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89.325 Geology for Engineers
Sediment Size Distribution, Sedimentary Environments, and Stream Transport

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 exercise we will use dry sieving to determine the size distribution of sand-sized material. The results will be used to infer the environment of deposition. We will also calculate the stream velocities necessary to move sediment of a particular size.

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. Krumbein 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 sizes less than 1 mm have positive φ values (Table 1).

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.

Table 1. Grade Scales (Wentworth and Krumbein)

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

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)	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 is shown in Figure 1.

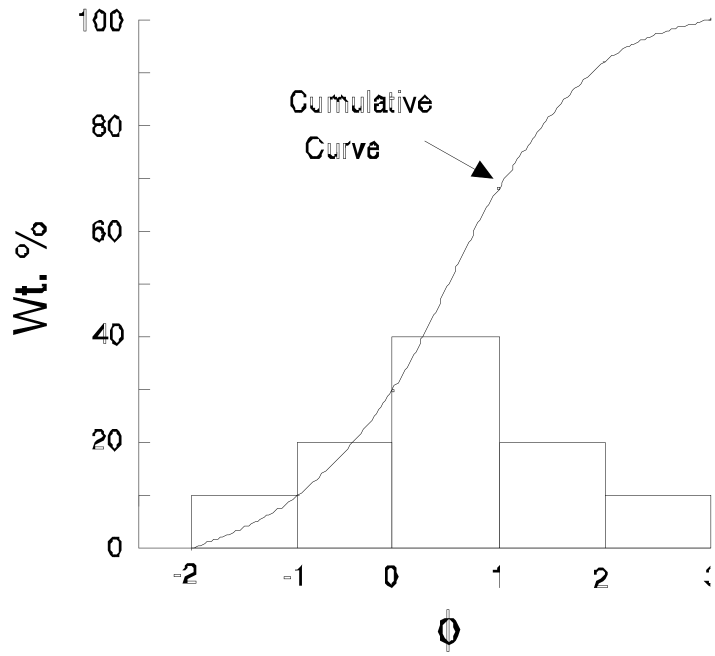


Figure 1. Histogram and cumulative curve constructed using the data in Table 2.

IV. Statistical Analysis

1. Quartile measures

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.

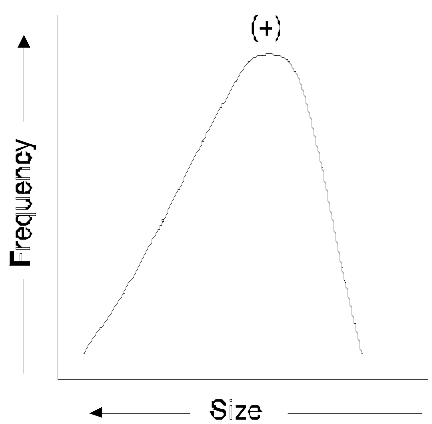


Figure 2. Graph showing positive quartile skewness.

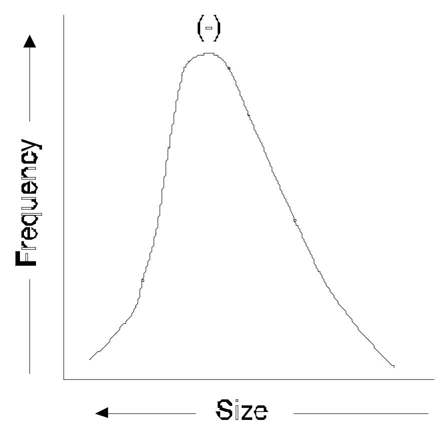


Figure 3. Graph showing negative quartile skewness.

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,

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

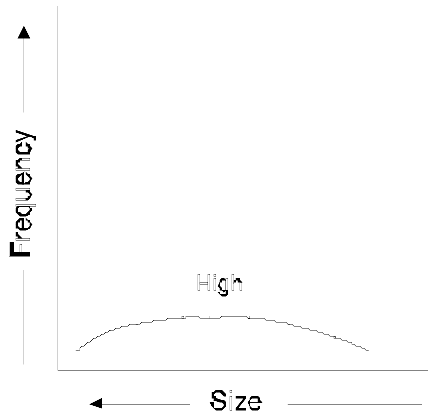


Figure 4. Graph showing high quartile kurtosis.

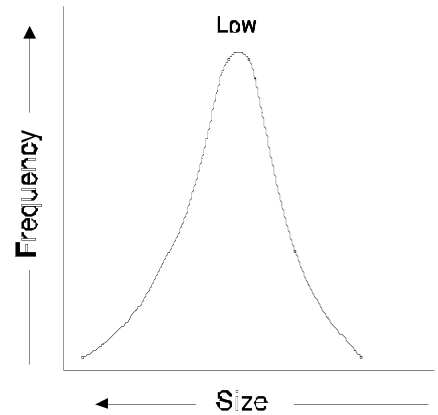


Figure 5. Graph showing low quartile kurtosis.

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 total spread of the curve, the kurtosis values also decreases. This is graphically illustrated in Figures 4 and 5.

