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Module Tag	SED & PG Ia

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1. Learning Outcomes

After studying this module you shall be able to:

- Know about grain size scales of clastic sediments. Necessity of having grain size scale.
- Learn about different grain size measurement procedures, use of different physical laws in grain size measurement.
- Understand the intricacies in grain size measurement, advantages and limitations of different measurement procedures.

2. Introduction

Grain size represents a fundamental character of clastic sedimentary rock and one of the most important property for description of these rocks. Sizes of clastic grains reflect their weathering and erosional history, besides providing idea about their transportation motif i.e as bed load, saltation or suspension. By the term grain size normally we mean grain diameter. This is true when the grain is perfectly spherical. However, most grains in nature are non-spherical and that generates most relevant question 'what is the representative diameter for a non-spherical grain?' To resolve this question the concept of 'nominal diameter' is proposed. The 'nominal diameter' of a grain is the diameter of a sphere that has equal volume as that of the grain. Again, in practice we are seldom in a position to measure volume of each grain, and therefore use indirect method for measurement of any grain. If a grain resembles tri-axial ellipsoid, we measure its long axis (a), intermediate axis (b) and short axis (c) for further use of data.

As in nature grain size of sediments vary widely i.e from clay size less than 0.002mm in diameter to boulder size more than 25cm in diameter, necessity was felt to categorize grains in terms of size scale.

3. Grain size Scales

Grain size Scales

Udden-Wentworth Scale:

Proposed by Udden in 1914, the scale divides consecutive classes of grain sizes in millimeter scale by multiples of 2 on higher side and decrease by multiple of 1/2 on the lower side.

Boulder	Cobble	Pebble	Granule	Sand	Silt	Clay
256	64	4	2	1/16	1/256	(mm)

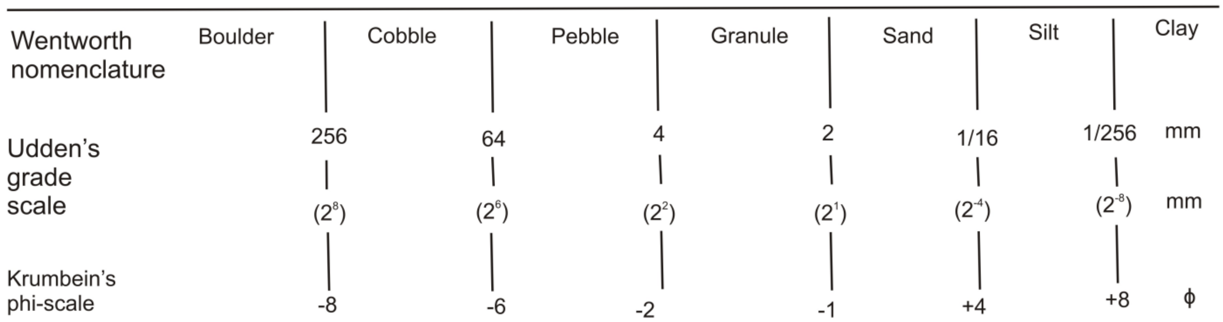
As commonly available grain sizes in nature falls in fine-size category i.e sand to clay and their class intervals comes in fraction following this scale, computations became very cumbersome in early days in absence of any high speed computational facility. This gave birth to another grain size scale which is referred as Phi scale.

Phi (Krumbein) Scale:

Krumbein in 1934 devised this scale that is referred as phi (Φ) scale.

Phi (Φ) = $-\log_2 d$; where d is diameter of a grain in mm

The use of 2 as the base of the logarithm allowed direct conversion of Udden's grade scale to Krumbein phi scale. Also, inversion of sign transformed the fractions to positive, round integers, thereby making computations much easier for the finer grains (sand, silt, clay).

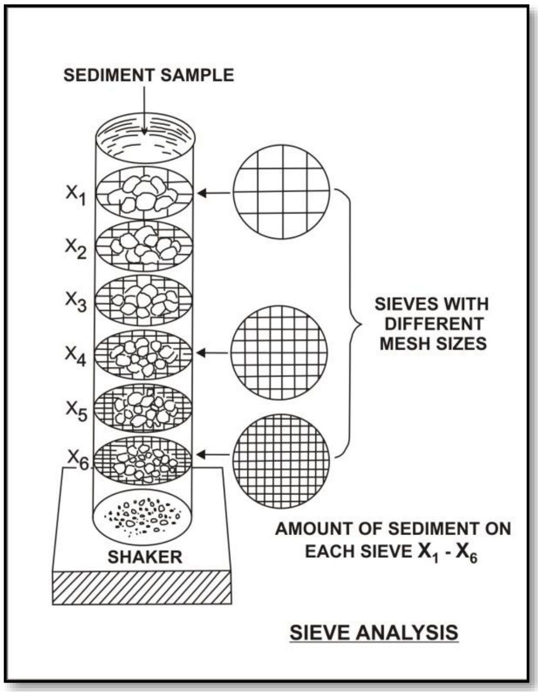


Conversion of Udden-Wentworth scale to Krumbein phi scale.

