SAND PROPERTIES AND DESCRIPTION: A WORKSHOP

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Introduction. The objective of this workshop is to review the terms geologists use to describe and classify sand. You can do this with your own sand samples or with those collected during SandFest. We will discuss color, grain size, sorting, grain shape, and maturity. These are fundamental properties that only require careful observations. The workshop will focus on the determination and recording of these simple observations, but we will also discuss the geologic processes that result in particular sand properties.

The identification of grains (mineralogy, rocks, biogenics) will be noted when possible from macroscopic observations using only the naked eye assisted with a hand lens or magnifying glass.

Grain-size distribution is an important property or all sands. A method for determining the distribution of grain size in a sand sample is explained. A measured amount of the sample is separated into seven size fractions with sieves. Each fraction is weighed and the results are plotted. A cumulative frequency plot of this data allows overall grain size and sorting to be evaluated.

Color. The first property most people notice when characterizing almost anything is color, and sand is no different. Beach sands are generally tan, but they can be gray, and we definitely notice when they are white, dark brown to black or pink.. But why are they those colors? Often a simple view with a hand lens shows that some quartz grains are coated with a bit of iron oxide to generate a tan color or even orange, or a small number of black grains impart a distinct gray color. It is important to note whether the color observed with the naked eye is imparted by staining of the grains, or by mixed mineralogy.

There are various color guides that can be used, but I have not found one that I prefer to simply using my naked eye and using colors like tan, brown, red, gray. Modifiers like light and dark or perhaps a secondary color (i.e. greenish-gray or reddish-brown) can also be used. For the purpose of consistency for my collection, I use a small set of sand vials as a reference for the more common colors of sand. Each new sand is compared to this set when assigning a color.

If you want to use a standard color scheme or chart, perhaps the most appropriate color chart is the Munsell Soil Color Chart [1]; various versions can be purchased online. However, soil scientists typically deal with sediments enriched in organics and I don't find the chart colors align with the nature of the inorganic sands arenophiles collect.

The *Munsell Geological Rock Color Chart* with 115 colors [2] is newer than the soil color charts and may have colors more closely aligned with the colors in sand. It runs about $80 US. A combination of both Munsell charts might be ideal for anyone seeking a complete and consistent color set. The original Munsell color charts assign numbers to the colors and do not provide names for the colors. There are over 1600, but the soil and rock charts do assign names.

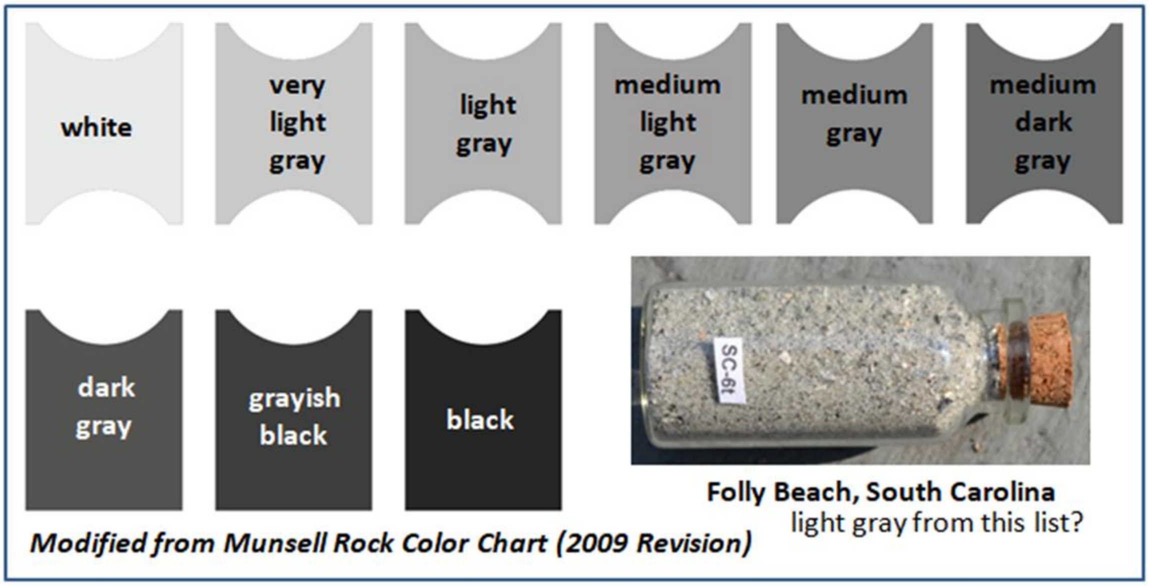

Figure 1. Here is a simple example of applying the Munsell Rock Color Chart to a sand sample from Folly Beach in South Carolina. All of the variations between white and black are shown with their associated color descriptors. I chose “light gray” to describe this beach sand. The same series of color modifiers (very light to dark) exists from brown to tan and with combinations involving hints of yellow, red, etc.

