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## Particle Size Analysis

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### I. INTRODUCTION

This chapter is not a laboratory manual. It is more concerned with the principles underlying the concepts of particle, size, and distribution, the relationships between them, and the methods by which they may be measured. There are now some 400 reported techniques for the determination of particle size (Barth and Sun, 1985; Syvitski, 1991), although the large body of measurements amassed by soil scientists has generally been made using simple methods and equipment, principally sieving, gravitational settling, the pipet, and the hydrometer. There is also a large body of experience in interpreting these data. However, there is still a surprising lack of uniformity in these simple procedures, and for that reason we consider them in some detail.

The classification of soils in terms of particle size stems essentially from the work of Atterberg (1916). He built on the work of Ritter von Rittinger (1867) in relation to rationalization of sieve apertures as a function of (spherical) particle volume, and that of Odén (1915), who applied Stokes' law to soil science for the first time. In 1927 the International Society of Soil Science adopted proposals to standardize the method for the "mechanical analysis" of soils by a combination of sieving and pipeting and, equally important, resolved to analyze (at least for agricultural soils) only the fraction passing a round-hole 2 mm sieve—the so-called "fine earth" (ISSS, 1928).

There have been many revisions of the particle size classes promulgated in 1927, and it is now recognized that soil science can make little further headway in

the interpretation of particle size distribution in the submicrometer range, because the simple methods are incapable of further resolution. For that reason we have reviewed a number of less common or more recent instrumental techniques, which are capable of extending our understanding of the distribution of particles in this region. We have also quoted much of the older literature, as this gives the physics and mathematics from which more recent developments have arisen.

A large number of standard methods for particle size analysis is available. Many have been published by bodies responsible for national standards\*, and others by the ISO\* (e.g., AFNOR, 1983c; DIN, 1983, 1996; BSI, 1990, 1998; ISO, 1998). Other key sources are Klute (1986), Head (1992), Carter (1993), USDA (1996), and ASTM (1998b). Readers should consult these publications, especially those by the ISO, for practical details of methods of analysis, as use of them will reduce the divergence of analytical results often found in interlaboratory “ring-tests.”

## II. BASIC CONCEPTS

### A. Particles

A particle is a coherent body bounded by a clearly recognizable surface. Particles may consist of one kind of material with uniform properties, or of smaller particles bonded together, the properties of each being, possibly, very different. Soils are formed under particular conditions, and the particles are to a greater or lesser extent products of those conditions. If the soil is disturbed, the particles may change: for example, salts and cements can dissolve, organic remains can be fragile, bonding ions can hydrolyze, and bonds thus be weakened. Not all these changes may be desirable if the original material is to be fully and properly characterized. AFNOR (1981b) has given a useful vocabulary that defines terms relating to particle size.

Few natural particles are spheres, and often the smaller they are, the greater is the departure from sphericity. One method of size analysis may not be enough, and the methods chosen should reflect the information desired; there may be little point in characterizing as spheres particles that are plates. Allen et al. (1996) listed a number of measures of particle size applicable to powders. In soil analysis, the commonest by far is the volume diameter, which is generally equated with Stokes' diameter.

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\* Throughout this chapter, AFNOR stands for Association Française de Normalisation (Paris); ASTM for American Society for Testing and Materials (Philadelphia); BSI for British Standards Institution (London); DIN for Deutsches Institut für Normung (Berlin); ISO for International Standards Organisation (Geneva).

Sedimentologists often characterize irregular particles in terms of “sphericity” or, more usually, an index to indicate departure from sphericity, although all the methods involve much labor to acquire enough measurements on enough grains to obtain statistically valid data (Griffiths, 1967). The introduction of image-analyzing computers has made the task of size analysis much easier and has extended the techniques beyond the range of the optical microscope (e.g., Ringrose-Voase and Bullock, 1984). Tyler and Wheatcraft (1992) made a useful review of the application of fractal geometry to the characterization of soil particles, and cautioned against the use of simple power law functions for particles as diverse as those found in soils. Barak et al. (1996) went further, and concluded that fractal theory offers no useful description of sand particles in soils and hence doubted the applicability of these methods to soils with large amounts of coarser particles. Grout et al. (1998) came to an almost identical conclusion. However, Hyslip and Vallejo (1997) stated that fractal geometry *can* be used to describe the particle size distribution of well-graded coarser materials. The utility of fractal mathematics in soil particle size analysis is clearly an area likely to develop further.

