ENGINEERING VALUES FROM SOIL TAXONOMY

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Many properties of engineering interest can be deduced from the connotative nomenclature of Soil Taxonomy, the pedological soil classification system adopted for use by the National Cooperative Soil Survey in 1965. The system is based on soil properties that have been defined quantitatively and named. Each soil class name, in turn, is composed of word elements taken from the names of those properties that are diagnostic for the soil class. The major features of a soil placed within any class are signified directly by the specific formative elements appearing in the soil class name. The descriptions and formative elements of six surface horizons (epipedons), 17 subsurface horizons, 56 special features, and the 10 soil classes at the highest level of the system (orders), are provided. Because the basis of this paper is use of Soil Taxonomy by engineers, emphasis is placed on the nomenclature rather than the structure of philosophy of the system. The 39 formative elements considered to be most informative for general engineering analysis are highlighted for handy reference.

•SINCE 1965, all U.S. Department of Agriculture soil survey reports have correlated soils into the new Soil Taxonomy (11, 12), until recently referred to as the 7th Approximation (10). In contrast to the qualitative nature of the previous pedological classification system (2, 8, 14), Soil Taxonomy provides a quantitative framework in which to place soils of the United States as well as many soils of the world. Authors, attempting to point out the engineering value of the previous system, have been forced to treat the general merits of pedological soil surveys (4, 5, 6) or to confine themselves to specific soil series encountered in their particular project (7, 13). Although soil series convey the most specific soil property information and are therefore the most valuable class for engineering investigations, their number and variability preclude their use for more than local investigations. The new Soil Taxonomy, as Arnold Suggests (1), provides the first practical basis for interchange of a broad range of quantitative soil information between the soil scientist and the engineer.

For engineers, the most important aspect of the new taxonomy is that information can be derived from soils classes according to the system with little understanding of pedology, the mechanics of the system, or soil series. The user need only recognize key formative elements in the soil class names. That Lithic Cryopsamments are classed at the subgroup level is of little concern to the engineer; that elements in the name Lithic Cryopsamments signify shallow, sandy soils in cold climatic regions is of definite concern. Consequently, Soil Taxonomy is summarized, emphasizing the connotative nomenclature of the system and omitting much purely agricultural information. Throughout the discussion, those properties and their formative elements that are considered to be of interpretive value to engineers will be highlighted as follows: An asterisk (*) indicates possible interest, a dagger (†) indicates definite interest, and a double dagger (‡) indicates major importance.

This rating scheme is subjective and directed toward a range of engineering problems; a rating scheme for, or by, any specific engineering group (e.g., highway engineers) would likely be different. It should also be recognized that Soil Taxonomy is not an engineering soil classification system. Although much engineering information

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can be derived from soils mapped and classed according to the system, the diagnostic soil properties and categorical levels of the taxonomy do not correspond to priority levels of engineering interest.

THE SOIL TAXONOMY

Soil Taxonomy is a multi-categoric, pedological soil classification system (3, 9). The system recognizes 10 soil orders at the highest level, each order being subdivided into suborders, great groups, subgroups, families, and series. Approximately 10,000 soil series have been recorded in the United States (11). Preliminary reports on Soil Taxonomy have been available since 1960 (10), and the complete details of the system are being published as a two-volume set (11, 12).

DIAGNOSTIC HORIZONS

Because certain soil horizons and layers are basic to the separation of soil classes in Soil Taxonomy, a brief description of each diagnostic surface horizon (epipedon) and subsurface horizon follows.

Epipedons

1. Mollic: dark surface horizon, at least 18 cm thick, with at least 1 percent organic matter and without a massive or hard structure.
2. Anthropic: similar to mollic but different chemically.
3. Umbric: similar to mollic but different chemically.
4. Histic†: surface or near surface horizon(s), 20 to 60 cm thick, with at least 14 percent organic matter; unless artificially drained, saturated for at least 30 consecutive days.
5. Plaggen: not found in United States; man-made surface layer, more than 50 cm thick, produced by long continuous application of manure.
6. Ochric: pedogenic surface horizon, usually light colored, which does not qualify for one of the preceding.

