3.1: Grain Size

3.1.1: Udden-Wentworth Grain Size Scale

The Udden-Wentworth grain size scale (or some derivative thereof) is the most common one used by geologists and forms the basis for subdividing clastic sedimentary rocks based on clast size. We tend to make the most basic subdivisions based on size because the maximum clast size is a function of the amount of energy in the system. We've used this classification scheme as the basis for Table 4.1.1, which combines grain size, phi units, and more detailed naming of clastic sediments and clastic sedimentary rocks.

Diameter (mm)	Phi units	Particle Size		Sedimentary Rocks				Settling velocity (cm/s)	Entrainment velocity (cm/s)
					Grain/Clast Composition				
					Quartz >90%	Feldspar > 10% Feldspar > Lithics	Lithics[1] > 10% Lithics > Feldspar		
		Boulder	Gravel (rounded) or Rubble (angular)	Conglomerate (rounded) or Breccia (angular)	X	X	______[2] Boulder Conglomerate (Breccia)		
256	-8								500
		Cobble			Quartz Cobble Conglomerate (Breccia)	X	_____[2] Cobble Conglomerate (Breccia)		
64	-6							163	175
		Pebble			Quartz Pebble Conglomerate (Breccia)	X	_____[2] Pebble Conglomerate (Breccia)		
4	-2							43	60
		Granule			Quartz Granule Conglomerate (Breccia)	Feldspathic Granule Conglomerate (Breccia)	______[2] Granule Conglomerate (Breccia)		
2	-1							26	50
		Very coarse	Sand	Sandstone	Quartz Arenite (<10% matrix) or Quartz Wacke[4] (>10% matrix)	Feldspathic Arenite[3] (<10% matrix) or Feldspathic Wacke[3,4] (>10% matrix)	Lithic Arenite (<10% matrix) or Lithic Wacke[4] (>10% matrix)		
1	0							15	38
		Coarse							
1/2	1							7	28
		Medium							
1/4	2							3	23
		Fine							
1/8	3							1	20
		Very fine							
1/16	4							0.3	Cohesion may become important and entrainment velocities may increase
		Silt	Mud	Mudrock (massive) or Shale (fissile)	Siltstone (silt > clay) Mudstone (silt ≈ mud) Claystone (silt < clay)				
1/256	8							0.08	
		Clay							

X = clasts of this size and composition are unlikely.
[1]Lithic fragments could be composed of chert, limestone, igneous, or metamorphic rock fragments (and many others).
[2]Lithologic descriptor of most abundant clast type should be used in the blank space (ex: basalt cobble conglomerate); use the term polymictic if no one lithology is dominant (ex: polymictic pebble conglomerate).
[3]Feldspar-rich sandstones are informally termed arkose.
[4]Sandstones with abundant muddy matric are informally called graywackes.

Table 3.1.1: Grain size classification from Wentworth (1922) and phi scale from Krumbein (1934). Settling velocities from Filtration and separation and entrainment (erosion) velocities from Wikipedia; both assume spherical particles of quartz.

3.1.2: Phi Units

In hydrogeology, we commonly describe sediment size in terms of phi units (Φ), where the conversion to real world units is:

Diameter (mm) = $1/2^n$
where n = phi (Φ) value

They key thing to remember about this is that the bigger the phi value the smaller the diameter of the particle.

3.1.3: Sorting

Sorting is a measure of the uniformity of grain size in a specimen. A well sorted sample will have relatively uniform grain size whereas a poorly-sorted sample has a wide range of grain sizes. Geologists generally apply positive-sounding terms to uniform grain size because those samples have the most porosity and thus have the best potential for fluid flow and storage.You can estimate sorting visually (Figure 3.1.1) or measure it quantitatively using sieve analysis and plotting up the data on a cumulative distribution plot and histogram (Figure 3.1.2). Once plotted, you can use the equations and techniques in Figure 3.1.2 to determine mean (average), median (middle value when data is sorted smallest to largest), and mode (value that occurs most frequently) values for grain size, as well as calculate a numeric value for sorting and skewness (a measure of the symmetry of grain size distribution).