2. Moment measures

Moment measures are a non-graphical way of determining size distributions. The computations in moment statistics involve multiplying a weight (weight frequency in percent) by a distance (from the midpoint of a size grade to the arbitrary origin of the abscissa). The formulas for calculating moment measures are found in Table 3.

Table 3. Formulas for calculating grain-size parameters by the moment method.

Mean (1st moment)	$\bar{x}_\phi = \frac{\Sigma fm}{n}$	(1)
Standard deviation (2nd moment)	$\sigma_\phi = \sqrt{\frac{\Sigma f(m - \bar{x}_\phi)^2}{100}}$	(2)
Skewness (3rd moment)	$Sk_\phi = \frac{\Sigma f(m - \bar{x}_\phi)^3}{100\sigma_\phi^3}$	(3)
Kurtosis (4th moment)	$K_\phi = \frac{\Sigma f(m - \bar{x}_\phi)^4}{100\sigma_\phi^4}$	(4)

where f = weight percent (frequency) in each grain-size grade present
m = midpoint of each grain-size grade in phi values
n = total number in sample; 100 when f is in percent

To facilitate your efforts (and because we're really nice people in the geosciences) you will find online a spreadsheet that can be used to do the moment measure calculations. The spreadsheet includes graphical output of the data. Good grief!! We're too nice!

3. Significance of size analysis data

Size analysis data has proven particularly useful in characterizing various sedimentary environments. It should be obvious that there is a relationship between the density and velocity of the transporting medium and the grain size. One would expect that air would transport smaller size particles than water. Glacial ice could transport very large particles. Because glacial ice can carry material of almost any size, glacial deposits are very poorly sorted. Wind deposits tend to be very well sorted because wind can transport only carry a small range of grain sizes. Water deposits tend to be less well sorted because water can transport a wider range of grain sizes. It has also been observed that there is a relationship between sorting and the size distribution (measured as skewness) of sediments deposited in beach environments (back and forth water flow) compared to stream deposits (one way current flow). To provide physical meeting to the concept of sorting, Figure 6 shows grain size variations as a function of sorting. Figure 7 shows the relationship between sorting and skewness for beach and stream deposits.

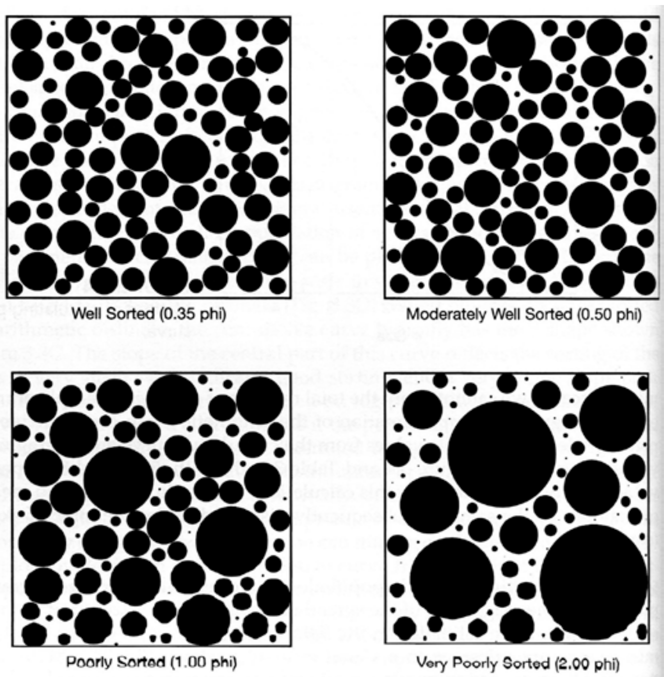


Figure 6. Visual images showing grain size sorting.

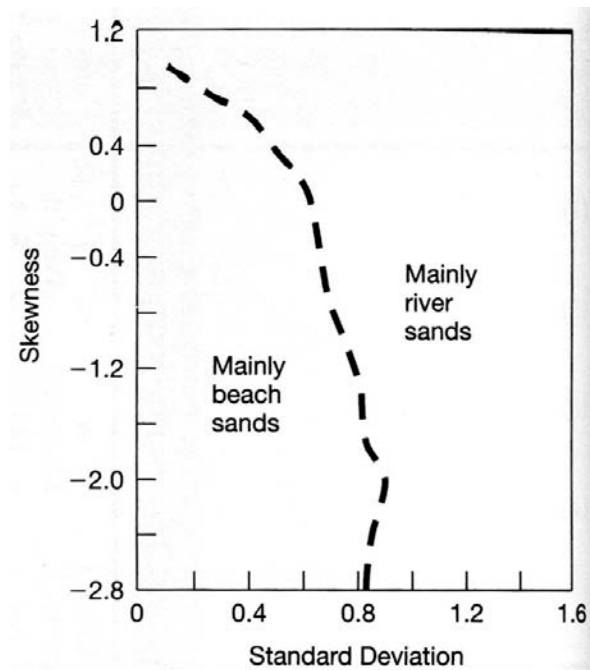


Figure 7. Grain-size bivariate plot of moment standard deviation vs moment skewness showing the fields in which most beach and river sands plot.

