REVIEW OF PARTICLE-SIZE CLASSIFICATIONS OF SOILS

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A review of particle-size classification systems for soils is made. Early systems and the evolution to systems now in use by agriculturalists, engineers, and geologists are presented. Thirty-two systems are given, and where possible the reasons for the various particle-size ranges and name designations are given. Factors considered in establishing particle-size limits include tillage properties, water retention, capillarity, root penetration, mineralogical and chemical composition, colloidal properties, specific soil usages, ease of presentation and data analysis, and method of testing. For systems commonly used at present, there is considerable variation in the size ranges assigned to the various descriptive names such as clay, silt, and sand. There is even more variation in subdivisions of major groups. Considerable compromising would be required to establish a common particle-size classification system for soils.

•SOILS consist of mineral particles that cover a wide range of sizes. It is advantageous to assign names to describe particles that lie between certain size limits. These names are convenient to use and give more information than does a mere statement that the particles lie between certain size limits.

Many systems for the particle-size limits of the various soil components have been proposed and used. However, many discrepancies exist among these systems. Thus, a certain term may designate very different materials depending on the system used.

All of the particle-size limit schemes are arbitrary because no clear-cut divisions can be made among members of a continuous series. The originators of the various systems were influenced by many factors when they made their selections. These include the field of study such as agriculture, engineering, or geology; the convenience of investigation; the methods and apparatus available for analysis; the ease of presenting data; the convenience for statistical analysis; and the previous work done and systems used.

Some of the investigators tried to place the limits to correspond with the various properties of the soil compenents; many were more interested in the ease and convenience of obtaining and presenting data.

The purpose of this paper is to review many of the systems that have been proposed and used and to present the reasons for the selection of particle-size limits, if possible. The systems are grouped according to the source of information, i.e., agricultural, engineering, or geological literature.

SYSTEMS REPORTED IN AGRICULTURAL LITERATURE

Figure 1 shows particle-size definitions reported in agricultural literature. The early European systems proposed by Wanschaffe (8), Wolf (55), Kuhn (14), and a German permanent committee for soil investigation (14) were apparently based on arbitrary selections.

In 1895 Williams (54), of Russia, presented the system, based on grain size and shape, used by Fadejeff in his lectures at the Agricultural Academic Petroffskaja. Wil-

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liams agreed with this system except for the earthy soil group, as shown. He called the last fraction clay because the soil owes almost all of its cohesion to this portion, the cohesion of the silts being due to organic matter present. In addition, the specific gravity of the clay fraction is less than that of the others. The transition from sand to silt results in a sudden strong increase in water retention, but the increase is even more significant when the transition is from silt to clay. The same trend is observed with permeability; sand is very permeable, silt is much less so, and clay sometimes is completely impermeable. The amount and rise of capillary water are also factors. All of the larger particles are products of physical reduction of quartz and other minerals, while clay is a product of chemical weathering.

One of the early investigators in the United States was Hilgard (23, 24, 25), who used an elutriating device to perform mechanical analyses. His particle size limits and hydraulic values are given in Table 1. The values for particle size refer to the diameters of the largest and most nearly rounded quartz grains in each sediment, the quartz grains being used as standard. Hilgard felt his hydraulic values gave a better definition. This value is the velocity of an upward current of water, in mm/sec, that will carry off a fraction of the soil, i.e., the buoyant power of an upward current of water moving under a constant and uniform velocity. With respect to the porosity of the soil on the one hand and its compactness and resistance to tillage on the other, he felt silt sediment with hydraulic value of 0.5 ($^{1}/_{36}$-mm diameter) was neutral. Therefore, portions $>^{1}/_{36}$ mm were designated as coarse materials that increase lightness and porosity of soil in proportion to percentage. The fine portion, $<^{1}/_{36}$ mm, modifies the plastic properties of the clay but also makes soil heavier in tillage than if it were absent.

In 1887 Osborne, of the Connecticut Agricultural Experiment Station (34), reported the results of a study of various mechanical analysis methods. He used purely arbitrary particle-size limits that could be conveniently determined with his optical micrometer. Sieves of 1, 0.5, and 0.25 mm were used, and elutriation and sedimentation were used for smaller particles. Other limits used for more detailed analyses were 1, 1 to 0.5, 0.5 to 0.25, 0.05 to 0.02, 0.02 to 0.01, 0.01 to 0.005, and <0.005 mm.

