MECHANICAL SIZE ANALYSIS OF SEDIMENTS

I. Introduction

The study of sediments is concerned with

1. the physical conditions of a sediment, whether glacial, fluvial, marine, etc;
2. the time of formation or age of the deposits and;
3. the provenance, or area of denudation that furnished the material composing the sediment.

It was recognized in the second half of the nineteenth century that the median size, and distribution of sizes around the median, of sedimentary materials could be useful in defining the physical conditions of sedimentation. Numerous methods have been developed for size analysis, in part as a function of the range of grain sizes. In this set of laboratory exercises we shall confine our attention to dry sieving of sand sized material and pipette analysis of silt and clay sized material.

II. Grade Scales

Although the texture of a sediment involves a variety of characteristics, by far the most important is grain size. There is a tremendous range in particle size with diameters ranging from microns to meters, and some system must therefore be used to describe grain size. A *grade scale* may be defined as an arbitrary division of a continuous scale of sizes, such that each scale unit or *grade* may serve as a convenient class interval for conducting an analysis or for expressing the results of an analysis. Because of the tremendous range in sizes, it is not practical to establish uniform intervals (an arithmetic scale) since we would have literally hundreds of such intervals. A logarithmic (geometric) scale was proposed in 1922 by William Wentworth. In this scale each successive size interval is 1/2 of its predecessor. W. C. Krumbien proposed a phi (φ) scale which reduced the fractional values of the Wentworth scale to whole numbers. By definition

$$1\varphi \text{ unit} = -\log_2$$

1 millimeter corresponds to 0φ. Sizes greater than 1 mm have negative φ values while those less than 1 mm have positive φ values. The Wentworth and Krumbein scales follow.

Table 1. Grade Scales

	φ	mm	µm
Boulder	-8	256	
Cobble	-7	128	
	-6	64	
Pebble	-5	32	
	-4	16	
	-3	8	

		φ	mm	μm
Granule		-2	4	4000
Sand	Very coarse	-1	2	2000
	Coarse	0	1	1000
	Medium	+1	1/2	500
	Fine	+2	1/4	250
	Very fine	+3	1/8	125
Silt	Coarse	+4	1/16	62.5
	Medium	+5	1/32	31.3
	Fine	+6	1/64	15.6
	Very fine	+7	1/128	
Clay	Coarse	+8	1/256	
	Medium	+9	1/512	
	Fine	+10	1/1024	
	Very fine	+11	1/2048	
Colloid		+12, <+12	1/4096	

III. Plotting of Size Analysis Data

One of the common methods of plotting size analysis data is the histogram. For this purpose the results of the analysis are compiled into a frequency table, which shows the class intervals in millimeters or any other convenient units (we will use φ), and the frequencies of each class or grade, usually as a percentage of the total weight. In general, the class intervals are scaled off along the horizontal X-axis, and above each of the classes a vertical rectangle is drawn with a width equal to the class interval and a height proportional to the frequency of the class. For the purpose of statistical analysis, which we will discuss in the next section, we will also draw a cumulative curve. This curve is constructed from the histogram by summing the percentage of material in each class to obtain the successive ordinates of the cumulative curve. It can be shown that the cumulative curve is the integral of the corresponding frequency curve and is, therefore, a more reliable index of the continuous nature of the sediment distribution than the histogram.

As an example, a hypothetical 100 gram sample is collected from a sedimentary environment. We take this sediment into the laboratory and pass it through a set of screens on a sieve shaker. The following masses of sediment were captured on each screen (Table 2).

Table 2. Size Analysis Data for Example Plot

Screen Size (mm)	φ Unit	Mass of Sed. (g)	% of Total Mass
4	-2	0	0
2	-1	10	10
1	0	20	20
1/2	+1	40	40
1/4	+2	20	20
1/8	+3	10	10
1/16	+4	0	0

The histogram and cumulative curve for these data are shown in Figure 1.

