5 dS/m).
- The salinity classes shown in table 12 are not applicable to these measurements.
- The standard international unit of measure for EC is decisiemens per meter (dS/m) corrected to a temperature of 25 °C.
- Millimhos per centimeter [mmhos/cm] are equivalent to dS/m, but this notation is not preferred.
- Measured electrical conductivity is reported in soil descriptions.
- The table on the following slide shows the classes of salinity used if the electrical conductivity (ECe) has not been determined but salinity is inferred.

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

Table 12: Salinity Class Terms.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

Sodicity

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

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

- Formerly, the primary measure of sodicity was the exchangeable sodium percentage, which equals exchangeable sodium (meq/100 g soil) divided by the cation-exchange capacity (meq/100 g soil) times 100.
- The test for exchangeable sodium percentage, however, has proved unreliable in soils containing soluble sodium silicate minerals or large amounts of sodium chloride.
- Sodium is toxic to some crops and affects soil physical properties, mainly saturated hydraulic conductivity.
- A sodic condition has little effect on hydraulic conductivity in highly saline soils.
- A soil that is both saline and sodic may, when artificially drained, drain freely at first.
- After some of the salt has been removed, however, further leaching of salt becomes difficult or impossible.
- The sodium adsorption ratio (SAR) typically decreases as a soil is leached because the amount of change depends in part on the composition of the water used for leaching.

- The following procedure can be used to predict whether the soil will be sodic after leaching.
- If the initial SAR is greater than 10 and the initial electrical conductivity is more than 20 dS/m, the SAR is determined on a sample after first leaching it with the intended irrigation water.
- For soils with an electrical conductivity of more than 20 dS/m, the SAR is determined after first leaching the sample with distilled water to an electrical conductivity of about 4 dS/m.
- No classes for sodium levels in the soil are provided.
- Laboratory analysis is required to document the SAR of individual horizons.
- Soils that have high sodium levels, but are not otherwise saline, commonly have pH of 9.0 or greater.
- Soils that are both saline and sodic tend to have pH values of less than 8.5.
- In addition, some sodic soils, especially in slightly depressional areas, may be black at the surface due to dispersion of clay and organic matter and poor drainage.
- In some sodic soils, natric horizons exhibit columnar structure.

Sulfates

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

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

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

Sulfides

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

- A few soils with appreciable amounts of sulfides contain enough carbonates to neutralize all or part of the acidity when the sulfides are oxidized.
- In these soils, the total amounts of both calcium carbonate and sulfides are needed to determine if effective neutralization can occur naturally.
- No reliable field methods are available for determining the amount of sulfides in marshes.
- A simple test to confirm the presence of sulfides (but not the amount) uses 30% hydrogen peroxide (H_2O_2) to determine if rapid oxidation causes a significant decrease in pH as compared to a similar sample treated with water.

- Marsh soils may give off a sulfurous odor.
- This odor is not a reliable indicator of the presence of significant amounts of oxidizable sulfides; however, odor can be a reliable indicator that sulfides are present.
- The sulfurous odor ("rotten egg smell"), if detected, should be noted in the soil description.
- Qualitative class terms for odor intensity are:
  - Slight. Odor is faint, only detected close to nose.
  - Moderate. Odor is readily noticeable, even at arm's length from the nose.
  - Strong. Odor is intense and readily noticed as soon as sample is exposed to the air.

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

Figure 14: Jarosite concentrations (yellowish color) that formed due to oxidation in this drained marsh soil containing sulfides.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

Soil Water

- This section discusses "water regimes",schemes for the description of the state of the soil water at a particular time and for the change in soil water state over time.
- Soil water state is evaluated from water suction, quantity of water, whether the soil water is liquid or frozen, and the occurrence of free water within the soil and on the land surface.
- The complexity and detail of water regime statements can range widely.