Subsurface Horizons

1. Agric: thin horizon of silt, clay, and humus; formed by cultivation immediately below plow layer.
2. Albic: bleached horizon.
3. Argillic: horizon of silicate clay accumulation.
4. Calcic*: horizon of calcium carbonate, or calcium and magnesium carbonate, accumulation; calcium carbonate equivalent more than 15 percent; more than 15 cm thick; may be in C-horizon or other horizons; found primarily in arid and semiarid regions.
5. Cambic: altered horizon with significant amounts of weatherable minerals; little evidence of accumulations of clay, iron, aluminum, organic matter, or of rock structure.
6. Duripan†: horizon cemented to the point that air-dry fragments will not slake in water or acid; largely restricted to areas of vulcanism, primarily subhumid Mediterranean or arid regions.
7. Fragipan†: horizon seemingly cemented when dry, having hard or very hard consistency; dry fragments slake or fracture in water; when moist, has moderate or weak brittleness; high bulk density relative to soil above it; upper boundary commonly within 40 to 80 cm of surface, with horizon thickness varying from about 15 to 200 cm; found primarily in humid regions.
8. Gypsic†: horizon of calcium sulfate accumulation; at least 5 percent more gypsum than C-horizon or underlying stratum; more than 15 cm thick; product of thickness (cm) and percentage of gypsum is 150 or more; found primarily in arid and semiarid regions.
9. Natric*: special kind of argillic horizon; in some subhorizon, has more than 15 percent saturation with exchangeable sodium or more exchangeable magnesium plus sodium than calcium plus exchange acidity; normally prismatic or columnar structure.

10. Oxic†: extremely weathered horizon; hydrated oxides of iron and/or aluminum, variable amounts of 1:1 lattice clays, and highly insoluble minerals (e.g., quartz); more than 15 percent clay; at least 30 cm thick; stone lines and/or ironstone pebbles common; soils exhibit low clay activity, high permeability, and low erodibility; generally found in soils of very old, stable surfaces, seldom beyond tropics or subtropics.

11. Petrocalcic‡: continuously cemented or indurated calcic horizon; when dry, fragments do not slake in water and material cannot be penetrated by spade or auger; when moist, very firm to extremely firm; permeability moderately slow to very slow; usually much thicker than 10 cm; found primarily in arid to semiarid regions.

12. Petrogypsic‡: rarely found in United States; a gypsic horizon cemented to the point that dry fragments do not slake in water; gypsum content usually exceeds 60 percent; restricted to arid climates and to parent materials rich in gypsum.

13. Placic*: thin layer, cemented by iron; generally 2 to 10 mm thick; usually within 50 cm of, and roughly parallel to, surface; slowly permeable; sometimes found in tropical or cold regions but always in very humid or perhumid climates.

14. Plinthite†: technically not a diagnostic horizon; material changes irreversibly to ironstone layer or irregular aggregates on exposure to repeated wetting and drying (nonindurated form of material that has been called laterite); once indurated, can be broken or shattered with a spade but cannot be cut; normally forms in various subsurface horizons but may form at surface; restricted to tropics and subtropics.

15. Salic†: horizon of accumulation of salts more soluble in cold water than gypsum; at least 2 percent salt; at least 15 cm thick; product of thickness (cm) and percentage of salt (wt) is 60 or more; generally restricted to arid regions.

16. Spodic: horizon in which mixtures of organic matter and aluminum, with or without iron, have accumulated; may have a continuously cemented subhorizon more than 2.5 cm thick; found most often in coarse-textured materials; found only in humid regions.

17. Sulfuric†: horizon of mineral or organic materials with pH less than 3.5; forms as a result of artificial drainage.

SOIL ORDERS

Ten soil classes have been established at the highest level of Soil Taxonomy. These orders relate to the complete soil profile, being differentiated largely with regard to the aforementioned horizons. Although each order represents a defined central concept (11, 12), property variations are possible. Features common to, or absent from, soils classed at the order level are reported here rather than the central concepts:

1. Alfisols—have an argillic or natric horizon, or have a fragipan in, below, or similar to an argillic; no spodic or oxic horizon over argillic; no continuous plinthite in upper 30 cm.
2. Aridisols—have an ochric or anthropic epipedon; no spodic or oxic horizon; found principally in arid regions.
3. Entisols—have few or no diagnostic horizons; may have ironstone at any depth but no continuous plinthite in upper 30 cm; no salic horizon in upper 75 cm; no calcic, petrocalcic, gypsic or petrogypsic horizon or duripan in upper 1 m; no fragipan.
4. Histosols‡—organic soils; range from undecomposed to highly decomposed materials; unless over fragmental or rock material, at least 40 cm deep; found generally in swamp or marsh, but may be artificially drained.
5. Inceptisols—any epipedon possible; no continuous plinthite in upper 30 cm; no salic horizon in upper 75 cm; no gypsic or petrogypsic horizon in upper 1 m; commonly have cambic horizon; no spodic, oxic, argillic, or natric horizon, unless buried.
6. Mollisols—with few exceptions, have a mollic epipedon; have bulk density of at least 0.85 g/cc and less than 60 percent pyroclastic materials; no continuous plinthite in upper 30 cm; no spodic horizon in upper 2 m; no oxic horizon; found generally in subhumid to semiarid regions, being most extensive in midlatitudes.
7. Oxisols†—have an oxic horizon, normally in upper 2 m, or have continuous plinthite in upper 30 cm and are saturated at some time in most years; no spodic or argillic horizon over the oxic; found in tropics or subtropics (see "oxic horizon").

8. Spodosols—have a spodic horizon in upper 2 m or a placic horizon over a fragipan; principally coarse-textured materials found in humid regions.

9. Ultisols—have an argillic horizon, or have a fragipan below, or similar to, an argillic; no continuous plinthite in upper 30 cm; no spodic horizon; no oxic horizon over an argillic; mean annual soil temperature at least 8 C; found principally in warm, humid regions, from low latitudes to midlatitudes.

10. Vertisols‡—have at least 30 percent clay (primarily expanding lattice) to at least 50-cm depth; unless irrigated, have cracks at or near surface that are at least 1 cm wide at a depth of 50 cm at some period in most years; mean annual soil temperature at least 8 C; generally found in subhumid to arid regions.

NOMENCLATURE AND FORMATIVE ELEMENTS

With the exception of soil series, the name of each soil class within each order is composed of formative elements that connote properties common to soils in that class. Although soil class names may contain more than one word, it is the final word that reflects those properties considered to be most important for the pedological classification. This final word contains two or three formative elements. All other modifying words (i.e., adjectives, ending with "ic") indicate whether the soil represents the central concept of the class, whether the soil is an intergrade to another class, or whether some special property is associated with the soil.

Classes Related to Orders

Ten soil orders have been outlined. The names of all soil classes within a particular order are related to their order by an element from the order name.

Order	Element	Order	Element
Alfisols	Alf(s)	Mollisols	Oll(s)
Aridisols	Id(s)	Oxisols†	Ox(s)
Entisols	Ent(s)	Spodosols	Od(s)
Histosols‡	Ist(s)	Ultisols	Ult(s)
Inceptisols	Ept(s)	Vertisols	Ert(s)

The elements form the suffixed base to every soil class name. With this base, each name records the soil's classification at the order level and, thus, the basic properties exhibited by the soil. The following serve as illustrations:

Soil Class	Order
Aquents	Entisols
Fragiaquepts	Inceptisols
Hydric Borohemists	Histosols
Vertic Haploborolls	Mollisols

Elements of the order names may also modify the final word in a soil class name. In the class Vertic Haploborolls, "olls" indicates that the soil is a Mollisol, but "Vertic" indicates that the soil has certain properties associated with Vertisols. Other examples of this usage are as follows:

Soil Class	Order
Ultic Paleustalfs	Alfisol grading to Ultisol
Entic Chromuderts	Vertisol grading to Entisol
Alfic Sideraquods	Spodosol grading to Alfisol

Classes Related to Horizons

Epipedons and various subsurface horizons have been described. If a soil has one or more of these horizons, and if the horizon is not required (or indicated) by the soil's order classification, the soil class name will contain elements from the names of those horizons present. Formative elements representing the most commonly recognized horizons are as follows:

Horizon	Element	Horizon	Element
Agric	Agr	Gypsic†	Gyps
Albic	Alb	Natric*	Natr
Anthropic	Anthr	Ochric	Ochr
Argillic	Arg	Placic*	Plac
Calcic*	Calc	Plaggen	Plag
Cambic	Camb	Salic†	Sal
Duripan†	Dur	Sulfuric†	Sulf
Fragipan†	Frag	Umbric	Umbr