## B. Size and Related Matters

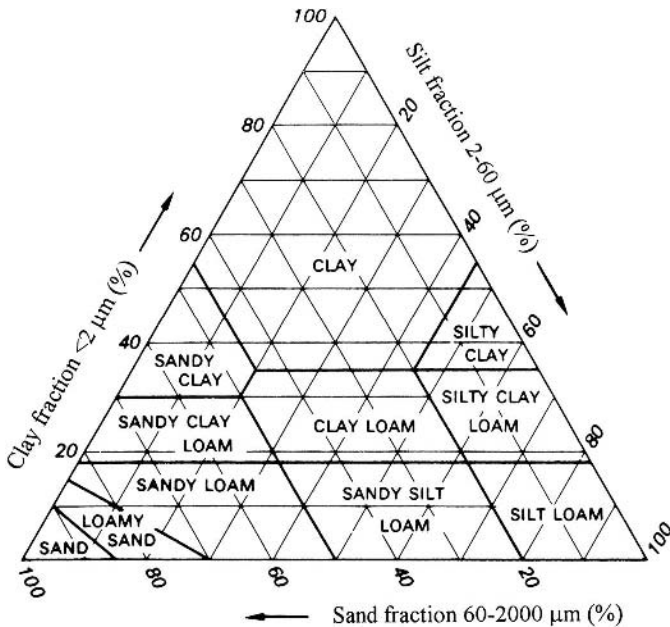
Soils may contain particles from  $> 1$  m in a maximum dimension to  $< 1 \mu\text{m}$ , i.e., a size ratio of 1,000,000:1 or more. For the larger particles, which can be viewed easily by the naked eye, a crude measure of size is the maximum dimension from one point on the particle to another. In many cases, only a scale for the coarse material is needed—for example, as a guide to the practicalities of plowing land. It is the smaller particles, however, on which most interest focuses, as these have a proportionately greater influence on soil physical and chemical behavior.

Size and shape are indissoluble. The only particle whose dimensions can be specified by one number (*viz.*, its diameter) is the sphere. Other particle shapes can be related to a sphere by means of their volume. For example, a 1 cm cube has the same volume as a sphere of 1.24 cm diameter. This is the concept of equivalent sphere (or spherical) diameter (ESD). Thus the behavior of spheres of differing diameters can be equated to particles of similar behavior to those spheres in terms of their ESD. However, the limitations of the equivalent sphere diameter concept are illustrated by the fact that a sphere of diameter  $2 \mu\text{m}$  has a volume of approximately  $4 \times 10^{-12} \text{ cm}^3$ , but the same volume is occupied by a particle of  $100 \text{ nm} \times 2 \mu\text{m} \times 20 \mu\text{m}$ .

Most soil scientists are interested in the proportion (usually the weight percent) of particles within any given size class, as defined by an upper and lower limit (e.g., 63–212  $\mu\text{m}$ ). Size classes are usually identified by name, such as clay, silt, or sand, and each class corresponds to a grade (Wentworth, 1922). It is

common, particularly among sedimentologists, to describe a deposit in terms of its principal particle size class, for example, of being “sand grade.” Soil scientists use a similar system when using the proportions of material in different size fractions to construct so-called texture triangles or particle size class triangles (Figs. 1 and 2). There is considerable variation among countries as to the limits of the different particle size classes (Hodgson, 1978; BSI, 1981; ASTM, 1998d), and hence the meaning of such phrases as “silt loam,” “silty clay loam,” etc. Rouseva (1997) has proposed functions that allow translation between these various particle size class systems.

The distribution of particles in the different size classes can be used to construct particle size distribution curves, the commonest of which is the cumulative curve, although there are others. Interpolation of intermediate values of particle size from such curves should be undertaken with care. The curves are only as good as the method used to obtain the data and the number of points used to construct them. Serious errors can arise if the latter are inadequate (Walton et al., 1980). Thus curve fitting, especially though software, should only be undertaken with a proper understanding of the underlying mathematics (ISO, 1995a, b; AFNOR, 1997b; ASTM, 1998c).



**Fig. 1.** Triangular diagram relating proportions of sand, silt, and clay to particle size classes as defined in England and Wales.