A Munsell color viewer can also be found online [3]. Pick the Hue1 number from the color range drop-down menu and all related colors will be shown below. It is not an exhaustive list of all Munsell colors and again it is hard to use computer screens for accurate color viewing.

There are broader color charts, including, of course, Pantone [4], but these often employ numbers as a standard identification and assign unusual names to many of their colors (like “greige” for darkish gray and “cloud dance” for grayish white). In addition, how many shades of purple or pink do sand collectors need?

Another interesting aspect of assigning color to sand samples is realized when different colored sand is mixed. Darker colors generally dominate the macroscopic view. This is illustrated by the outcrop pictured in Figure 2. The interbedded Late Cretaceous lacustrine and alluvial sandstones show a wide diversity of colors. A sand collector could certainly have an interesting day attempting to separately sample each unit. However, the talus slope at the base of the outcrop which mixes the various units appears to have a uniform reddish-gray color. Although the dominant single color in the cliff face is red or maroon, the mixed sand is gray or perhaps reddish-gray. The color assigned will vary based on the location sampled or the mix of units included, but it would definitely be skewed towards a darker color than might be expected from just viewing the outcrop..

We often see a variety of colorful grains when we view fine- or medium-grained sand under a microscope. A minor component or coating that imparts a significant coloration to the naked eye is observed to be much less important to the overall composition of the sand itself. You might decide that you need to use two colors to define a sand sample, a macroscopic color and a microscopic color. Like everything else in the hobby of sand collecting, this is up to each individual collector to decide.

Figure 2. Rock Formations near Cafayate, Salta Province in northwestern Argentina. Photo is from La Yesera, Salta, Argentina Facebook page.

Grain Size. Sand is actually defined by this property. Naturally occurring, loose granular material resulting from the erosion of rocks or biogenic material within the size of 0.06mm to 2.0mm is classified as sand. Finer grains are silt and clay; grains larger than 2.0mm are termed gravel. Most natural sands, of course, do contain some grains that are finer and/or coarser than those limits, but if the majority of grains fall in that range the deposit is typically referred to as sand. Sand with biogenic grains often has a bimodal distribution of grain size with a coarse biogenic component found together with a finer mineral grains.

The most widely used classification system for defining sand size is celebrating its 100th anniversary in 2022. In 1922, Wentworth introduced a classification scheme for grain size (Table 1) that has met the test of time. It is still used today to describe five grain sizes of sand in addition to grain sizes for finer and coarse material [5].

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0		
				Boulder	Gravel
	256		-8.0		
				Cobble	
	64		-6.0		
				Pebble	
	4		-2.0		
				Granule	
	2.00		-1.0		
				Very coarse sand	Sand
	1.00		0.0		
				Coarse sand	
1/2	0.50	500	1.0		
				Medium sand	
1/4	0.25	250	2.0		
				Fine sand	
1/8	0.125	125	3.0		
				Very fine sand	
1/16	0.0625	63	4.0		
				Coarse silt	Silt
1/32	0.031	31	5.0		
				Medium silt	
1/64	0.0156	15.6	6.0		
				Fine silt	
1/128	0.0078	7.8	7.0		
				Very fine silt	
1/256	0.0039	3.9	8.0		
				Clay	Mud
	0.00006	0.06	14.0		

Table 1. Wentworth clastic size distributions (5). Phi (ø) is a logarithmic transformation of the geometric grain size scale.

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Instead of carrying a ruler around to measure/record grain size, geologists often carry what is known as a grain-size card. There are many versions of this card, but a portion of the card is always dedicated to depicting granular material of varying grain size. We hope to use the sand card shown in Figure 3 in this workshop to assign a grain size to each sand you have collected. Remember, most natural sands will contain grains with a wide size distribution range of variable-sized grains. The assignment of grain size is an attempt to identify the dominant sand-size fraction. Often this is not as easy as it might sound, especially with sands with both a biogenic and a mineral component.