Inundation Classes

- Free water may occur above the soil.
- Inundation is the condition when the soil area is covered by liquid free water.
- Flooding is temporary inundation by flowing water.
- If the water is standing, as in a closed depression, the term ponding is used.
- Flooding and ponding are temporal conditions.

- In most cases, soils are not described while inundated (exceptions include subaqueous soils and some soils that are subject to ponding of very long duration).
- To the extent possible, estimates for inundation should include frequency, duration, and months of occurrence.
- Depth of inundation is also commonly recorded.
- The table on the next slide shows the classes for frequency and duration of inundation.
- The rare and very rare frequency classes may be combined.
- The very frequent class takes precedence over frequent if both definitions are met.
- Very frequent flooding includes tidal inundation.
- Frequency of flooding should reflect the current conditions.
- A soil that would be frequently flooded in its natural state, but is now protected by a dam or levee, should be assigned the class that reflects the level of protection provided.

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

Table 13: Frequency and Duration of Inundation Classes (Flooding or Ponding).

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

Internal Soil Water State

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

Classes

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

- Three classes and eight subclasses for water state are defined in the table here.

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

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

Table 14: Water State Classes.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

- Dry is separated from moist at 1500 kPa suction.
- Wet is separated from moist at the condition where water films are readily apparent.
- The water suction at the moist-wet boundary is assumed to be about 0.5 kPa for coarse soil materials and 1 kPa for other materials.
- The formal definition of coarse soil material is given later.
- Three subclasses of dry are defined,very dry, moderately dry, and slightly dry.
- Very dry cannot be readily distinguished from air dry in the field.
- The water content extends from ovendry to 0.35 times the water retention at 1500 kPa.
- The upper limit is roughly 150 percent of the airdry 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 determines the upper water retention (UWR).
- A suction of 5 kPa is used for coarse soil material; a suction of 10 kPa is used for other material.
- To be considered coarse, the soil material that is strongly influenced by volcanic ejecta must be nonmedial and have few or no vesicular pores in the mineral particles.
- If not strongly influenced by volcanic ejecta, it must meet the sandy or sandy-skeletal family particle-size criteria and also be coarser than loamy fine sand, have less than 2 percent organic carbon, and have less than 5 percent water at 1500 kPa suction.
- Furthermore, the computed total porosity of the < 2 mm fabric must exceed 35 percent.

- Very moist has an upper limit at the moist-wet boundary and a lower limit at the upper water retention.
- Similarly, moderately moist has an upper limit at the upper water retention and a lower limit at the midpoint in gravimetric water content between retention at 1500 kPa and the upper water retention.
- This lower limit is referred to as the midpoint water retention (MWR).
- Slightly moist extends from the midpoint water retention to the 1500 kPa retention.

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

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

Evaluation

- Wet is indicated by the occurrence of prominent water films on surfaces of sand grains and structural units that cause the soil material to glisten.
- If free water is absent, the term nonsatiated wet is used.
- If free water is present, the term satiated wet is used.
- In the field, the position of the uppermost boundary in the soil profile meeting the satiated wet class is the top of the water in an unlined bore hole after equilibrium has been reached.

- Lined bore holes or piezometers, installed to several depths across the zone of free water occurrence, are needed to determine the thickness of a perched zone of free water.
- Piezometers are tubes placed to a designated depth that are open at both ends.
- They may have a perforated zone at the bottom but do not permit water entry along most of their length.
- For the purpose of simply obtaining information about the depth of free water and the location and thickness of the free water zone, the installation of bore holes or piezometers is not required.
- This information can be obtained in the course of observing soils during regular soil survey field operations.

- Ideally, evaluation within the moist and dry classes should be based on field instrumentation.
- However, this instrumentation is typically not available and approximations must be made.
- Gravimetric water content measurements may be used.
- To make the conversion from measured water content to suction, information is needed on the gravimetric water retention at different suctions.
- The water retention at 1500 kPa may be estimated from the field clay percentage evaluation if dispersion of clay is relatively complete for the soils concerned.