Early workers in the U. S. Department of Agriculture adopted most of Osborne's limits (16, 17, 31, 53). Whitney (53) placed a lower limit of 0.001 mm for clay because a soil suspension that has stood for several weeks will show particles of that size. Later the Bureau of Soils combined the 2 silt groups into 1 from 0.05 to 0.005 mm and designated clay as anything <0.005 mm (16).

In 1899 Hopkins, of the Bureau of Chemistry, U.S. Department of Agriculture (28), made a proposal for a more scientific division of soil particles. To illustrate the arbitrariness of the method being used by the Bureau of Soils, he quoted correspondence from Osborne:

> In working out the beaker method of soil analysis I employed the limits of the various grades with reference simply to convenience in using my eyepiece micrometer. I have always thought that the limits of the various grades should be determined by a careful consideration of the various conditions involved in the problem of proper mechanical analysis of a soil, and have been surprised to see that the arbitrarily chosen limits of the various grades employed by me have been followed by others in applying the method in practice.

Hopkins considered as a serious objection the fact that the ratio of the largest to the smallest particles of each division was not constant. The limits for silt were 2 times wider than those for fine sand and $2\frac{1}{2}$ times wider than those for other groups. The differences in the ratios of surfaces and volumes were even larger, yet capillarity and porosity are more closely related to these than to the diameters.

Hopkins' method assumes that there is a theoretical composition of a soil of uniform gradation within the limits of the system and that the end divisions contain the average percentage of material. He adopted a common factor of $\sqrt{10}$ (approximately 3.2) in passing from the smallest to the largest particle in all divisions of defined limits; therefore, the ratios are all constant. The system can be expanded by using $\sqrt[4]{10}$ (approximately 1.8); each of the divisions defined above will be divided into two.

Figure 1. Particle-size classifications from agricultural literature.

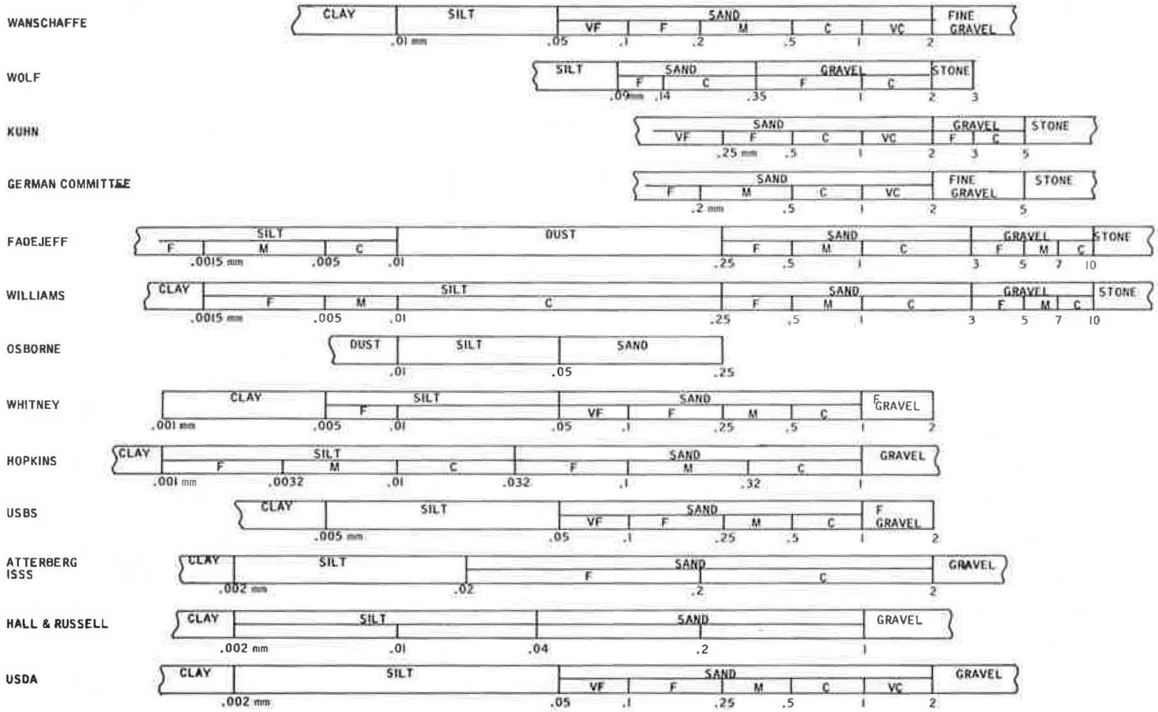


Table 1. Hilgard's hydraulic values and particle sizes for soil fractions.