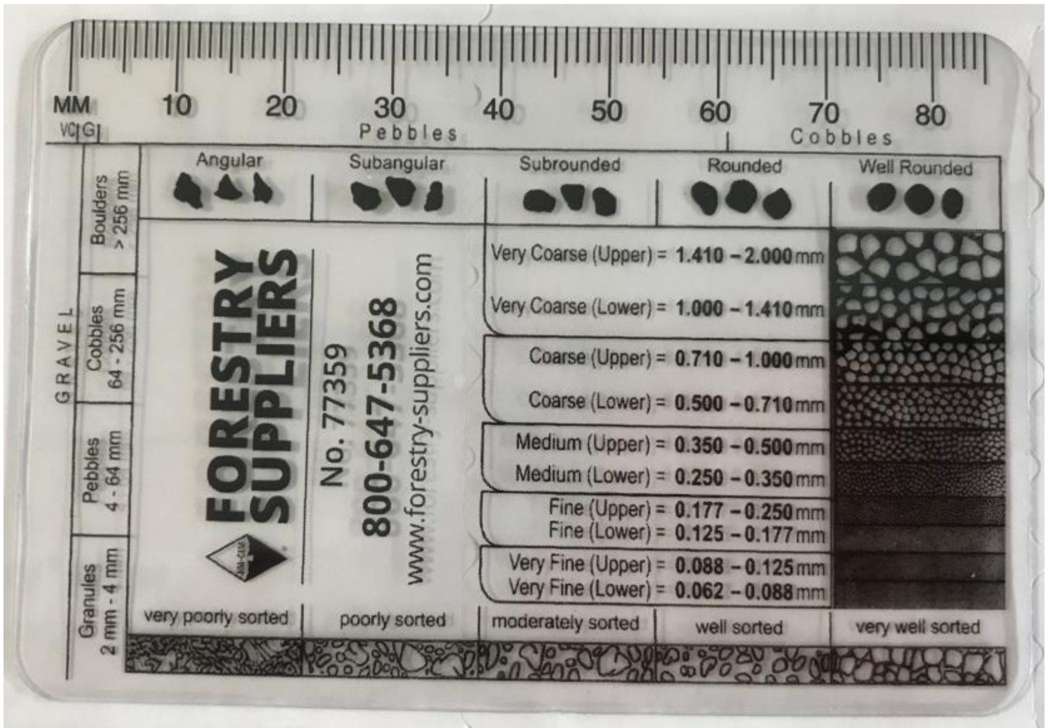


Figure 3. Typical Sand Size Card. This version is available from Forestry Suppliers [6]

Grain Sorting. The degree to which nature has distributed grain size within a sediment is referred to as sorting. Sands are described as either very poorly sorted, poorly sorted, moderately sorted, well sorted, or very well sorted. There are technical and statistical definitions for these terms revolving around the distribution of grain sizes, but often these terms are used quantitatively as we will do here. Sand collectors may find the depiction of each level of sorting on most grain size cards useful (although these snippets are admittedly rather small).

Many folks alter these definitions a bit and may use terms like unsorted, fair sorting, or good sorting. It is probably more important a) to be consistent in how you define sorting and b) to appreciate the significance of sorting in understanding geologic processes. The degree of sorting usually reflects the energy level, the time, or the rate of the sedimentary process leading to the deposition of the sand. The actual mechanism of transport (river, debris flow, ocean tides, wind, glacier) plays a factor as well.

Because rocks derived from sand-sized sediments provide some of the world's most important aquifers (for water) and reservoirs (for hydrocarbons), sedimentary petrologists and economic geologists study grain sorting. This is because well-sorted sediments are also the most porous and permeable, properties that are often retained when sediments are buried and lithified into sedimentary rocks.

Grain-Size Distribution. When it is necessary to quantify sand-size distribution, a set of sieves can be used to separate material into each size fraction (Figure 4). Then each fraction can be weighed. The data can then be plotted onto cumulative percentage plots using as many size fractions as are necessary to capture the desired resolution (Figure 5). For the plots in this presentation, I have used just 6 sieves to capture the five major sand size fractions. Coarser material is simply lumped as gravel and all material that passes through the 0.0625mm sieve is labeled silt+clay. Although probably insufficient for rigorous scientific work, this small set of sieves helps illustrate two of the important aspects of sand size distribution.

The sand fractions in each of the sieves in Figure 4 are from a "manufactured" sand designed for use in a golf-course sand trap. Medium-grained sand is the dominant grain size, but there is also an appreciable amount of coarse and fine sand. This is an example of a moderately sorted sand. This level of sorting is desirable in sand traps to help retain the slope face in the trap and to limit plugging of the golf ball when it enters the trap. The uniformity coefficient and the coefficient of gradation (Figure 5) are two terms used by soil and sand scientists to further characterize sand sorting [7].