Examples of soil class names that signify the presence of horizons listed previously are as follows:

Soil Class	Horizons Indicated
Ochrepts	Ochric
Fragiochrepts	Fragipan and ochric
Natric Durixeralfs	Duripan (also natric or similar)
Calcic Argixerolls	Argillic (also calcic or similar)

With the last two examples, Natric Durixeralfs and Calcic Argixerolls, it is noted that horizon names may also be used to modify the final word. Three other horizon modifiers are petrocalcic, petrogypsic, and nadur. Petrocalcic and petrogypsic horizons have been described; "nadur" signifies that both a natric horizon and a duripan occur in the soil profile. When used as modifiers, "mollic," "spodic," and "oxic" relate to both soil horizons and soil orders, in that these horizons are also diagnostic for the orders. "Histic," on the other hand, relates only to the presence of a histic epipedon.

Classes Related to Other Features

Formative elements that are indicative of properties other than those associated with the soil's order classification or with particular horizons exhibited by the soil are as follows. Their common interpretation, where significant, and examples of their usage in soil class names are provided. As noted, the dominant soil properties are signified by the two or three formative elements that are contained in the final word in each soil class name. When used in the final word, a formative element connotes a characteristic soil property; when used as an adjective to modify the final word, it merely modifies those properties signified by elements in the final word. For example, "Aqu" in "Aquents" indicates complete profile saturation at some period (unless drained), but "Aquic" in "Aquic Calciorthids" indicates a Calciorthid that is wetter than a Typic Calciorthid.

Element	Common Interpretation	Example
Abruptic*	Abrupt clay increase; generally more than 20 percent (absolute) change in 7.5 cm or less, from ochric or albic to argillic (near surface charge)	Abruptic Tropaqualfs Abruptic Durixeralfs Abruptic Durargids
Acr*	Extreme weathering; only used with Oxisols	Acrohumox Plinthic Acrorthox
Aeric	Only used with "aqu"; soil drier than normally associated with "aqu"	Aeric Haplaquents Aeric Umbric Tropaquults

Element	Common Interpretation	Example
And*	Pyroclastic materials; upper horizon of textures finer than loamy fine sand; bulk density of 0.95 g/cc or less	Andepts Andic Cryochrepts Andeptic Ochraqualfs
Aqu‡	Wetness; generally, at least temporary saturation	Aquents Aquic Calciorthids
Ar	Mixed horizons, usually destroyed by plowing	Arents
Arenic*	Sandy surface (loamy fine sand or coarser) 50 to 100 cm thick	Arenic Haplastults Arenic Argiaquolls
Bor	Cold or properties associated with cold; normally mean annual soil temperature below 10 C	Boralfs Typic Fragiboralfs Borollic Haplargids
Chrom	Only used with Vertisol; surface browner and drier than that of "pell"	Chromusterts Chromic Pelloxererts
Cry	See "bor"; normally mean annual soil temperature 0 to 8 C	Cryofolists Cryic Rendolls
Cumulic	Epipedon more than 50 cm thick; organic matter may decrease irregularly with depth	Cumulic Haplumbrepts Cumulic Haplustolls
Dystr	Relates to lower base saturation	Dystrochrepts
Epiaquic*	Characteristics approaching those associated with "aquic"	Epiaquic Palehumults Epiaquic Tropudults
Eutr	Relates to higher base saturation	Eutrorthox
Ferr*	High iron-to-carbon ratio in spodic horizon; or iron-cemented nodules (2 to 30 cm in diameter) in argillic horizon	Ferrods Ferrudalfs
Fluv†	Recent alluvial deposits	Fluvents Fluvaquentic Cryohemists
Gibbs†	In upper 1 to 1.25 m, have cemented sheets or subhorizon with at least 20 percent (vol) gravel-size aggregates, containing 30 percent or more gibbsite (Al_2O_3)	Gibbsihumox Gibbsiaquox Typic Gibbsiorthox
Gloss	Albic horizon tongues into argillic or natric horizon	Glossudalfs Glossic Natrudalfs
Grossarenic†	Sandy surface (loamy fine sand or coarser) more than 1 m thick	Grossarenic Paleaquults
Hal‡	Salty; only used with "aquept" (wet-salty soil); at least 15 percent sodium saturation in at least half of upper 50 cm; decreases below 50 cm	Halaquepts Aeric Halaquepts Fluvaquentic Halaquepts
Hapl	Normal horizon development; "Haplic" indicates minimal horizon development	Haplorthods Haplic Durargids
Hum	Organic matter content higher than normal	Humox Humic Cryorthods
Hydr‡	Thixotropic in some horizon between 25 and 100 cm (relatively low bearing capacity); may have clays that dehydrate irreversibly to sand or gravel-size aggregates; normally	Hydraquents Hydrandepts Hydric Tropofibrists (with Histosols, indicates water layer below 30 to 60 cm)