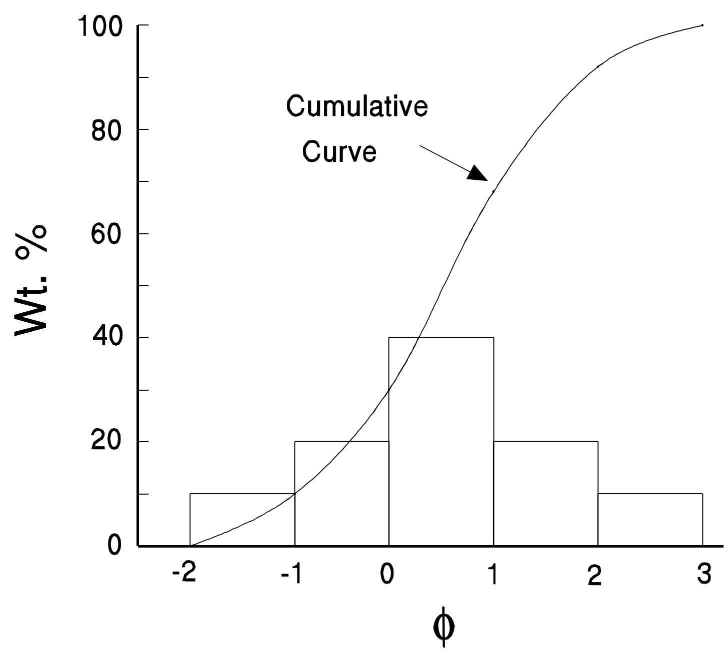

Figure 1. Histogram and cumulative curve constructed using the data in Table 2.

One of the major sources of errors in these laboratory exercises is the plotting of the histograms and cumulative curves. If you do not understand the illustration on the preceding page, **ask questions!**

IV. Statistical Analysis

A number of statistical measures have been proposed for treating size analysis data. In this laboratory we will use quartile measures and moment measures. Moment measures are discussed in the textbook. The advantage of quartile measures is the ease with which they are determined from the analytical data. The quartile values can be obtained directly from the cumulative curve.

Definition of symbols:

Q_1 = sediment size at the 25% point on the cumulative curve.

Q_3 = sediment size at the 75% point on the cumulative curve.

Md = sediment size at the 50% point on the cumulative curve.

P_{10} = sediment size at the 10% point on the cumulative curve.

P_{90} = sediment size at the 90% point on the cumulative curve.

The *median value* is defined as the middlemost member of the distribution. It is that diameter which is large than 50% of the diameters in the distribution, and smaller than the other 50%. For its graphic determination it is only necessary to draw a cumulative curve for the sediment size distribution, and then read the diameter value which corresponds to the point where the 50% line crosses the cumulative curve. For the example we are using,

$$Md = 0.5$$

The *quartile deviation* (also known as sorting) is a measure of the dispersion of the grain sizes around the median. This measure is confined to the central 50% of the distribution. The simplest form of the quartile deviation is the arithmetic quartile deviation, QD_a, which is a measure of half the spread between the two quartiles. Mathematically,

$$Qd_a = (Q_3 - Q_1)/2$$

For the example we are using,

$$Qd_a = [(1.25)-(-0.25)]/2 = 0.75$$

The *quartile skewness* is a measure of the departure of the arithmetic mean of the sample from the median. Mathematically,

$$Sk_a = 1/2[(Q_1 + Q_3) - 2Md]$$

For the example we are using,

$$Sk_a = 1/2[(-0.25 + 1.25) - 2(0.5)] = 0$$

Skewness can be either positive or negative. The significance of the sign is shown by the graphs plotted in Figures 2 and 3.

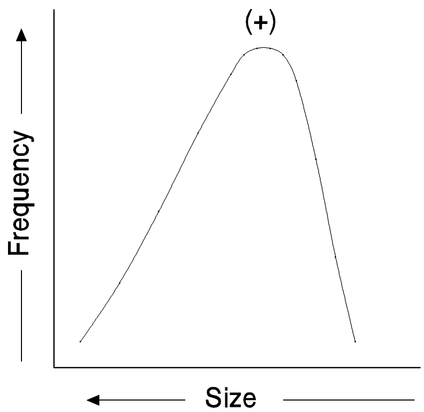

Figure 2. Graph showing positive quartile skewness.