4. Measurement of grain size:

Gravel and Sand size:

Measurement of sand and gravel grains are done by means of mechanical seiving. Seives are screens of standard size and specified by the American Society of Testing Materials (A.S.T.M). Openings of screens increase uniformly in multiples of $\sqrt[4]{2}$ following size grades of Wentworth size scale, starting from an opening of 0.0029 inch (200 mesh). For size measurement, a bank of seive is taken with downward decreasing opening (mesh) size (Fig. 1). Sediment with measured weight is kept on the topmost seive and then the seive bank is mechanically or electrically shaken. Depending on the size of grains, the sediment get distributed among the seives used; grains larger than the seive size will remain on the seive and grains with smaller size pass on to the seives further down. By weighing fraction of sample lying on each seive, a grain size distribution curve is constructed. The lower limit of seive analysis is 0.04-0.03 mm, grains finer than this size show large amount of cohesion and do not allow measurement of individual grain by this method.



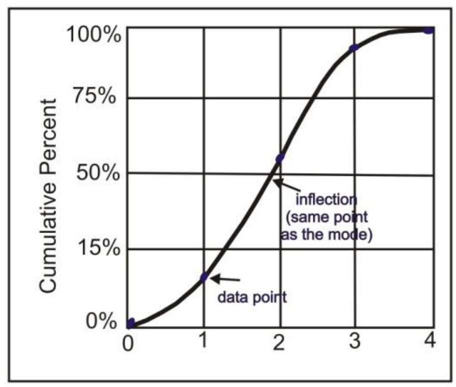


Fig. 1 Bank of seives with decrease in opening size downward. Depending on number of seives used and their respective opening sizes, the original sediment sample get divided into a number of size fractions on seiving.

Silt and Clay size fraction:

As discussed earlier, sediments of this size fraction cannot be measured by seive analysis because of their high cohesive character. In lieu, measurement of size for these sediments are done through number of other methods, most of which deals with settling velocity of sediment grain in liquids following Stoke's law.

According to the Stoke's law when the settling velocity of grains falling through a uniform solution (solution at which density is same at all depth levels) is constant, the resistance to the movement (friction), which acts upward balance the force of gravity on the grain, which acts downward (Fig. 2).

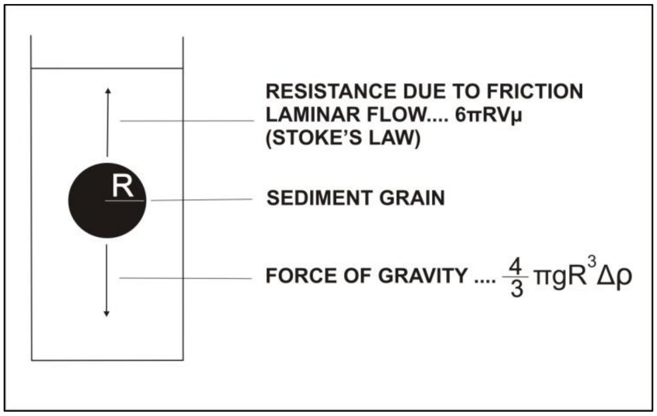


Fig. 2 Forces act on a falling sediment grain. For a grain settling with uniform velocity the downward force of gravity balance upward frictional force.

$6\pi\ R\ v\ \mu = 4/3\ \pi\ g\ R^3\ \Delta\rho$
(Friction)   (Gravity)

$v = 2/9\ \mu\ g\ R^2\ \Delta\rho$

Where μ is viscosity and Δρ is density difference between the grain and liquid. R is the radius (in cm) of sediment grain. From the relation it can be noticed that the settling velocity proportionally varies with the radius of the grain ($V \propto R^2$) as π, g and Δρ are constant between the grain and liquid.

For settling through water, the relation becomes $\log v = 2 \log R + C$

This relationship applies well for grains smaller than 0.1mm in diameter. With increase in grain size (i.e 0.1 to 0.5mm) settling velocity increases and turbulence develops around the grain. Settling velocity of such relatively large size grains varies proportionally with square root radius of the grain.