- Commonly, the 1500 kPa retention is roughly 0.4 times the clay percentage.
- This relationship can be refined considerably as the soil material composition and organization are increasingly specified.
- Another rule of thumb is that the water content at air dryness is about 10 percent of the clay percentage, assuming complete dispersion of clay.
- Model-based curves that relate gravimetric water content and suction are available for many soils.
- These curves may be used to determine upper water retention and the midpoint water retention and to place the soil material in a water state class based on gravimetric water contents.

- Furthermore, in many cases they can be used as the basis for estimating water retention at 10 kPa from measurements at 33 kPa.
- The figure on the following slide shows a model-based curve for a medium textured horizon and the relationship of water state class limits to water contents determined from the desorption curve.
- The figure includes the results of a set of tests designed to provide local criteria for field and field office evaluation of water state.
- These tests are discussed later in this chapter.

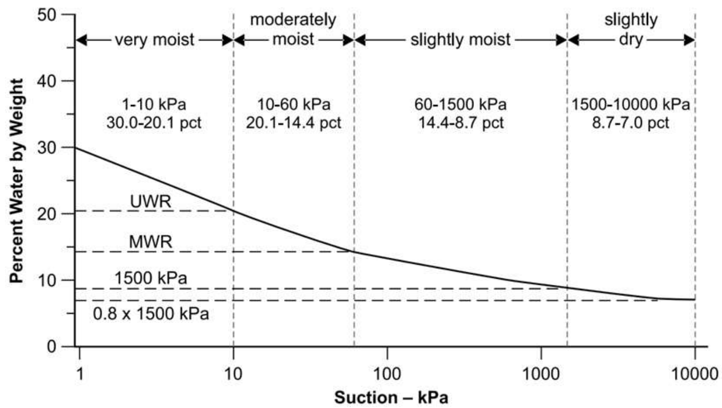

Figure 15: Model-based curve for a medium textured horizon and the relationship of water state class limits to water contents determined from the desorption curve.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

- Criteria are more difficult to formulate for soil material that is between the moist-wet and the moderately dry-very dry separations.
- Four tests useful for mineral soils are the color value, ball, rod, and ribbon tests.
- The three tests that involve tactile examination are performed on soil material that has been manipulated and mixed.
- This manipulation and mixing must be thorough enough to break down aggregates and provide consistent, repeatable results.
- The change may be particularly large for dense soil.
- In the field, this limitation should be kept in mind.

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

- Ball test.
  - A quantity of soil is squeezed firmly in the palm of the hand to form a ball about 3 to 4 cm in diameter.
  - This is done in about five squeezes.
  - The sphere should be near the maximum density that can be obtained by squeezing.
  - Different people will prepare the ball differently; however, an individual should learn to perform the procedure consistently.
  - In one approach, the ball is dropped from progressively increasing heights onto a nonresilient surface.
  - The height in centimeters at which rupture occurs is recorded.
  - Typically heights above 100 cm are not measured.
  - Additionally, the manner of rupture is recorded.
  - If the ball flattens and does not rupture, the term "deforms" is used.
  - If the ball breaks into about five or fewer units, the term "pieces" is used.
  - Finally, if the ball breaks into five or more units, the term "crumbles" is used.
  - Another approach uses penetration resistance.
  - A penetrometer is inserted in the ball the same way it is done for soil in place.
  - This alternative is only applicable for medium and fine textured soil materials at higher water contents because these materials are relatively plastic and not subject to cracking.