Name	Hydraulic Value (mm/sec)	Size (mm)
Coarse grits	?	1 to 3
Fine grits	?	0.5 to 1
Coarse sand	64	(80 to 90) × 1/180
Medium sand	32	(50 to 55) × 1/180
Fine sand	16	(25 to 30) × 1/180
Finest sand	8	(20 to 22) × 1/180
Dust	4	(12 to 14) × 1/180
Coarsest silt	2	(8 to 9 × 1/180
Coarse silt	1	(6 to 7) × 1/180
Medium silt	0.5	(4 to 5) × 1/180
Fine silt	0.25	(2.5 to 3) × 1/180
Finest silt	0.25	(0.1 to 2) × 1/180
Clay	0.25	?

Extensive studies of soil properties were made in Sweden in the early part of this century by Atterberg (7, 8, 9, 10, 11, 12). He classified soil particles finer than 2 mm into 5 principal groups:

1. Large sand grains that form water-permeable sands;
2. Finer grains that form water-retaining sands;
3. Microscopic "silt" particles that form mud with rain and that display a certain cohesiveness on drying;
4. Fine particles, or semicolloids, that can be measured by a microscope and that in water show the molecular motion characteristic of colloids and are coagulated easily by acids and salt; and
5. Colloid particles that cannot be measured with a microscope.

Because the fourth and fifth groups cannot be quantitively separated, they are placed together in one group.

The particle-size limit between water-permeable and water-retaining sands is not sharp. Atterberg placed it at 0.2 mm. Sand from 0.5 to 0.2 mm diameter can retain only 30 mm of water, while sand from 0.2 to 0.1 mm can retain 110 mm of water above the capillary limit.

Atterberg placed the size limit between sand and silt at 0.02 mm for various reasons. Particles from 0.2 to 0.02 mm possess good capillarity and allow fast capillary movement of water. Materials finer than 0.02 mm show very high capillarity, but the movement of water in the capillaries is retarded. Also, 0.02 mm appears to be the upper bound for the strong coagulation of fine materials in water containing acids or salts. This particle size is also about the limiting size that can be distinguished by the naked eye. Also, the boundary for the penetration of the root hairs of grasses into interspaces between soil grains occurs at grain sizes of about 0.02 mm.

The limit between silts and clays was placed at 0.002 mm primarily because particles smaller than this exhibit strong Brownian motion when settling from a water suspension. Grains of 0.002 mm are only weakly affected; those of 0.003 mm not at all. Also, materials finer than 0.002 mm show very retarded movement of water in the capillaries.

Atterberg placed the limit between sand and gravel at 2 mm material larger than this possesses an insignificant capillarity. Stones of dimensions between 2 to 20 cm, which are moved about by wave action on beaches, he designated as pebbles. Larger stones, not rolled by waves, were called boulders.

Atterberg's main particle-size limits were, therefore, 20, 2, 0.2, 0.02, and 0.002 mm. Limits for subdivisions were set at 6 times powers of ten, for $2 \times \sqrt{10} = 6.32$ and $6.32 \times \sqrt{10} = 20$; 6.32 was rounded off to 6. These dimensions will plot as equal lengths on a logarithmic scale.

Later Atterberg felt it would be advantageous to change the limits between coarse sand and fine sand, fine sand and silt, and silt and clay from 0.2, 0.02, and 0.002 mm to 0.3, 0.03, and 0.003 mm (7, 9). The limit between water-permeable and water-retaining sands is not sharp but lies at about 0.3 or 0.2 mm. The limit between macroscopic and microscopic particles is somewhat sharper; particles of 0.04 mm can be clearly distinguished with a magnifying glass, whereas those of 0.03 can hardly be. The root hairs of plants such as peas and beans are too large to penetrate between soil particles finer than 0.03 mm, although grass root hairs are limited to 0.02 mm. He found that grains larger than 0.03 have the appearance of true sand grains and smaller ones appear as dust. Brownian movement is affected by temperature, and so the size limit is not constant but probably lies near 0.003 mm. The 0.003-mm limit is also of great physiological significance in that most bacteria cannot move between soil particles of small diameter.

The chief advantage to be found in changing the limits would be the length of time required to separate the fractions in a sediment analysis. When the fine clay was separated from silt in the sediment analysis then in use, a settling time of 8 hours was required. Changing the limit to 0.003 mm would shorten this to 4 hours. Likewise, the settling time for separation of silt from fine sand would be shortened from 7½ to 3¾ min by changing the limits from 0.02 to 0.03 mm.