Element	Common Interpretation	Example
	low bulk density and high water content	
Lithic‡	Rock contact in upper 50 cm	Lithic Rhodustalfs
Orth	Common horizon development	Orthox
Pachic	Epipedon thicker than that of "Typic"; normally more than 50 cm thick	Pachic Argiborolls Pachic Xerumbrepts
Pale*	Older soil development; have petrocalcic and/or thick, fine-textured argillic horizon; may have some plinthite in sub-horizons; normally old, stable surfaces	Palexeralfs Paleorthids Spodic Paleudults
Paralithic‡	Lithic-like contact, or altered rock retaining its structure, within 50 cm of surface	Paralithic Vertic Haplustolls
Pell	See "chrom"	Pelleusterts
Pergelic‡	Have permafrost; mean annual soil temperature below 0 C	Pergelic Cryopsamments
Petroferric‡	Petroferric contact (ironstone) within upper 1 m	Petroferric Acrohumox
Plinth†	Plinthite is continuous, or constitutes more than one-half soil matrix, in upper 1.25 m; "Plinthic"—more than 5 percent (vol) plinthite in upper 1.5 m	Plinthaquepts Typic Plinthaquox Plinthic Tropudults
Psamm†	Below plow layer or 25 cm, have sandy textures to 1 m or to lithic or paralithic contact	Psamments Psammentic Haploxeralfs
Quartz*	Only used with "psamm"; sand fraction has at least 95 percent quartz or other insoluble minerals	Quartzipsamments Quartzipsammentic Haplumbrepts
Rend*	Have at least 40 percent calcium carbonate equivalent in or below epipedon	Rendolls Rendollic Eutrochrepts
Ruptic* (Ruptic-Lithic‡)	Intermittent or broken horizons; commonly shallow soils; with "Lithic," indicates horizons interrupted by bedrock	Ruptic-Vertic Albaqualfs Ruptic-Lithic-Entic Hapludults
Sider	Spodic horizon has ratio of free iron to carbon of 0.2 or more	Sideraquods Sideric Cryaquods
Sulf‡	Waterlogged or organic soil materials with at least 0.75 percent sulfur (mostly sulfides) and less than 3 times as much carbonate as sulfur in upper 1 m; drainage normally produces sulfuric horizon	Sulfihemists Sulfic Fluvaquents
Thapto* (Thapto-Histic‡)	Buried horizon or buried soil within 50 to 100 cm of surface	Thapto-Histic Fluvaquents Thapto-Histic Cryaquolls
Torr	Dry soil moisture regime; found primarily in arid and semiarid climates	Torrerts Torriorthentic Haplustolls
Trop	See "ud"; properties associated with humid tropical climates	Tropudalfs Tropic Fluvaquents

Element	Common Interpretation	Example
Typic	Typical profile of soil class (subgroup level)	Typic Medisaprists Typic Placohumods
Ud	Soil moisture regime dry less than 90 days in most years; properties associated with humid temperate climates	Uderts Entic Vermudolls Udic Ustrochrepts
Ust	Soil moisture regime between "torr" and "ud"; properties associated with wet-dry climates, usually warm	Ustox Lithic Ustorthents Ustertic Argiborolls
Verm	Below plow layer or 25 cm, at least 50 percent of volume is worm holes, casts, or filled burrows	Vermustolls Haplic Vermiborolls Vermic Udorthents
Vitr*	Only used with "and"; large amounts of vitric ash (glass) and pumice; commonly found near active volcanoes	Vitrandepts Plaggic Vitrandepts
Xer	Soil moisture regime and properties typified in Mediterranean climates; wet-dry, nontropical	Xerults Durixerollic Natrargids