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.**

Questions:

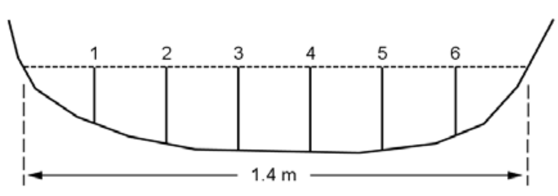
1. Draw a histogram and a cumulative curve and calculate the various quartile statistics using the equations given above.

2. Calculate the moment measure statistics for your sample using the spreadsheet.

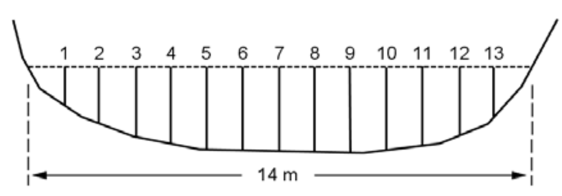
3. Plot your sample on the Skewness - Standard deviation diagram (Fig. 7). Based on this diagram, what is the source of your sand sample. Explain.

VI. Stream Sediment Transport

In this part of the exercise we are going to investigate the transport of sediment, both in suspension and as bed load, for two different streams. The cross sections for the two streams are shown below.



Stream A



Stream B

The numbers refer to measuring stations which are evenly spaced across the stream channel. At each station water depth and average current velocity were measured. The data are tabulated below. In the table, U is the current velocity. Besides making the current measurements, pebbles were randomly collected from each stream bed. The pebbles in Bag A and Bag B were collected at different times from Stream A. The pebbles in Bag C and Bag D were collected at different times from Stream B.

Stream A

Station	Depth (m)	Area (m^2)	U (cm/s)
Left	0		0
1	0.1		3
2	0.2		5
3	0.3		8
4	0.3		12
5	0.2		9
6	0.1		5
Right	0		0

Stream B

Station	Depth (m)	Area (m^2)	U (cm/s)
Left	0		0
1	0.4		15
2	0.8		30
3	1.1		42
4	1.5		79
5	1.8		101
6	1.8		120
7	1.8		122
8	1.8		120
9	1.8		121
10	1.6		105
11	1.5		95
12	1.2		80
13	0.7		50
Right	0		0

1. Calculate the mean velocity for each stream.

2. Calculate the mean water depth for each stream.

3. Calculate the cross-sectional area for each stream. The easiest way to do this is to calculate the area of each box and then sum to give the total cross-sectional area. For each box you will need to calculate an average depth.

4. For each stream calculate the discharge where discharge (Q) = cross-sectional area (A) x mean water velocity (U).

5. With reference to Figure 8, what is the largest grain size that can be transported in suspension by each stream?

6. Measure the median diameter (the length of the intermediate axis using an x, y, z measurement grid. This is the same type of measurement you made in the pebble lab.) for each pebble in your bag and calculate the average pebble size. If you have Bag A or Bag B, will Stream A transport pebbles of this size? If not, what velocity is required to transport the pebbles? If you have Bag C or Bag D, will Stream B transport pebbles of this size? If not, what velocity is required to transport the pebbles?

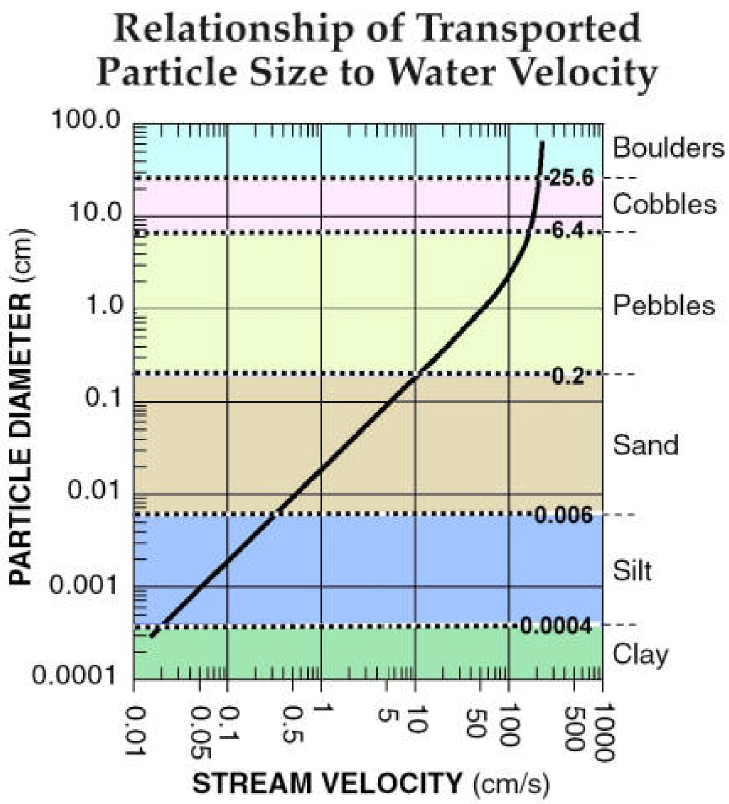


Figure 8. Relationship of transported particle size to water velocity