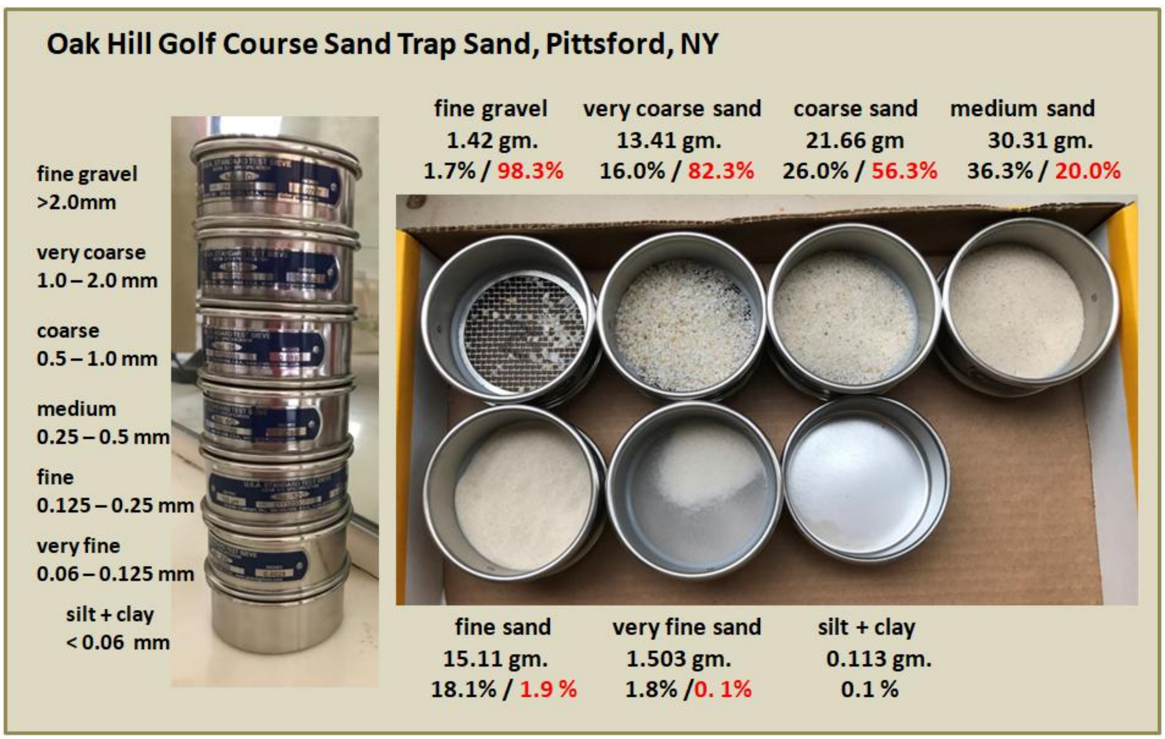
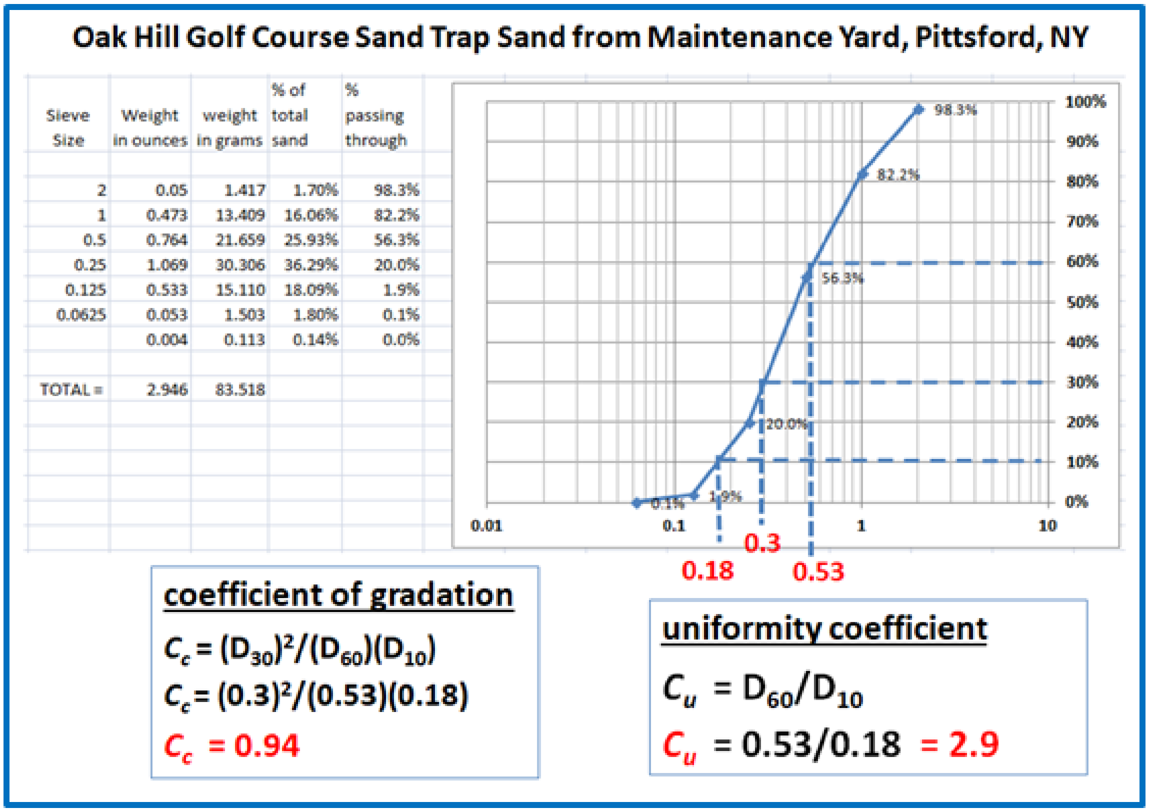