- Rod test.
  - The soil material is rolled between the thumb and forefinger or on a surface to form a rod 3 mm or less in diameter.
  - A rod 2 cm or more in length must be able to remain intact while being held vertically from one end.
  - If the maximum length that can be formed is 2 to 5 cm, the rod is weak.
  - If the maximum length equals or exceeds 5 cm, the rod is strong.
  - The rod test has close similarities to the plastic limit test.
  - Plastic limit values exceed the 1500 kPa retention at moderate clay contents and approach, but are not commonly lower than, the 1500 kPa retention at high clay contents.
  - If a strong rod can be formed, the water content typically exceeds the 1500 kPa retention.
  - The same is generally true for a weak rod.
  - An adjustment is necessary if 2 to 0.5 mm material is present because the plastic limit is measured on material that passes a number 40 sieve (0.43 mm in diameter).

- Ribbon test.
  - The soil material is smeared out between thumb and forefinger to form a flattened body about 2 mm thick.
  - A ribbon must be at least 2 cm in length.
  - If the maximum length possible is 2 to 4 cm, the ribbon is weak.
  - If the maximum length possible is 4 cm or more, the ribbon is strong.
  - General relationships of the tests to water state, with the exception of the relationship of the rod test to 1500 kPa retention, have not been formulated.
  - Locally applicable field criteria can be formulated using groupings of soils based on composition.

Natural Drainage Classes

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

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

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

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

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

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

- Very poorly drained.
  - Water is removed from the soil so slowly that free water remains at or very near the surface during much of the growing season.
  - Internal free water occurrence is very shallow and persistent or permanent.
  - Unless the soil is artificially drained, most mesophytic crops cannot be grown.
  - The soils are commonly level or depressed and frequently ponded.
  - In areas where rainfall is high or nearly continuous, slope gradients may be greater.
- Subaqueous.
  - Free water is above the soil surface.
  - Internal free water occurrence is permanent, and there is a positive water potential at the soil surface for more than 21 hours of each day.
  - The soils have a peraquic soil moisture regime.

Internal Free Water Occurrence

- The table here gives the classes and criteria used to describe free water regimes in soils.

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

Table 15: Classes of Internal Free Water.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

Water State Annual Pattern

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

- (Months when the layer is frozen are indicated by an "F." Other symbols are defined in table 14.)

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

Table 16: Example of a Water State Annual Pattern.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

Table 16: Example of a Water State Annual Pattern.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

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

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

Table 16: Example of a Water State Annual Pattern.

(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

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

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

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

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

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

- Saturated hydraulic conductivity can be expressed by different forms of mathematical equations.
- When the flux and gradient are expressed on a mass basis, the resulting dimensions for K_{sat} are (mass x time)/volume and the SI units (International System of Units) are kg s m^{-3} (kilogram seconds per cubic meter).
- When they are expressed on a volume basis, the dimensions are (volume x time)/mass and the SI units are m3 s kg-1 (cubic meter seconds per kilogram).
- If one expresses the flux on a volume basis and the gradient on a weight basis, then the dimensions of K_{sat} are length/time and the SI units are m s^{-1} (meters per second).
- This last mathematical form has the simplest units, but it only applies under unique conditions in the field.
- Care must be taken to interpret this correctly and not conclude that hydraulic conductivity is literally the rate of water movement through the soil.
- Saturated hydraulic conductivity is not a rate of water movement; it is a measure of a saturated soil's ability to transmit water under a hydraulic gradient.
- Or, in general terms, it is the ease with which pores of a saturated soil permit water to move.
- Low values indicate restricted movement, and higher values indicate relative ease of movement.

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

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

- Coefficients of variability in excess of 100 percent for saturated hydraulic conductivity are common.
- Measured K_{sat} values may vary dramatically with the method used for measurement.
- Laboratory-determined values rarely agree with field measurements; the differences can be on the order of 100-fold or more.
- Field methods generally are considered more reliable than laboratory methods, but this may be an illusion due to differences in sample volumes and method.
- The volume of the sample being tested relates to the possibility of a sample including unusually large pores due to animal burrows, root channels, desiccation cracks, etc.
- For smaller volumes, this has the character of a "hit or miss" proposition, and the result can be high variability within relatively small areas.