However, measurement of settling velocity of each grain is also not a practicable idea and hence, attempts were made to overcome the difficulty in some indirect way by use of hydrometer or sedimentation balance. Other methods which are in use in recent times include refraction or dispersion of light through suspensions of sediment (scattering) or use of x-ray instead of light.

Hydrometer:

A suspension of sample is created with a mixer in a cylinder so that at time T_0 there is an even distribution of grains in the solution and density of solution is same throughout the cylinder. A hydrometer will float in the solution and register density of the solution on a scale on the upper part of the tube (Fig. 3). If the suspension is allowed to stand for a time T1, grains

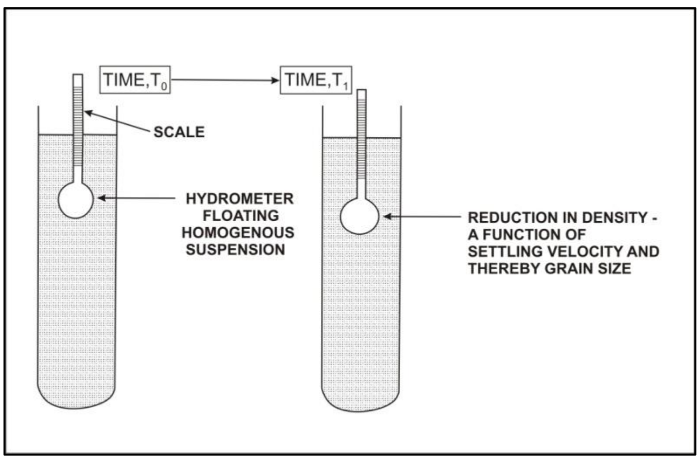


Fig. 3 Operational procedure of a hydrometer. Note change in degree of submergence of hydrometer in a solution with time depending on change in density of solution.

will settle in the bottom of the cylinder. At the level at which the bulb of the hydrometer is floating the largest of the grain sizes already must have settled resulting decrease in density of the solution. This reduction in density of solution gets registered by further submergence of hydrometer and recorded in the scale at the upper part of tube. By taking successive readings of the density we plot a density variation curve with respect to time. Since density reduction is a function of settling velocity, the density variation curve can be calibrated as a grain-size distribution curve. In case the sediment contains a large clay fraction, use of centrifuge may be a more desired option. The acceleration term g in the Stoke's law increased in the centrifuge, which can be calculated from the velocity of rotation and length of rotating arm.

Sedimentation Balance:

In this method sediments suspended in a solution in a cylinder fall through the water column and settle on a balance pan kept at any depth level within the cylinder (Fig. 4). The balance pan is kept connected with a weigh meter. With passing time more and more sediment will get settled on the pan and the increasing weight of the pan get recorded in the weigh meter. The increase in weight is plotted against time, which indicated suspension settlement from solution as a function of time. This gives a direct cumulative curve that can be calibrated to give a grain-size distribution curve.

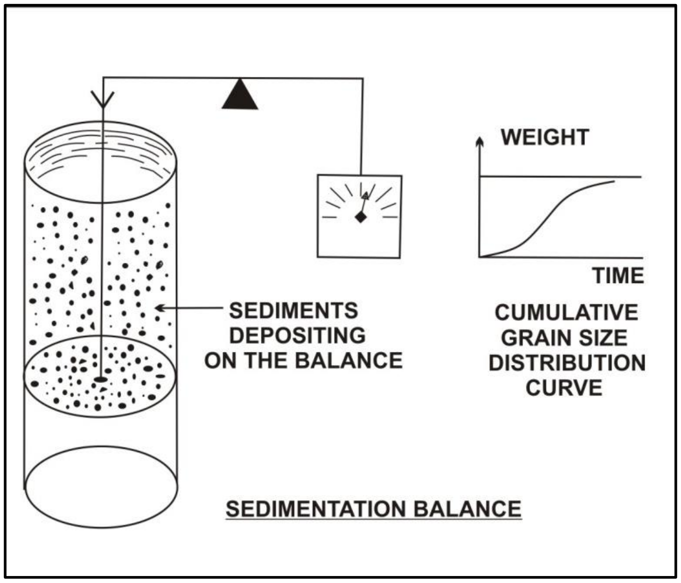


Fig. 4 Use of sedimentation balance for measurement of increase of weight with respect to time and therefore cumulative grain size distribution.

However, settling velocity of particles depend on their shapes. A spherical grain settles faster than a non-spherical grain of same mass. Hence, measurement of size for non-spherical grains through sedimentation balance may not yield same result as that from the seiving method.