Although Atterberg was in favor of the changes, his originally defined limits gained wider usage. Later he expressed the opinion that the 0.02-mm limit was more correct than 0.03 mm for the upper limit of water-retaining sand (13).

Atterberg felt his system agreed fairly well with that proposed by Williams (54). In his opinion, the U.S. Bureau of Soils System placed too much emphasis on the macroscopic particles and not enough on the microscopic portion, the limits should go lower than 0.005 mm, and the system had far too many divisions.

In 1914 an international commission on mechanical and physical soil investigations discussed a proposal to accept Atterberg's scale as an international system (41). Hilgard felt Atterberg's limits of 2.0 to 0.2 mm for coarse sand was too extensive. He wanted coarse sand to be 2.0 to 0.5 mm, fine sand to be 0.2 to 0.02 mm, and coarse and fine silt to be <0.02 mm. In his opinion, clay has no specific diameter, but practically it must include the silts finer than 0.0016 mm. Whitney did not see how Atterberg's system was any better or worse then any other. He thought the U.S. Bureau of Soils System should be given consideration. However, most members of the commission were in favor of Atterberg's methods although a few wanted to use a different method for clay determination. Atterberg's scale was accepted as the International System.

In 1911, Hall and Russell (22) presented a system that was used in Great Britain for a number of years. The fractions, except for clay and part of the fine silt, do not represent distinct substances, so the limits are artificial, merely for convenience of discussion. Fine silt from 0.01 to 0.005 mm was considered to be of the same character as the coarser materials although the silica content is less. The finer fraction, 0.005 to 0.002 mm, has about 20 percent less silica while the alumina, ferric oxide, and potash contents increase. Clay, <0.002 mm, is a complex silicate, or a mixture of several, and is most important in determining soil fertility. It binds the soil and increases water-holding capacity, depending on the amount of clay content present. The clay possesses properties of colloids while the fine silt does not.

Atterberg's scale was adopted by the Great Britain Agricultural Education Association in 1927 (39) and was adopted as the official British method in 1928 (38); however, a modified velocity scale was used. In Atterberg's system, material with an equivalent diameter of 0.002 mm was considered to have settled from a 10-cm height of water at 20 C after a period of 8 hours; 0.02-mm equivalent diameter material settled out in 7½ min, and 0.2-mm material settled in 5 sec (40). For the modified scale, Atterberg's designation for 0.002 material was used as a base. A particle that settled 10 cm in 8 hours in water at 20 C was defined as 0.002-mm equivalent diameter, and the others were computed by Stoke's law on that basis. This gives 4 min 48 sec for 0.02 mm and 2.88 sec for 0.2 mm, although the last fraction is separated in practice by sieving. The new scale was adopted because, inasmuch as it was an international scale, it was widely used in the dominions and colonies, and uniformity in scale for the British Empire could be attained.

In the United States, conflicts in laboratory limits between silt and clay in the U.S. Bureau of Soils System and textures determined by soil surveyors in the field often occurred. In 1936, Shaw and Alexander (42) reported results of a study that they made. Soils were divided into silt 0.05 to 0.005, coarse clay 0.005 to 0.002, and fine clay or colloid <0.002 mm groups. They found that the coarse clay acted physically very like silt, and several soil surveyors classified it as silt. Chemical tests showed that the silica content of the 0.005- to 0.002-mm fraction was more closely related to the silt than to the fine clay. They recommended changing the lower limit of silt to 0.002 mm. Also, Troug, Taylor, Simonson, and Weeks (47, 48) in 1936 recommended changing the lower limit of silt from 0.005 to 0.002 mm. Clay with an upper particle-size limit of 0.002 mm is practically free of primary minerals, such as feldspars that weather easily. Certain minerals, such as quartz and muscovite, which are relatively resistant to chemical weathering, may be present in both primary and secondary form. Thus, clay less than 0.002 mm consists almost entirely of material that has great resistance to further decomposition. If separation is made at 0.005 mm, appreciable amounts of feldspar and other easily weathered minerals may be present.

In 1938, the U.S. Department of Agriculture System was adopted with the silt range from 0.05 to 0.002 mm and clay <0.002 mm (30). The other limits were the same as those in the older U.S. Bureau of Soils System. Later, in 1947, the size range from 2.0 to 1.0 mm was renamed "very coarse sand" rather than "fine gravel." Fine gravel is used for fragments from 2 mm to ½ in. in diameter (43).