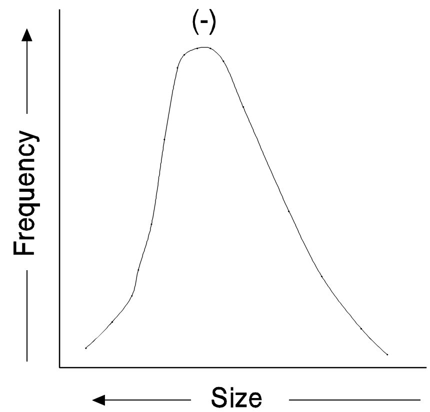

Figure 3. Graph showing negative quartile skewness.

The *quartile kurtosis* is a measure of the degree of peakedness of a curve. It essentially involves a comparison of the spread of the central position of the curve to the spread of the curve as a whole. Mathematically,

$$K_{qa} = (Q_3 - Q_1)/2(P_{90} - P_{10})$$

For the example we are using,

$$K_{qa} = [1.25 - (-0.25)]/2[2 - (-1)] = 0.25$$

The kurtosis as defined above yields values which decrease with increasing peakedness. As the cluster of values in the central part of the curve become more pronounced, without a corresponding decrease in the totalspread of the curve, the kurtosis values also decreases. This is graphically illustrated in Figures 4 and

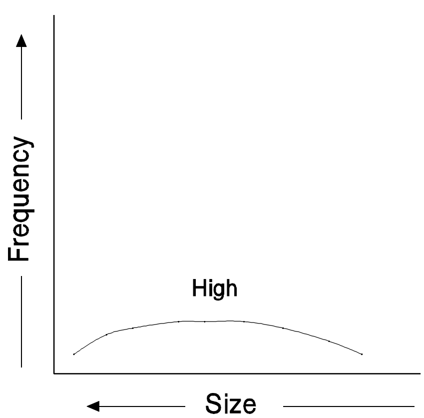

Figure 4. Graph showing high quartile kurtosis.

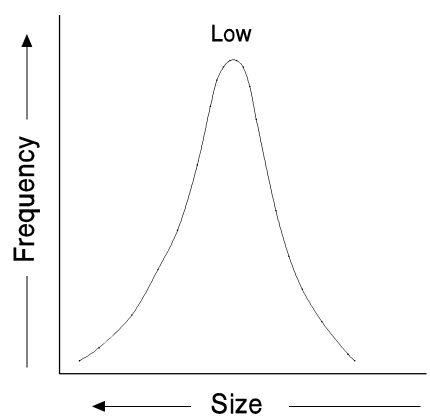

Figure 5. Graph showing low quartile kurtosis.

V. Mechanical Analysis by Dry Sieving

Size analysis by dry sieving is a straightforward procedure. The details are outlined below.

1. Weigh out approximately 100 grams of sample.

2. Set up the sieve rack from coarse at the top to fine at the bottom. Attach the pan to the bottom of the sieve rack.

3. Dump the sample into the top of the rack and cover.

4. Place the sieve rack on the sieve shaker, securely fasten, and run the shaker for 10 minutes.

5. Remove the sieve rack and weigh the amount of sediment collected on each sieve and in the pan.

6. Add these values and compare the sum to the original weight. The difference should not be greater than 1%.

7. Thoroughly clean the sieves using the soft-bristle brushes. **Never bang the sieves on any object or with your hand. Do not run sharp objects over the mesh.**

Draw a histogram and a cumulative curve and calculate the various quartile statistics using the equations given above.

Read Chapter 3 (Sedimentary Textures) in the textbook (Boggs, 2001, *Principles of Sedimentology and Stratigraphy, 3rd Edition*, Prentice-Hall) which describes various aspects of size analysis. Calculate the various moment statistics using the equations in Table 3.4 (p. 70). On page 71 there is a table (Table 3.5) that outlines the moment measure calculations. Note that these calculations can be readily done on a spreadsheet. Plot your two samples on the Skewness - Standard deviation diagram (Figure 3.8, p. 72). Using this plot, what do you think was the source of each of your sand samples? Explain.