Classes Related to Histosols

Nine formative elements are employed to distinguish various classes of the order Histosols. Recognition of these elements will assist the engineer who is forced to deal with organic soils as well as the engineer who must decide whether to design around such soils. The elements are summarized as follows:

Element	Common Interpretation	Example
Fibr	Least decomposed state; commonly have bulk densities less than 0.1 g/cc, fiber contents (unrubbed) more than two-thirds of volume, and saturated water contents of 850 to 3,000 percent (oven-dry)	Fibrists Cryofibrists Fibric Borohemists
Fol	Never saturated more than a few days after heavy rains; lithic or paralithic contact within 1 m of surface, and/or fragmental materials with organic materials in interstices	Folists Cryofolists Typic Tropofolists
Hem	State of intermediate decomposition (values between "fibr" and "sapr")	Hemists Hemic Borofibrists
Limnic	Organic and inorganic materials deposited in water or derived from aquatic plants (marl, diatomaceous earths, sedimentary peat, etc.)	Limnic Borofibrists Limnic Medihemists
Luv	Unknown in U.S.; horizon of humus materials, at least 2 cm thick, derived from higher in profile	Luvifibrists Luvihemists

Element	Common Interpretation	Example
Med	Less than three-quarters fiber volume derived from sphagnum peat; temperate climate	Medifibrists Lithic Medihemists
Sapr	Most decomposed state; relatively stable; commonly have bulk densities of 0.2 g/cc or more, fiber contents (unrubbed) less than one-third of volume, and saturated water contents below 450 percent (oven-dry)	Saprists Cryosaprists Sapric Tropofibrists
Sphagn	At least three-quarters fiber volume derived from sphagnum peat	Sphagnofibrists Sphagnic Medifibrists
Terric	Have mineral layer, at least 30 cm thick, with upper boundary within 60 cm of surface	Terric Troposaprists Sphagnic Terric Borofibrists

FAMILIES AND SERIES

All of the examples previously listed represent soils classed at the order, suborder, great group, and subgroup levels of the Soil Taxonomy. Subgroups are divided into families, and each soil family name consists of the subgroup name and several additional adjectives. These adjectives include class names for texture and contrasting texture, mineralogy, reaction or calcareousness, soil temperature, permeability, depth, slope, consistence, and coatings. For example, a "sandy, mixed, thermic" family of any subgroup indicates sand or loamy sand with less than 35 percent rock fragments by volume in a specified control section of the profile; a mixture of minerals, each less than 40 percent, in the 0.02- to 2.0-mm fraction of the control section; and a mean annual soil temperature at 50 cm depth between 15 and 22 C, with at least a 5 C difference between mean summer and winter soil temperatures. Class names, definitions, and recommended use of family characteristics are provided in the two volumes of the Soil Taxonomy (11, 12).

Soil series, when identified and classified in a survey, convey the greatest amount of soil property information and are of special value for local investigations. Series, however, are commonly named for geographic locations that seldom indicate soil properties. In most cases, the previously recognized series of the National Cooperative Soil Survey are classified in the hierarchy of the taxonomy (11).

SUMMARY

The previous U.S.D.A. system for soil classification has been replaced by the new Soil Taxonomy, a comprehensive, multi-categoric, pedological soil classification system. Although it may appear complex, the new Soil Taxonomy can be used by engineers who have little understanding of the mechanics of the system, of pedology, or of soil series. With the exception of soil series, each soil class name in Soil Taxonomy is composed of words or formative elements that connote properties expressed by the soil. Specific information about the soil is thereby obtained directly from the soil class name. Those formative elements and soil orders considered to be most informative for engineering analysis are listed as follows:

Element or Order	Brief Interpretation
Abruptic*	Abrupt textural change
Acr*	Extremely weathered (see Oxisols)
And*	Pyroclastic materials
Aqu‡	Wetness; possible saturation
Arenic*	Sandy surface
Calc*	Calcic horizon with or without gypsic horizon