SYSTEMS REPORTED IN ENGINEERING LITERATURE

Figure 2 shows particle-size definitions reported in engineering literature.

In 1925, Terzaghi (46) set forth the system that evolved to what is known as the Continental System. His system utilized part of Atterberg's and part of one presented by Ramann that was essentially the same as the one proposed by a German permanent committee (14) in 1894. Terzaghi used the latter for coarser material and Atterberg's for the finer portions. In the Continental System (19) the clay portion is reduced to one group of <0.002 mm, and particles larger than sand are defined.

In early studies of sand-clay and topsoil roads in the United States, the Bureau of Public Roads used the following definitions for various soil fractions (15, 20, 26).

Sand: That portion of the soil that passes the No. 10 sieve but is retained on the No. 200 sieve (2.0 to 0.07 mm) and that settles out of a 500-cc mixture of soil and water in 8 min. Coarse sand and fine sand were initially separated by the No. 60 sieve (0.25 mm); this was later changed to the No. 40 sieve (0.42 mm).

Silt: That portion that passes the No. 200 sieve (0.07 mm) and that settles out of the water suspension in 8 min.

Clay: That portion that passes the No. 200 sieve and remains in suspension after 8 min but that is thrown down by a centrifugal force equal to 500 g exerted for a period of ½ hour. This grain size is about 0.03 or 0.02 mm.

Suspension Clay: That portion that remains in suspension after centrifuging.

The limits given above were purely arbitrary and set because of convenience of separation by the method then being used. These early size ranges were later supplemented by the Bureau of Public Roads System as shown in Figure 2.

Hogentogler (26) gave several reasons for the system: (a) Use of the No. 40 sieve to separate coarse sand from fine sand eliminates one determination in the mechanical analysis because tests for properties of the finer portions are performed on the material that passes the No. 40 sieve; (b) with the exception of the division between coarse and fine sands, the limits correspond to those of the U.S. Bureau of Soils System, and this facilitates use of information in soil surveys made by that bureau, in which the mechanical analysis plays an important part; (c) grading by the sizes given above is accomplished as easily as grading by the former sizes was accomplished by earlier methods; and (d) each division represents a group of particles having a special significance.

The physical significance of the various size divisions were presented as follows.

Gravel is rock fragments that are usually rounded by water action and abrasion. Quartz is the principal constituent. Gravel that is only slightly worn, rough, and subangular commonly includes granite, schist, basalt, or limestone.

Coarse sand is likely to consist of the same minerals as the gravel. It is usually rounded like pebbles.

Fine sand is usually more angular than coarse sand.

Silt consists of bulky grains that are similar to fine sand except for size and have the same mineral composition. However, it may be largely a product of chemical decay rather than of rock grinding and, therefore, may consist of silicates of aluminum and alkaline earths and of oxides of iron. In other cases, the silt may be composed of foreign materials such as diatoms, pumice, or loess.

Clay is the coarser fractions that usually and mainly consist of original fragments such as quartz and feldspar. However, clay consists almost entirely of the secondary products of chemical weathering. It differs from the coarser fractions in that it is the chemically reactive portion of the soil; the coarser fractions are inert.

Colloids, in a strict sense, are only those finer clay particles that show pronounced Brownian movement when suspended in water. Some authorities place the upper limit at 0.002 mm. In tests of soils for highway purposes, colloids are considered as particles 0.001 mm in diameter and finer.

The American Society for Testing and Materials (4) and the American Association of State Highway Officials (1) originally used the same limits as used in the older Bureau of Public Roads System. Later both of these organizations (2, 5, 6) changed the limits of the coarser material to correspond to openings in standard sieves used. These include No. 4 (4.76 mm), No. 10 (2.00 mm), No. 40 (0.42 mm), and No. 200 (0.074 mm).

In 1930, Gilboy put forth a system that has gained wide engineering usage. It is commonly known as the M. I. T. System and has been adopted by the British as a standard system (33). This system was also recommended by Kopecky (18, 29) as early as 1914.

In 1947 the Civil Engineering Division of the American Society of Engineering Education presented its definitions of the various soil components (36, 45). From an engineering point of view, the primary difference between sand and gravel is the size of the grains. The primary differences between sand and silt are that particles of silt cannot be readily distinguished by the unaided eye and that silt exhibits considerable capillarity. The significant difference between silt and clay is that clay has plastic properties that silt does not. In fine-grained soils, the influence of grain size is dominated by the influence of mineralogical and chemical composition. Therefore, gravel and sand should be defined on the basis of grain size; sand and silt on the basis of grain size and capillarity; and silt and clay on the basis of plasticity.