VI. Mechanical Analysis by Pipette

Pipette analysis is used for sedimentary material when the grain size is 4φ or smaller. For grains of this size, Stoke's Law may be used to calculate the settling velocities for particles of various sizes. Since particles of various sizes will settle at different rates, these differential settling velocities can be used to separate sedimentary material into size intervals.

Due to net charge on the surface of small grains, materials in the size range 4φ and smaller will tend to clump together. The first step in the procedure is to disaggregate the material. About 25 grams of sedimentary material finer than 4φ should be weighed out and placed in a 250 ml Erlenmeyer flask. Approximately 100 ml of N/100 sodium oxalate solution should be added to the flask and the samples should be soaked in this solution for about 24 hours.

*N/100 sodium oxalate solution (known as the working solution or disaggregant solution) is prepared by taking 50 ml of sodium oxalate stock solution (N/5) and diluting this solution, in a graduated cylinder, to 1000 ml using distilled water.

After soaking, the sediment sample is washed into a 1000 ml cylinder, with N/100 sodium oxalate solution, and the cylinder is filled to the 1000 ml mark with N/100 sodium oxalate solution. 20 ml samples of solution are withdrawn, by pipette, from the cylinder using the time-depth schedule tabulated below (Table 3).

Table 3. Time-depth Chart

Size (φ)	Sampling Depth (cm)	Sampling Time		
		Hours	Minutes	Seconds
4	20	0	0	58
5	10	0	1	56
6	10	0	7	44
7	10	0	31	--
8	10	2	3	--
9	10	8	10	--
10	5	16	21	--
11	5	65	25	--

The various depths are marked on the pipette. The pipette should be inserted to the mark when withdrawal is started. After the first pipette sample has been withdrawn, the suspension is again agitated, and at the expiration of the next time interval another pipette sample is withdrawn. Each pipette sample is taken with respect to the new level of the suspension - *no water should be added to the suspension during the analysis*. Agitation is accomplished by placing the palm of the hand over the mouth of the cylinder and inverting. Each 20 ml sample is pipetted into a clean, dry, **preweighed** 50 ml beaker. After weighing, the beaker should not be touched with the hands since finger prints make a discernable difference. The solution is evaporated in an oven and the beaker is reweighed. The difference in weights is the residue which consists of both sediment and sodium oxalate salt. 20 ml of N/100 sodium oxalate solution contains 0.0130 gms sodium oxalate salt and subtraction of this value from the weight of the residue yields the actual weight of sedimentary material. Since 20 ml represents 1/50 of the total volume, this result should be multiplied by 50. This value represents the total amount of material the same size and smaller than the particular grain size sampled by the analysis. The amount of material in an given φ interval is found by difference. The following example should make this all perfectly clear.

Example:

(1) 20 ml sample taken at 1 minute 36 seconds after agitation. 10 cm depth.

Weight beaker + residue	= 28.5130 gm
Weight beaker	= 28.0000 gm
Weight residue	= 0.5130 gm
Weight Na-oxalate	= 0.0130 gm
Weight sediment	= 0.5000 gm
	X50
	25.0000 gm

This is the amount of material 5φ and smaller in grain size.

(2) 20 ml sample taken at 7 minutes and 14 seconds after agitation. 10 cm depth.

Weight beaker + residue	= 28.4130 gm
Weight beaker	= 28.0000 gm
Weight residue	= 0.4130 gm
Weight Na-oxalate	= 0.0130 gm
Weight sediment	= 0.4000 gm
	X50
	20.0000 gm

This is the amount of material 6φ and smaller in grain size.

(3) The amount of material between 5φ and 6φ in grain size

25.0000 gm (1) - 20.0000 gm (2) = 5.0000 gm

Continue your pipette analysis down to, and including, the 10φ size interval. Plot a histogram and cumulative curve and compute the quartile measures for your sample.