Figure 4. Sieve set used for sand size distribution plots and their use with a golf course sand.

The grain-size distribution of two additional sands has been added to the plot in Figure 6. The Israel River sand shows a similar slope to the golf course sand but is shifted to the right as it is overall coarser sand. There is also a wider spread in the data leading to a higher uniformity coefficient (6.5) and a higher coefficient of gradation (0.94). These values are indicative of poorly sorted sand. The sand from Woodland Beach (Figure 7)



Sieve Size	Weight in ounces	weight in grams	% of total sand	% passing through
2	0.05	1.417	1.70%	98.3%
1	0.473	13.409	16.06%	82.2%
0.5	0.764	21.659	25.93%	56.3%
0.25	1.069	30.306	36.29%	20.0%
0.125	0.533	15.110	18.09%	1.9%
0.0625	0.053	1.503	1.80%	0.1%
	0.004	0.113	0.14%	0.0%
TOTAL =	2.946	83.518		

Figure 5: Cumulative percentage plot and distribution coefficients.

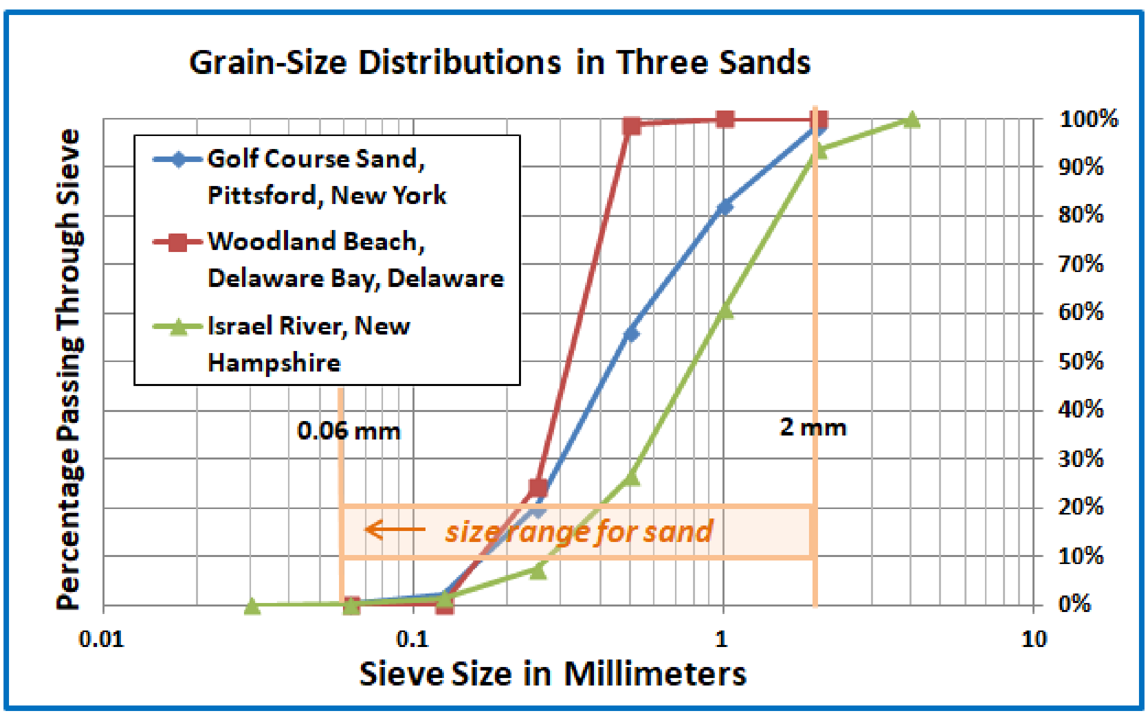


Figure 6. Cumulative frequency sand-size distribution plot for three sands.

is garnet-rich heavy sand collected along the Potomac River in Delaware. The steepness of the cumulative percentage plot for this sand reflects the fact that more than 60% of the grains in this sand are in the medium grain-size category, caught by the sieve with 0.25mm openings.