5. Grain size measurement in rocks

Grain size measurement in sedimentary rocks is done in thin section by use of microscope. However, it is difficult to measure fine fractions (fine silt and clay) in this method. One major caution in this method is 'sectional effect' i.e under thin section diameter of a grain will depend on relative orientation of grain and the cut section on which thin section is made and hence, in most cases we do not get the greatest diameter. With spherical grains, statistically expressed relation between real diameter d_r and observed diameter d_o is $d_r = 4/\pi d_o$. However, in practice we do not give this correction to measured grain sizes from a rock as sectional effect on all grains of a rock makes no change on their relative sizes.

Summary:

Grain size represents a primary attribute of clastic sedimentary rock which help in understanding the transportation and depositional history of the sediment besides providing idea about weathering and erosion in the provenance. Measurement of grain sizes, classifying them in different size ranges as proposed in Udden-Wentworth and Krumbein (Φ) scale is the primary duty to take up any modern sedimentology work. The concept of nominal diameter of a grain is introduced as most grains in nature are non-spherical in character. While measurement of larger size grains viz. gravel, pebble etc. can be easily done with the help of meter and vernier scales, measurement of sand size grains are done through seiving. Grains finer than 0.04 mm cannot be measured by seive analysis because of grain cohesion and hence, measurement of such fine grains are done by settling them through liquids and through application of Stoke's law. Grain size measurement in well-cemented rocks is done with the help of thin section under microscope.

FAQs

Q.1. What does the term 'Sand' refers?

Ans. The term sand refers to a grain size varying between 2 mm and 1/16 mm. It does not have any compositional connotation. A sand grain can be of quartz, limestone or any other material of that size grade.

Q.2. Why in Krumbein phi scale the base of log is kept as 2?
Ans. It is to ease the computation involving finer grain sizes. In Udden-Wentworth scale the grain class boundaries are kept as powers of 2. Keeping the log base 2 allow direct conversion of Udden class boundaries.

Q.3. Why a negative sign is associated with Krumbein phi scale?
Ans. Assigning a negative sign allow conversion of sign in fractions of Udden scale into position round integers. These conversions help in easy computation involving finer grains (sand, silt and clay).

Q 4. Why seive analysis not fruitful for grains less than 0.03mm in size? By what principle we can measure those grains?
Ans: The lower limit of seive analysis is 0.04-0.03 mm. Grains finer than this size show large amount of cohesion and do not allow measurement of individual grain by this method. Measurement of fine grained sediments i.e <0.03mm is done with the help of settling velocity of sediment grain in liquids following Stoke's law. According to the Stoke's law the settling velocity of a grain proportionally varies with the radius of the grain ($V \propto R^2$) in a given set of grain and liquid. Taking help of this relationship grain sizes are measured with employment of hydrometer, sedimentation balance, etc.

Q5. How do we measure grain size in a lithified sedimentary rock? What sort of caution one may exercise in practicing this method?

Ans: Grain size measurement in sedimentary rocks is done in thin section by use of microscope. However, it is difficult to measure fine fractions (fine silt and clay) in this method. One major caution in this method is 'sectional effect' i.e under thin section diameter of a grain will depend on relative orientation of grain and the cut section on which thin section is made and hence, in most cases we do not get the greatest diameter. With spherical grains, statistically expressed relation between real diameter d_r and observed diameter d_o is $d_r = 4/\pi d_o$.

MCQs:

Q1. In Krumbein grain size scale Φ refers to

a. $\log_{10} d$ (where d is grain diam. in mm)
b. $\log_{2} d$ (where d is grain diam. in mm)
c. $-\log_{2} d$ (where d is grain diam. in mm)
d. $-\log_{10} d$ (where d is grain diam. in mm)

Q2. According to Stoke's law settling velocity of a non-accelerating grain has following relationship with diameter of the grain

a. $V \propto R^2$

b. $V \propto R$

c. $V \propto \log R$

d. $V \propto \sqrt{R}$

Q3. The lower limit of seive size used in grain size analysis is

a. 0.1-0.05mm

b. 0.04-0.03mm

c. 0.004-0.003mm

d. 0.2-0.1mm

Q4. Nominal diameter of a sedimentary grain refers to

a. Shortest diameter of a grain

b. Average diameter of a non-spherical grain

c. Easily measureable diameter of a non-spherical grain

d. Diameter of sphere that has same volume as that of the grain

Q5. A grain of 8mm in size will have a phi (Φ) value of

a. 3

b. -3

c. -5

d. -8

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