- For larger sampling volumes, the chance of observing similar K_{sat} values from multiple readings within a study area is higher and the variability among samples is lower.
- The smallest volume in which the lowest variability can be attained is called the "representative elementary volume" (REV).
- The REV for K_{sat} measurements is currently unknown. It likely varies by soil type.
- Because the field is the best setting for approximating a representative elementary volume, field measurements are emphasized.

- Because of the highly variable nature of soil hydraulic conductivity, a single measured value is an unreliable indicator of the hydraulic conductivity of a soil.
- An average of several values provides a reliable estimate, which can be used to place the soil in a particular saturated hydraulic conductivity class.
- Log averages (geometric means) should be used rather than arithmetic averages because hydraulic conductivity is a property with log-normal distribution.
- The antilog of the average of the logarithms of individual conductivity values is the log average, or geometric mean, and should be used to place a soil into the appropriate hydraulic conductivity class.
- Log averages are lower than arithmetic averages.

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- Classes of saturated hydraulic conductivity.
  - In this manual, saturated hydraulic conductivity classes are defined in terms of vertical, saturated hydraulic conductivity.
  - The table here identifies the vertical, saturated hydraulic conductivity classes used in the National Cooperative Soil Survey.

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

Table 17: Classes of Saturated Hydraulic Conductivity.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- The saturated hydraulic conductivity classes in this manual have a wider range of values than the classes that were previously used by the NCSS, as published in the previous edition of the Soil Survey Manual (Soil Survey Staff, 1951) and the Guide for Interpreting Engineering Uses of Soils (USDA-SCS, 1971).
- The dimensions of hydraulic conductivity vary depending on whether the hydraulic gradient and flux density have mass, weight, or volume bases.
- Values can be converted from one basis to another with the appropriate conversion factor.
- Typically, the hydraulic gradient is given on a weight basis, the flux density is given on a volume basis, and the dimensions of K_{sat} are length per time.
- The correct SI units are therefore meters per second.
- Micrometers per second are also acceptable SI units and, due to fewer decimal places, are more convenient.

- The table here gives the equivalent class limits in other commonly used units.
- Converting to equivalent units is useful when presenting the data to members of the public who may not be familiar with SI units.

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

Table 18: Saturated Hydraulic Conductivity Class Limits in Equivalent Units.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

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

- 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 Ksat are described in Agronomy Monograph No. 9 (Klute and Dirksen, 1986; Amoozegar and Warrick, 1986) and in SSIR 38 (Bouma et al., 1982).

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

- The method presented here is very general.
- It was developed from a statistical analysis of several thousand measurements on a variety of soils.
- It is intended for a wide application and must be used locally with caution.
- This method does not account for the circumstances mentioned in the previous paragraph.
- Commonly, the results must be adjusted based on experience and local conditions.
- Figures 16 and 17 used together provide a method for approximating K_{sat} class based on soil texture and bulk density.
- Each figure consists of three textural triangles.
- Based on the texture and bulk density of a particular soil horizon, the bulk density class is estimated by determining which triangle in figure 16 the horizon belongs to.
- The chosen bulk density class determines which triangle in figure 17 is used to estimate K_{sat} class.

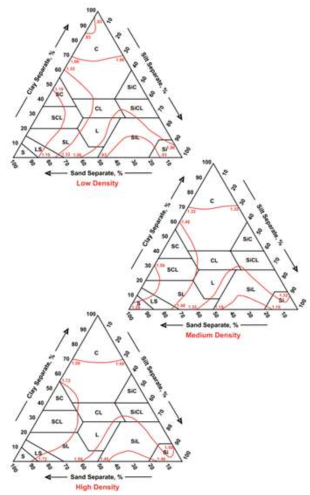


Figure 16: Bulk density classes: low, medium, and high.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