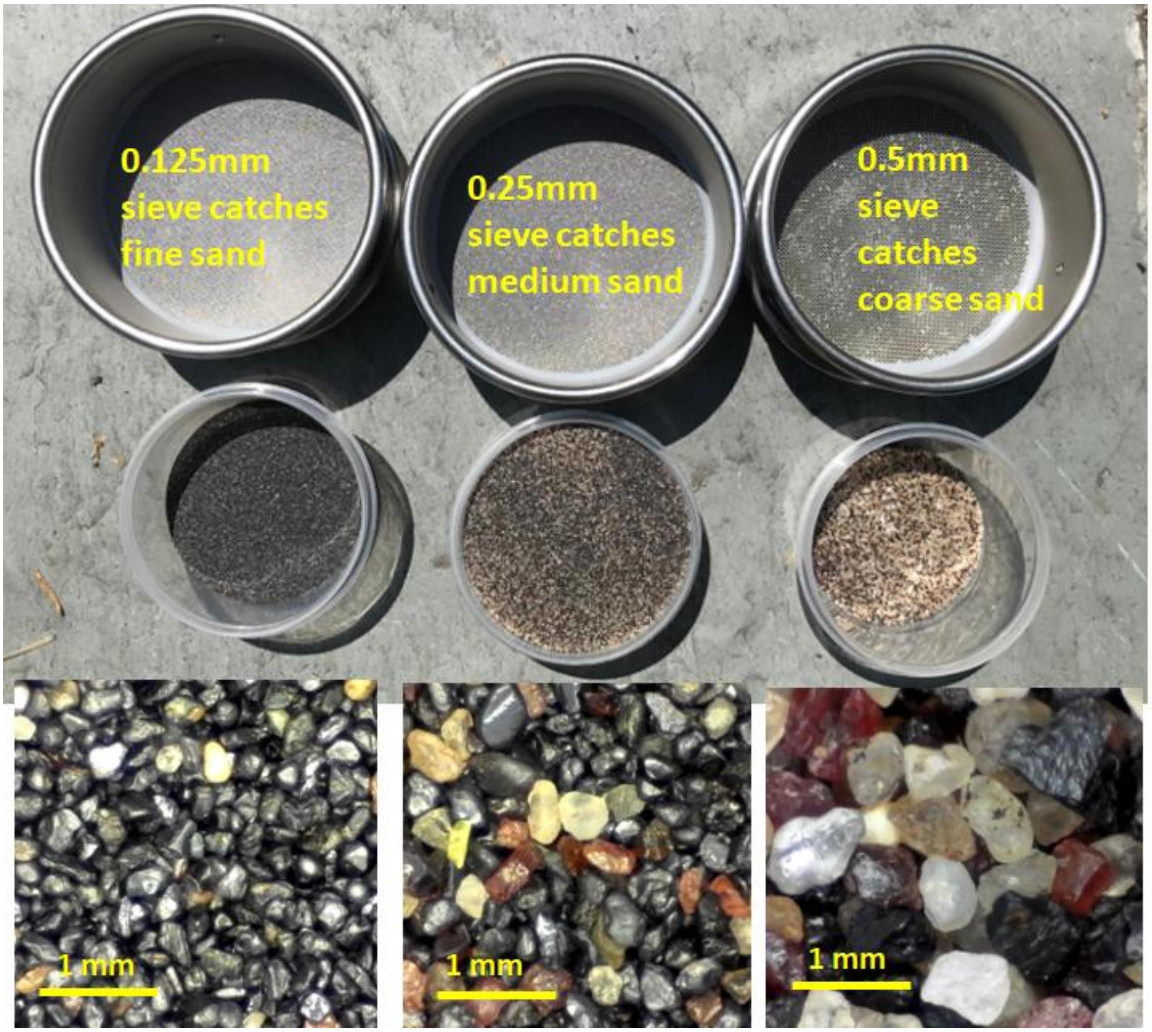


Figure 7. Three sieves captured 99% of the sand grains in the Woodland Beach sample. Notice how the mineralogy differs among the three groups.

Loam. Loam is a rather interesting material relative to a discussion of sediment grain size. Gardeners and farmers often think of "loam" as a mixed soil with sufficient humus (organic content) for promoting plant growth. And when you purchase loam in a garden store that is what you likely get. But strictly speaking and in a purely geologic context, organic content is **not** part of the definition. Rather, loam is simply a term applied to a soil with mixed grain size, specifically a soil with about 40% sand-size grains, 40% silt, and 20% clay. Modifiers can be applied when one of two of these grain-size fractions exceeds the threshold for loam, as illustrated by a ternary graphic (Figure 8).