Sorting terminology (describes grain size distribution)	
Descriptive terminology	***Sorting value (Φ)***
Very well sorted	<0.35Φ
Well sorted	0.35Φ to 0.50Φ
Moderately well sorted	0.50Φ to 0.71Φ
Moderately sorted	0.71Φ to 1.00Φ
Poorly sorted	1.00Φ to 2.00Φ
Very poorly sorted	2.00Φ to 4.00Φ
Extremely poorly sorted	>4.00Φ

Skewness terminology (describes symmetry around ϕ50)		
Mathematical terminology	***Values***	***What it means***
Strongly positive skewed	+1.00 to +0.30	Very skewed toward coarse (-ϕ) size fraction
Positive skewed	+0.30 to +0.10	Slightly skewed toward coarse (-ϕ) size fraction
Near symmetrical	+0.10 to -0.10	Nearly symmetrical distribution
Negative skewed	-0.10 to -0.30	Slightly skewed toward fine (+ϕ) size fraction
Strongly negtive skewed	-0.30 to -1.00	Very skewed toward fine (+ϕ) size fraction

Table 3.1.1: Sorting and skewness terminology and values from Folk (1966).

Engineering Terminology

Engineers and geologists live in opposite terminology worlds when it comes to grain size distribution. They use the term "grading" to describe the distribution of grain size. For them, compaction is what is important and a well-graded specimen has a wide range of grain sizes (can be densely compacted) and a poorly graded specimen has uniform grain size and does not compact as well.