In view of the general agreement of the systems in use, such as the International, the M. I. T., and the Public Roads, the size limit between gravel and sand was defined at the No. 10 sieve (2.0 mm). The maximum gravel size corresponds to the maximum size generally used in highway and airport engineering.

On the basis of practical engineering considerations, the limit between sand and silt was put at the No. 200 sieve (0.074 mm). The sand grains passing the No. 100 sieve and retained on the No. 200 are about the finest particles that can be easily distinguished by the unaided eye. Also, the No. 200 sieve is the practical limit of sieving in a mechanical analysis. Coarse sand has a harsh gritty feel; medium sand has a less pronounced gritty feel, but every grain can be felt; fine sand has a much softer and less gritty feel.

As the portion of silt exceeds about 10 percent of the total, capillarity becomes increasingly important. It is almost as significant in determining the properties and behavior of silts as plasticity is for clays or the lack of capillarity is for sands. Drainage and frost heaving properties of silts follow the same general patterns as capillarity. As little as 10 percent finer than the No. 200 sieve considerably impedes drainage; more than 20 percent silt makes the soil almost nondrainable.

Knowledge of a lower size limit for silt would be of great practical value because of the marked differences between silt and clay. These differences, however, are due not simply to grain size but to colloidal and other properties of clay. Silts are composed of fine mineral fragments that are altered very little from the parent material, while clay minerals are formed by chemical weathering and decomposition. There is no simple and satisfactory method for separating silt and clay because of an overlapping range of particles sizes that may or may not display properties of clay. Silt is defined as material passing the No. 200 sieve, being nonplastic, and having little or no strength when air dried. Clay-soil is material passing the No. 200 sieve, having plastic properties, and having considerable strength when air dried.

The U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation use the Unified Soil Classification System based on a proposal by Casagrande (18). In this system, the grain-size limits (44) are essentially the same as those reported in ASTM Standard D422-63.

In 1957, the Highway Division Committee of ASCE (35) presented a system that corresponds closely with the old Bureau of Public Roads System. The only exception is that there are 3 rather than 2 sand subdivisions. These are defined by standard sieves, i.e., No. 10 (2 mm), No. 30 (0.6 mm), No. 80 (0.2 mm), and No. 270 (0.005 mm). Gravelly soils contain ≥15 percent gravel; sandy soils, ≥50 percent sand or gravel; silty soils, 40 to 100 percent silt size; and clays, 30 to 100 percent clay and colloids.

SYSTEMS REPORTED IN GEOLOGIC LITERATURE

Figure 3 shows particle-size definitions reported in geologic literature. Early systems were presented by Orth (52), Diller (51), Udden (50), and Keilhack (21, 52). Diller's system was later used by the New York City Aqueduct Commission with the exception that fine gravel was defined as being between 1 and 5 mm.

Udden's system (50) is a uniformly decreasing series in which each limit is $\frac{1}{2}$ the preceding one. They system was used for reporting data on wind deposits. Later, in a report on clastic sediments, Udden (49) expanded his scale upward and downward to include size ranges for coarse, medium, and fine clay; large, medium, small, and very small boulders; and very coarse gravel. In Udden's system all portions plot as equal lengths on a semilog plot.

Boswell's system (32) was used in Great Britain for studying materials used in glass industries.

In 1913, Grabau (21) took the systems of Diller and Keilhack and several variations of these to device a scale to serve as a standard for comparison.

Wentworth proposed a scale of grade and class terms for clastic sediments in 1922 (52). In fixing the limiting sizes, he was governed by 2 considerations. First, there was a growing acceptance among geologists and engineers of a series of sieves for classification in which openings of consecutive sizes were in the ratio of 2 of $\sqrt{2}$, starting with 1-mm standard. A geometrical series is ideal for the purpose, for a change of 1 in. is of the same significance and importance in the size of 10-in. cobbles as a change of $\frac{1}{10}$ in. in the size of 1-in. pebbles. The use of a geometric series makes the successive grades fall into equal units on a graph for easier reading and interpretation. Wentworth considered 2 as the most convenient ratio and 1 mm as the most convenient and logical starting point. More minute subdivisions could be obtained by using $\sqrt{2}$ or $\sqrt[4]{2}$; these fit with and form subdivisions for the fundamental power series of 2. His second consideration was to make the limits as close as possible to those commonly used by the majority of geologists. He presented the systems of Keilhack, Grabau, Orth, Diller, U.S. Bureau of Soils, Baker, Udden, and New York City Aqueduct Commission as those in common use.