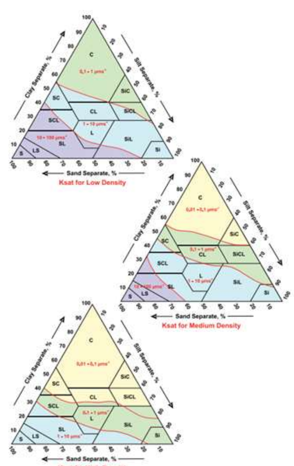


Figure 17: Saturated hydraulic conductivity classes based on bulk density and texture relationships.
(Source: USDA, "Soil Survey Manual", March 2017, USDA Handbook 18)

- For a particular soil texture with either measured or estimated bulk density, interpolating between the iso-bulk density lines in figure 16 yields a bulk density class.
- The triangle in the figure that provides the value closest to the measured or estimated bulk density for that particular textural class determines which triangle in figure 17 should be used.
- For example, in figure 16, a clay loam with both 35 percent sand and clay and a bulk density of 1.20 g/cc plots between the iso-bulk density lines of 1.06 and 1.32 of the textural triangle marked "low" and thus is in the low bulk density class.

- A clay loam with both 35 percent sand and clay and a bulk density of 1.40 g/cc plots between the iso-bulk density lines of 1.32 and 1.48 on the textural triangle marked "medium" and thus has a medium bulk density class.
- For soils having medium or average bulk densities, the center triangle is used.
- The triangles above and below the center triangle are for soils with high and low bulk densities, respectively.
- The textural triangle in figure 17 that corresponds with the bulk density class determined from figure 16 is selected, and the clay and sand percentages are plotted to determine K_{sat} class placement.
- The K_{sat} class is "moderately high" for the clay loam in the low bulk density class and "moderately low" for the clay loam in the medium bulk density class.
- A numerical value of K_{sat} can be estimated by interpolating between the iso-K_{sat} lines.
- However, the values should be used with caution.
- They should be used only to compare classes of soils and not as an indication of the K_{sat} of a particular site.
- If site values are needed, it is best to make several measurements at the site.

- The K_{sat} values determined using the above procedure may need to be adjusted based on other known soil properties.
- Currently, there are no guidelines for adjusting the estimated K_{sat}.
- The soil scientist must use best judgment based on experience and the observed behavior of the particular soil.
- Saturated hydraulic conductivity can be given for the soil as a whole, for a particular horizon, or for a combination of horizons.
- The horizon with the lowest value determines the saturated hydraulic conductivity class assigned to the whole soil.
- If an appreciable thickness of soil above or below the horizon with the lowest value has significantly higher conductivity, then estimates for both parts are typically given (i.e., high over very low).

Infiltration

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

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

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

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

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

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

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

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

Soil Temperature

- Soil temperature, like soil moisture, is an important component of the overall soil climate.
- It exerts a strong influence on biological activities.
- It also influences the rates of chemical and physical processes within the soil.
- As a result, the chemical properties of the soil, including organic matter content, mineralogy, and fertility levels, are significantly impacted by soil temperature.

- When the soil is frozen, biological activities and chemical processes essentially stop.
- Physical processes that are associated with ice formation are active if unfrozen zones are associated with freezing zones.
- Below a soil temperature of about 5 °C (referred to as "biologic zero" in Soil Taxonomy), growth of roots of most plants is negligible.
- However, in areas where soils have permanently frozen layers near the surface, even large roots of adapted plants are present immediately above the frozen layer in late summer.
- Most plants grow best within a restricted range of soil and air temperatures.
- Knowledge of soil and air temperatures is essential in understanding soil-plant relationships.
- Temperature, like the soil water state, changes with time. It generally differs from layer to layer at any given time.

Characteristics of Soil Temperature

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

- Soil temperature varies at a given site from layer to layer according to the time of the year; yet, if the average annual temperatures at different depths in the same pedon are compared, they typically do not differ.
- Mean annual soil temperature is one of several useful values that describe the temperature regime of a soil.
- The seasonal fluctuation of soil temperature is a characteristic of a soil.
- Soil temperature fluctuates little seasonally near the equator; it fluctuates widely according to season in the middle and high latitudes.
- Mean seasonal temperatures can be used to characterize soil temperature.
- As soil depth increases, the magnitude of the differences in seasonal soil temperature decreases and the seasonal cycles exhibit a delay compared to temperatures at shallower depths.