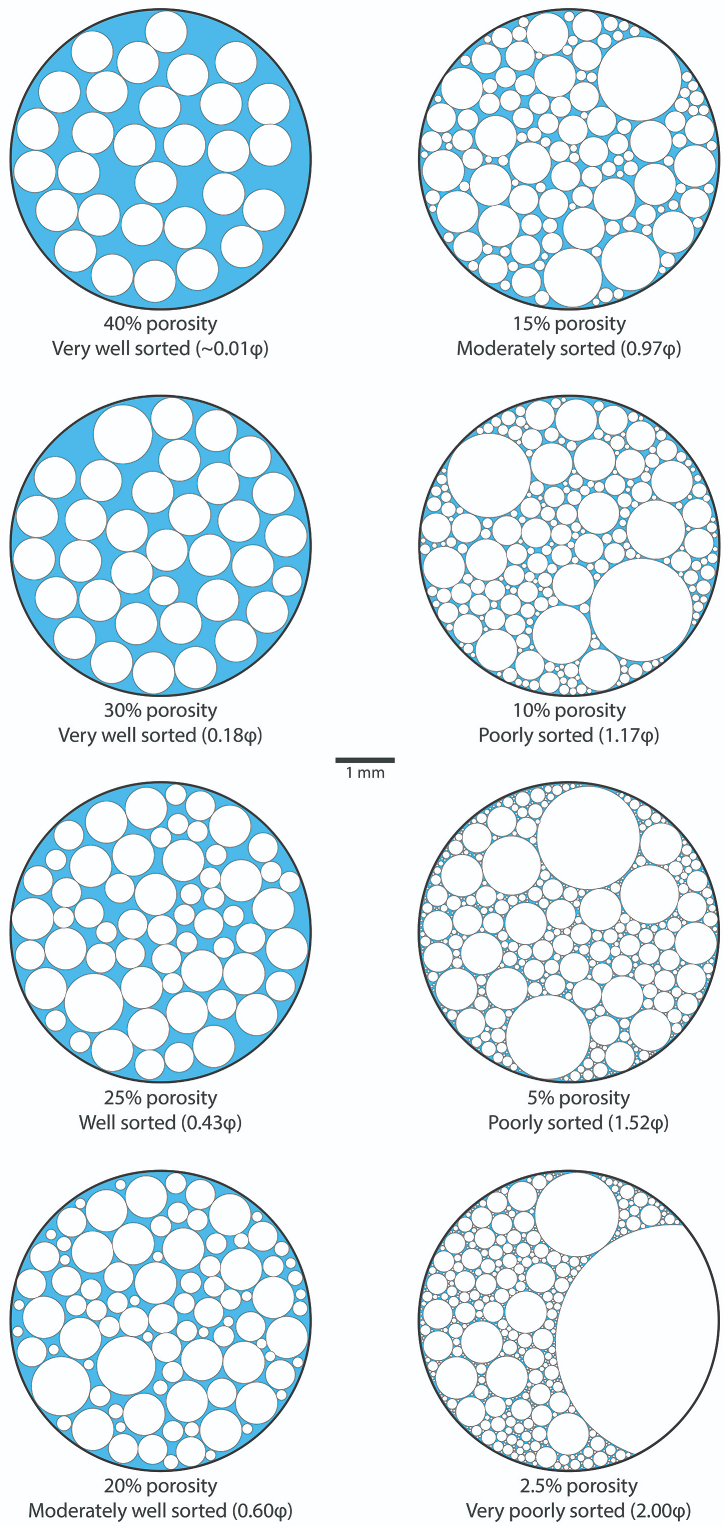
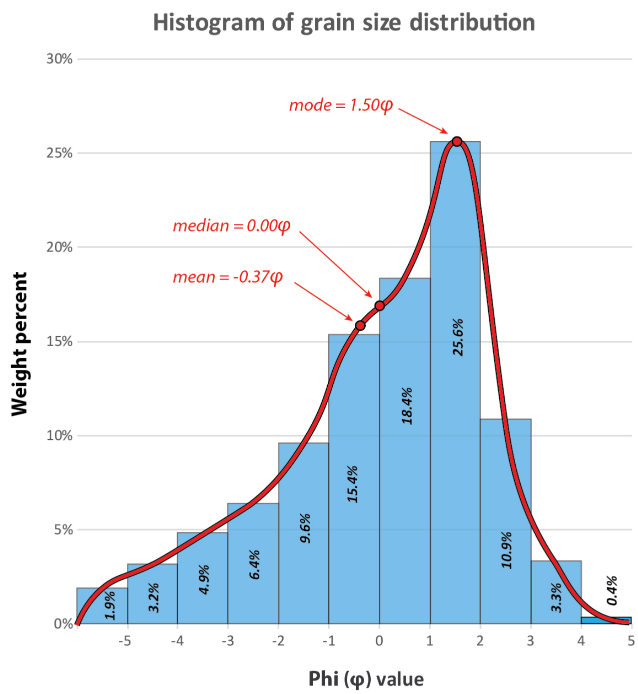


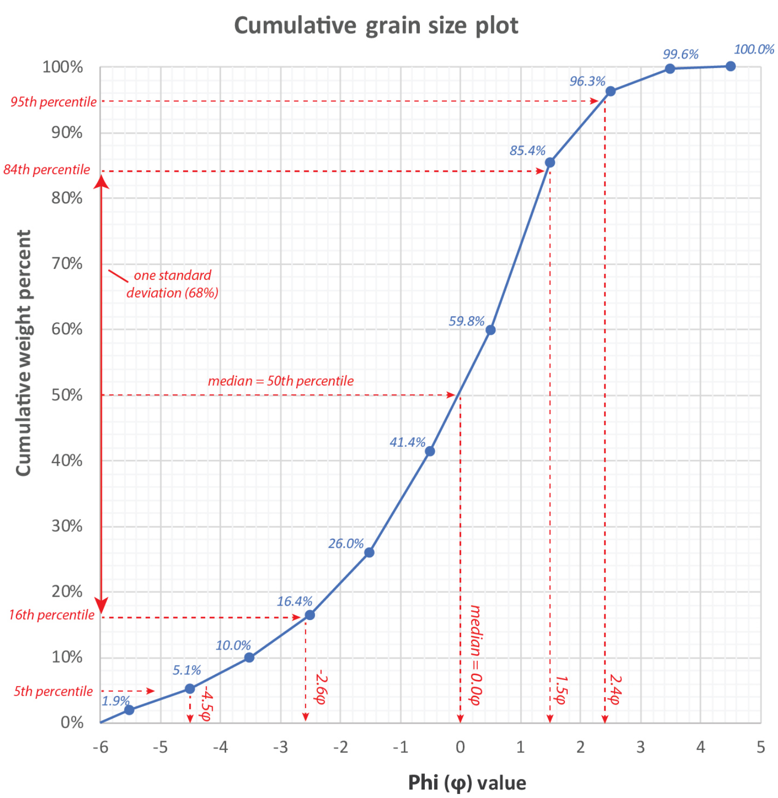
Figure 3.1.1: Illustration of spherical sand grains (white) and pore spaces (blue) showing changes in sorting and porosity (Michael C. Rygel via Wikimedia Commons; CC BY-SA 4.0).