Alling proposed a grade scale for sedimentary rocks in 1943 (3). He was looking for a convenient scale for use with thin sections and polished blocks; his scale is not meant for 3-dimensional studies. Alling believed a satisfactory scale should have 4 fundamental properties: (a) The grain sizes should constitute a continuous series; (b) any division of the series will be arbitrary; (c) convenience of use is a criterion; and (d) statistical analysis requires the use of a constant geometric ratio. He disagreed with Wentworth's contention that 2 was the most convenient constant ratio to use. Rather than 2, he preferred to use a constant ratio of 10. This places the limits for the major division at 0.0001, 0.001, 0.01, 0.1, 1, 10, 100, and 1,000 mm He used Hopkins' proposal of a factor of $\sqrt[4]{10}$ for expanding the system (28). This divides each major division into 4 minor ones (very fine, fine, medium, and coarse), all of which give sections of equal width when plotted on a logarithmic scale. His major divisions are colloid, clay, silt, sand, gravel, cobble, and boulder.

In 1947 a subcommittee on sediment terminology for the American Geophysical Union proposed a scale of grain sizes (37). This scale was made up after a survey of systems in use and recommendations of practicing geologists. Again, each portion plots as an equal length on a semilog plot.

NEED FOR A COMMON CLASSIFICATION SYSTEM

There are obvious advantages in having a standard particle-size limit system that would apply to all fields of endeavor. This would enable workers to use data from other sources without first translating them into their particular system.

In this author's opinion, the first step in establishing such a standard system should be to determine the basis on which the particle-size limits are to be selected. The most logical basis would be the natural properties of the soil, such as permeability, capillarity, plasticity, and mineralogical and chemical composition. The next step would be to define what is meant by the terms used to designate the various soil fractions.

Figure 2. Particle-size classifications from engineering literature.

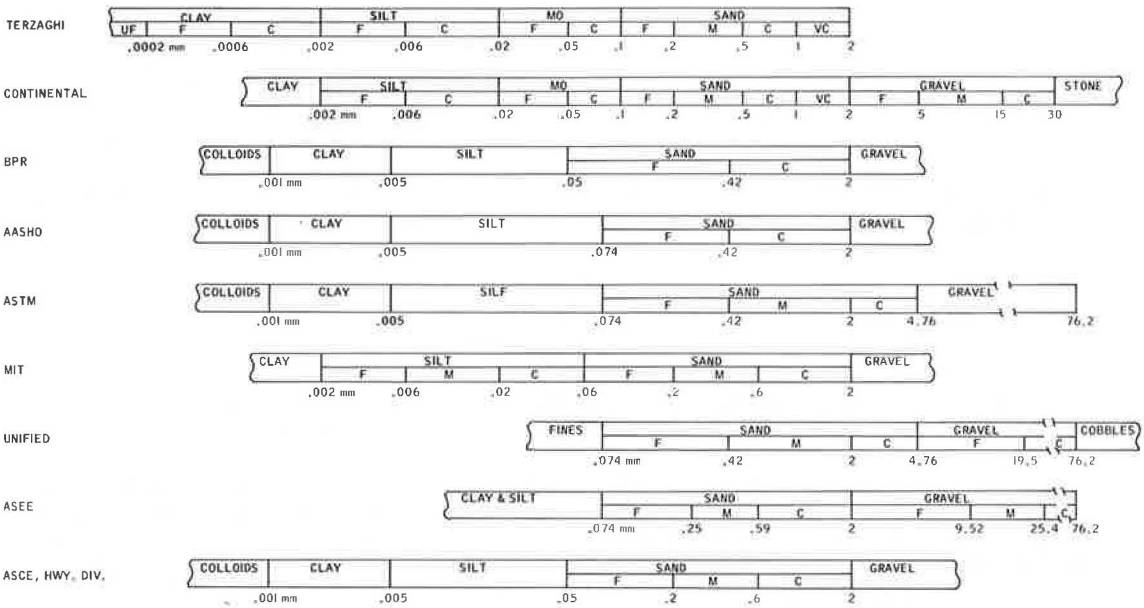
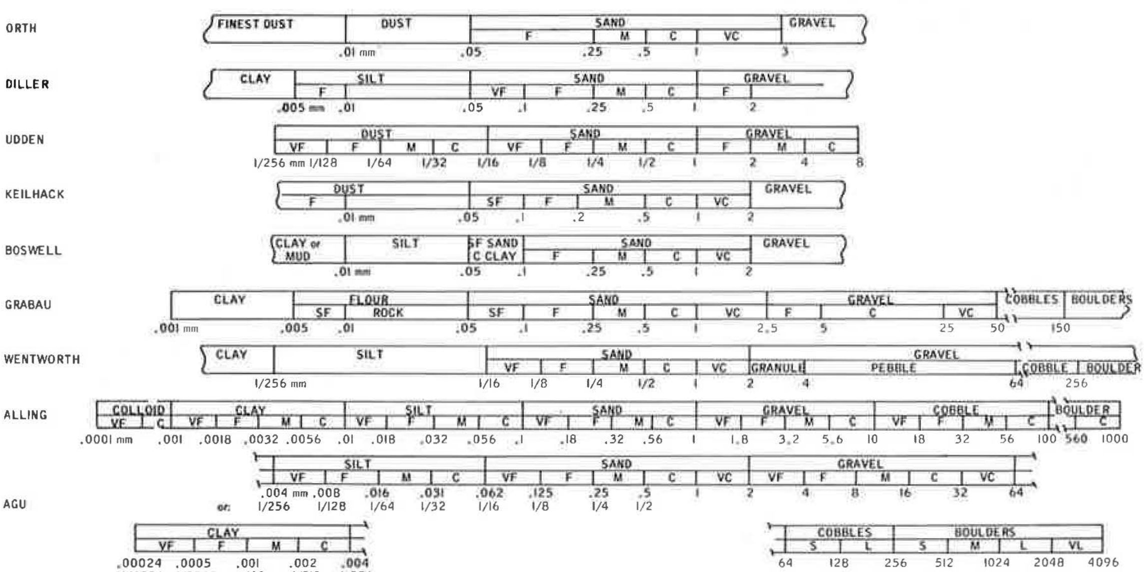