Figure 8. "Soil" definitions based on relative amounts of sand, silt, and clay. Modified from [8].

Figure 9. A method to test your favorite "sand" sample and assign a correct name.

A home gardener website [9] offers another method described in a graphic from their webpage (Figure 9). The soil depicted in this sample is about 50% sand, 30% silt and 20% clay. This plots in the extreme left corner of loam's compositional range (see the red dot on Figure 8). It might be interesting to compare the results from this wet experiment with one obtained from a dry test employing sieves. From experience, however, I know it is hard to accurately separate silt and clay with a sieve unless you have a sieve-shaking device.

The experiment with the jar is actually an excellent method to understand Stokes' Law. We won't attempt to explain the math, but the relationship derived by Irish physicist George Gabriel Stokes in 1851 quantifies the frictional force (also called drag) exerted on spherical objects as they settle in a viscous fluid under the force of gravity. Larger particles are able to settle faster and accumulate on the bottom. Finer clay particles settle more slowly. The density of the grains and the viscosity of the liquid also affect the settling and separation, but for a mixed grain-size sample settling in water the particle size will be the controlling factor. Want to learn more about Stokes' Law? Check out this entertaining 5 minute video [10].

Grain Shape: An inspection of the shape of the grains can also be informative. Erosion and long distances of transport will gradually lead to rounding of the grains by abrasive action, usually between the grains being transported. In effect, natural processes offer the ultimate rock tumbler, not only reducing grain size into the sand range, but also rounding the grains. Grain shape is typically determined qualitatively by simple observation. As with sorting, a good grain size card depicts five generally accepted designations: angular, subangular, subrounded, rounded, and well rounded.

It is not uncommon for different components of a sand to vary in shape. Sometimes there is a simple reason. Biogenic sands on a beach (broken shells, sea urchin spines, or foraminifera) have a local origin. Although they may be broken they have not been submitted to extensive weathering. They can be present as angular grains within an otherwise well-sorted sand of subrounded or even rounded mineral grains.

Sphericity, Roundness. These two terms can be used to further describe the shape of individual sand grains. Sphericity and roundness can be visually evaluated based on observations of grains and comparison to the shapes in Figure 10.