Element or Order	Brief Interpretation
Dur†	Duripan
Epiaquic*	Surficial wetness
Ferr*	May have iron-cemented nodules
Fluv†	Alluvial deposits
Frag†	Fragipan
Gibbs†	Cemented sheets or aggregates (Al_2O_3)
Grossarenic†	Thick sandy surface
Gyps†	Gypsic horizon
Hal‡	Salty (wet)
Histic†	Organic surface
Histosols, ist(s) fibr, sapr, hem, med, limnic, sphagn, luv, fol, terric‡	Organic soils (fol: less than 1 m deep) (terric: mineral soil layer within 60 cm of surface)
Hydr‡	Thixotropic, clays may dehydrate irreversibly to aggregates (possible wetness)
Lithic‡	Bedrock within 50 cm of surface
Nadur†	Natric horizon and duripan
Natr*	Natric horizon
Oxisols, ox(s), Oxic†	Extremely weathered, stable soil, commonly deep; oxic horizon
Pale*	Petrocalcic or thick argillic horizon
Paralithic‡	Lithic-like contact within 50 cm of surface
Pergelic‡	Frozen soil or permafrost
Petrocalcic‡	Petrocalcic horizon
Petroferric‡	Ironstone contact within 1 m of surface
Petrogypsic‡	Cemented gypsic horizon
Plac*	Placic horizon
Plinth†	Plinthite within upper 1.25 m
Psamm†	Sandy soil
Quartz*	Sand fraction predominantly in-soluble minerals
Rend*	Material with high $CaCO_3$ equivalent
Ruptic* (Ruptic-Lithic‡)	Broken horizon, commonly by shallow bedrock
Sal†	Salic horizon
Sulf†	Sulfuric horizon or sulfidic material
Thapto* (Thapto-Histic‡)	Buried horizon or buried soil
Vertisols, ert(s), Vertic‡	Swelling clay soil
Vitr*	Volcanic glass; nonthixotropic

REFERENCES

1. Arnold, R. W. Soil Engineers and the New Pedological Taxonomy. Published in this Record.
2. Baldwin, M., Kellogg, C. E., and Thorp, J. Soil Classification. In Soils and Men; Yearbook of Agriculture. U.S. Govt. Print. Office, Washington, D.C., 1938, pp. 997-1001.
3. Cline, M. G. Basic Principles of Soil Classification. Soil Sci., Vol. 67, 1949, pp. 81-91.

4. Felt, E. J. Soil Series as a Basis for Interpretive Soil Classifications for Engineering Purposes. In Symposium on Identification and Classification of Soils, ASTM Spec. Tech. Pub. 113, 1950, pp. 62-84.
5. Greenman, R. L. The Engineer Looks at Pedology. In Symposium on Surface and Subsurface Reconnaissance, ASTM Spec. Tech. Pub. 122, 1952, pp. 46-56.
6. The Use of Agricultural Soil Maps and the Status of Agricultural Soil Mapping in the United States. HRB Bull. 22, 1944, 128 pp.
7. Lacey, D. L. Applications of Soil Survey Data to Highway Engineering in Kansas. HRB Bull. 83, 1953, pp. 29-32.
8. Riecken, F. F., and Smith, G. D. Lower Categories of Soil Classification: Family, Series, Type and Phase. Soil Sci., Vol. 67, 1949, pp. 101-115.
9. Simonson, R. W. Soil Classification in the United States. Science, Vol. 137, 1962, pp. 1027-1034.
10. Soil Conservation Service. Soil Classification: A Comprehensive System (7th Approximation). U.S. Govt. Print. Office, Washington, D.C., 1960; and 1967, 1968, and 1970 supplements.
11. Soil Conservation Service. Soil Series of the United States, Puerto Rico, and the Virgin Islands: Their Taxonomic Classification. U.S. Govt. Print. Office, Washington, D.C., 1972.
12. Soil Conservation Survey. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. USDA Handbook No. 436, U.S. Govt. Print. Office, Washington, D.C., in press.
13. Thornburn, T. H., and Bissett, J. R. The Preparation of Soil Engineering Maps From Agricultural Reports. HRB Bull. 46, 1951, pp. 87-95.
14. Thorp, J., and Smith, G. D. Higher Categories of Soil Classification: Order, Suborder, and Great Soil Groups. Soil Sci., Vol. 67, 1949, pp. 117-126.