Figure 3. Particle-size classifications from geologic literature.



This is where the most difficulty would be encountered. First, the limits between the major soil components—gravel, sand, silt, and clay—should be defined and then the limits for subdivisions of the major components selected.

The difficulty would be in reaching agreement on what constitutes the "natural limits" of a soil. This would require compromise by all sides because what is considered an obvious limit by one group may be quite different from the views of others. If a system attempts to include all of the limits that may be desired by various groups, it will soon become unwieldy and defeat the purpose for which it is designed. The number of limits should be kept at a minimum, which will ensure ease of analysis and still present the desired information.

SUMMARY

All of the systems for designating particle-size limits are based on arbitrarily selected limits. Some investigators attempted to make their selections correspond with various properties of the soil fractions. Thus, in agricultural investigations things such as tillage properties, water retention, capillarity, penetration of plant roots, mineralogical and chemical composition, and colloidal properties were used as bases for various particle-size limits.

Early engineering systems were based on the agricultural limits then in use. Some of the newer systems have particle-size limits that roughly correspond to materials used for specific engineering purposes. Engineering systems tend to evolve to the use of certain standard sieves for the particle-size limits. The shape and slope of the particle-size distribution curve are considered to be of more importance than arbitrary grain-size limits. In some of the systems, no limit is placed between silt and clay; the classification is made on the basis of plasticity and cohesion, which are more direct functions of clay mineralogy.

Some of the systems reported in geological literature are quite similar to those proposed in agricultural literature. Geological systems tend to follow a geometric series of particle-size limits. The use of a constant geometric ratio (such as 2 or 10) makes the system more convenient to use and makes statistical analyses of data easier.

There is a general agreement among the systems commonly used at present on 2 mm as the lower limit for gravel. A few engineering systems (such as concrete technology) use the No. 4 sieve (4.76 mm) for this limit, 4.76 to 2.0 mm being designated "coarse sand." The limits between sand and silt are more varied. Common sizes are 0.02, 0.05, 0.06, 0.62, and 0.074 mm. The 0.02-mm limit, however, is not widely used in this country. Common limits between silt and clay are 0.002, 0.005, and 0.004 mm. Some engineering systems do not use a particle-size limit but base this division on plasticity and cohesion.

The limits commonly used for subdividing the major components are even more varied. Even here some of the limits are approximately the same, but different terms are used to describe the fractions thus separated. Some systems employ many more subdivisions than do others.

A common classification system, applicable to all of the disciplines concerned, would eliminate present contradictions and be of considerable value. However, compromises by all areas would be required to devise such a system.

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