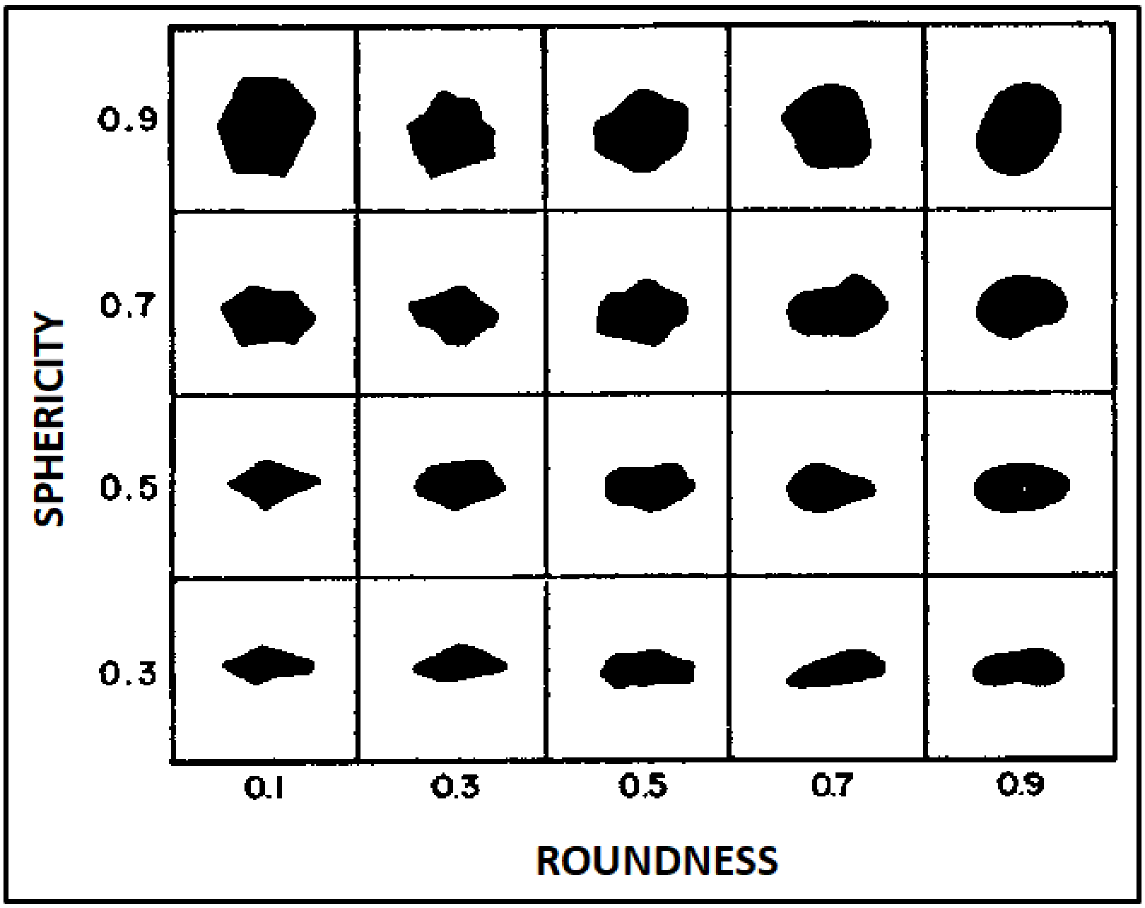


Figure 10. Subset of Krumbein roundness/sphericity chart [11]

Of course, advances in computational techniques have allowed for far better quantification of shape description than can be done visually. For anyone interested, a global group of scientists has done this for sand and by extension to grains within sedimentary rocks [12]. Grain size and grain sorting in sedimentary rocks, such as sandstone, influence the amount and geometry of the pore space between the lithified grains. This is important to scientists studying the porosity and permeability in both water aquifers and hydrocarbon reservoirs because it is the pores and the connectivity between them that allows for fluid transport.

Grain Surface Texture. Much as luster and texture can be used to describe the surface of rocks and the minerals from which they are made, textural descriptors can be used for sand grains as well. After all, sand is simply a miniaturized and weathered version of the rock(s) from which it originated. Unlike grain size, roundness, and other quantitative measurements, assignment of textural terms to sand grains is somewhat subjective. As Blau noted in his contribution to ISCS 2018 [13], the most important reason a sand collector might wish to assign a textural descriptor to a sand sample is probably to help define "aspects of surface features of grains that relate to their origins and travels to reach the site where they were collected." Blau offered textural terms like micro-smooth, micro-rough, faceted, fluffy, fractured, and patterned as possible textural modifiers for sand grains [13]. Sand grains transported by wind often abrade each other created a frosted surface texture.

Maturity. A discussion of sand maturity requires an introduction of sand mineralogy. Softer minerals like calcite (hardness=3) or fluorite (hardness-4) do not survive long-distance transport and significant reworking by streams, rivers, or ocean tidal actions. Therefore, they are not common components of sand that has undergone significant transport. These softer minerals are reduced to clay-size particles or are dissolved. Feldspar and quartz are the most common minerals in continental rocks like granite or in sedimentary sequences with significant sandstones. Quartz has a hardness of 7, feldspars range from about 5.5 to 6.5. Consequently, sand maturity is often defined by the relative amounts of quartz vs. feldspar. Sand with significant feldspar (whether it is plagioclase or potassium feldspar) is considered immature. Sand dominated by quartz (such as most beach or dune sands) is considered to be mature.

Sand Type, Mineralogy, Petrology, and Biogenic Components. A complete sand description also involves defining a sand type [14] and identifying the dominant and subordinate components. This can lead to investigating the origin of those components: in geologic parlance, the provenance for the detrital grains. Some grain identification can be done with the naked eye or with the help of a hand lens. For example, you can see the black magnetite, the red garnets, and the white quartz in the Woodland Beach sample (Figure 7). But many times identification of the secondary minerals in sand requires microscopic investigation which is beyond the scope of this paper.

Let's Describe Some Sands. With this background, let's see if we can describe some of the sands we have collected and record their properties. A spreadsheet has been provided at the conclusion of this chapter for you to capture data in many of the categories that have been discussed.

References

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About the Speaker

Fred Haynes received geology degrees from Lehigh University (B.S.), the University of Arizona (M.S) and the University of Michigan (Ph.D. in 1986) before working as a geologist and petrophysicist for ExxonMobil for 25 years. After retiring a decade ago, Fred has continued his passion for geology through membership in a number of local and regional geology organizations in his home in western New York State. He edits three club newsletters and maintains a personal webpage. He has enjoyed collecting minerals and fossils for much of his life, but a few years ago a colleague introduced him to sand collecting and the ISCS and he was hooked immediately. His collection now exceeds 1500 samples, more than a quarter of which are self-collected. Fred co-administers the ISCS Facebook page and writes a quarterly sand newsletter for his local club in western New York (Wayne County Gem and Mineral Club).

#	Location Name GPS Coords.	grain size	sorting	grain shape	color	environment	primary components	secondary components