Grain Size Data Table

Screen size in φ units	*Average Diameter (φ) retained*	*Diameter (mm)*	*Weight (g)*	*Individual weight (%)*	*Cumulative weight (%)*
-5		32	15	1.9%	1.9%
-4	-4.5	16	25.0	3.2%	5.1%
-3	-3.5	8	38.0	4.9%	10.0%
-2	-2.5	4	50.0	6.4%	16.4%
-1	-1.5	2	75.0	9.6%	26.0%
0	-0.5	1	120.0	15.4%	41.4%
1	0.5	0.5	143.5	18.4%	59.8%
2	1.5	0.25	200.0	25.6%	85.4%
3	2.5	0.125	85.0	10.9%	96.3%
4	3.5	0.0625	26.0	3.3%	99.6%
5	4.5	0.01	3.0	0.4%	100.0%
		End weight (g)	780.5	100.0%	
		Start weight (g)	795		
		Difference (%)	-1.8%		

Characteristic	Value	Source
Median grain size (φ units)	0.00	*50th percentile on cumulative chart (φ50)*
Median grain size (mm)	1.00	*converted from above*
Mean grain size (φ units)	-0.37	*calculated from mean equation*
Mean grain size (mm)	0.77	*converted from above*
Mode (ϕ units)	1.50	*midpoint of most abundant class on histogram*
Mode (mm)	2.83	*converted from above*
Sorting (φ) *inclusive graphic standard deviation*	2.07	*calculated from inclusive graphic standard deviation*
Skewness (symmetry) *inclusive graphic skewness*	-0.29	*calculated from inclusive graphic skewness equation*





Equations

$$\text{Median} = \phi 50$$

$$\text{Mean} = \frac{(\varphi 16 + \varphi 50 + \varphi 84)}{3}$$

$$\text{Sorting} = \frac{(\varphi 84 - \varphi 16)}{4} + \frac{(\varphi 95 - \varphi 5)}{6.6}$$

$$\text{Skewness} = \frac{(\varphi 16 + \varphi 84 - 2\,\varphi 50)}{2(\varphi 84 - \varphi 16)} + \frac{(\varphi 5 + \varphi 95 - 2\,\varphi 50)}{2(\varphi 95 - \varphi 5)}$$

Figure 3.1.2: Example grain size data shown in tabular, histogram, and cumulative distribution curve form. Median (50th percentile of grain size), mean (average grain size), mode (most abundant size), sorting (grain size variation), and skewness (symmetry of histogram) can be calculated from this data using the equations on the bottom right of the diagram. Techniques and equations from Folk (1966).

3.1.4: Readings and Resources

- Folk, R. L., 1966, A review of grain-size parameters. Sedimentology, v. 6, no. 2, p. 73-93.
- Krumbein, W. C. M., 1938, Size frequency distributions of sediments and the normal phi curve. Journal of Sedimentary Research, v. 8, no. 3, p. 84-90.
- Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments. The Journal of geology, v. 30, no. 5, p. 377-392
- https://www.geological-digressions.com/analysis-of-sediment-grain-size-distributions/