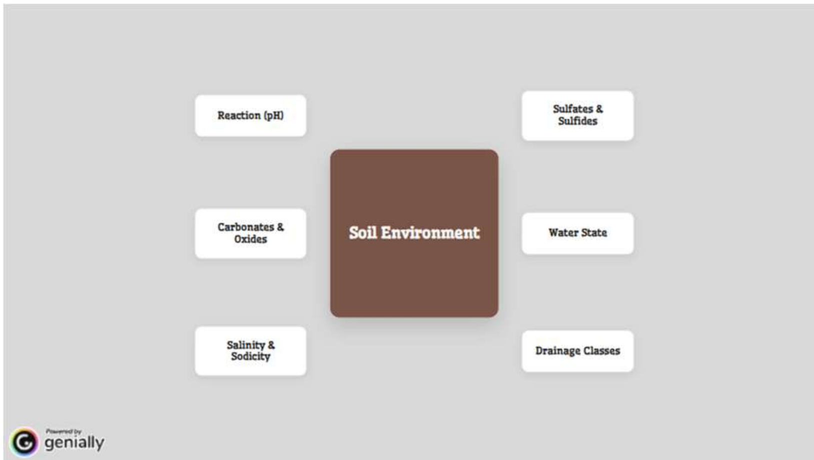
- For soils that freeze in winter, soil temperature is influenced by the release of heat when water changes from liquid to solid.
- This release is about 80 calories per gram of water.
- Heat must be dissipated before the water in soil freezes.
- The rate of thaw of frozen soils is slower, because heat is required to warm the soil in order to melt the ice.
- In areas of heavy snowfall, the snow provides an insulating blanket and soils do not freeze as deeply or do not freeze at all.
- Many factors influence soil temperature.
- They include amount, intensity, and distribution of precipitation; daily and monthly fluctuations in air temperature; insolation; kinds, amounts, and persistence of vegetation; duration of moisture states and snow cover; kinds of organic deposits; surface soil color; aspect and gradient of slope; elevation; and ground water.
- All of these factors may be described in a soil survey.

Estimating Soil Temperature

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

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

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



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REFERENCES

This interactive presentation was adapted from Chapter 3 of the document by the Unified States Department of Agriculture (USDA), Soil Survey Manual, March 2017, USDA Handbook 18.

COURSE PROVIDER BIOGRAPHY

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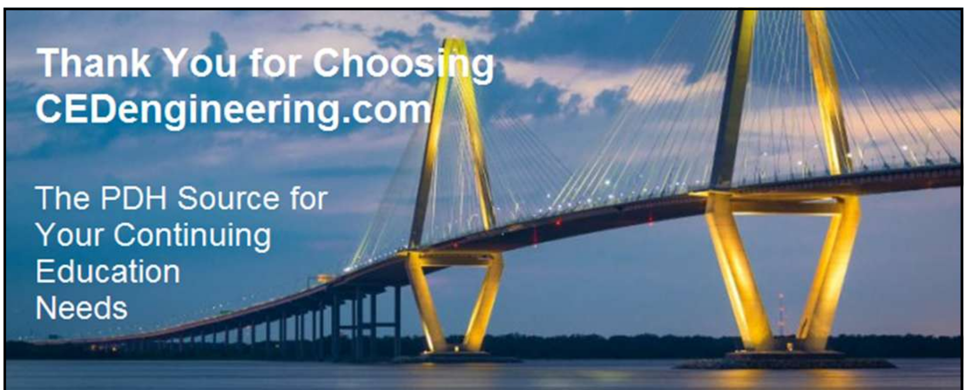

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