HORIBA Scientific

Application Note

Particle Sizing of Sediments
AN144

Particle size analysis of a geologic area can reveal critical information about the region's formation, history and climate. Particle characterization is an important tool for studying changes in geology and climate over time, mode of formation, and current environmental effects related to pollution transport, erosion, and sediment transport.

Summary

Sediments are geologic materials that are formed in one place, moved to another, and deposited. The study of ocean and lake sediments provides a wealth of information about the geological history of a particular area. The characterization of sediments involves a number of parameters including size, composition, shape, spatial arrangement of grains, and the mode of formation (the origin of the material).

Geologists commonly use the Wentworth Scale (a geometric scale based on 1mm, decreasing in diameter by ½). The Phi Scale is a commonly-used modification that allows the use of simple whole numbers for class boundaries by applying the logarithmic transformation: *phi = -log2d*, where d is the particle diameter in millimeters.

The geometric size scale offers a simple relationship to physical transport properties, specifically current velocity.

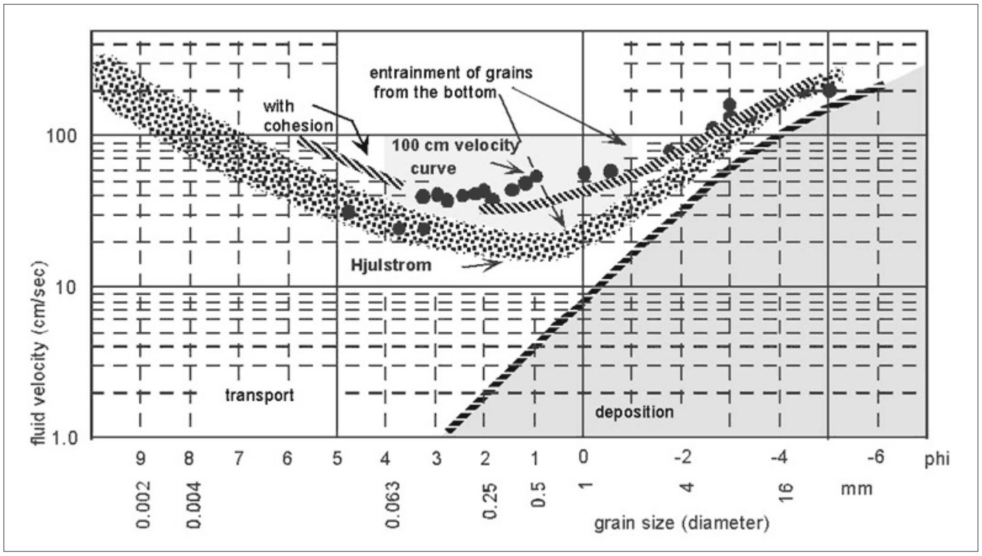

Figure 1. Hjülstrom diagram

Correlating Particle Size to Environment

The principal factors controlling sedimentation are particle size and deposition-site energy conditions. Generally, the particle size of a deposit is proportional to the energy level present at the time of deposition. Thus, high energy beaches are composed of coarse sand and, conversely, quiet lagoons are composed of fine mud.

Grain size and current velocity determine whether a particle will be eroded, transported, or deposited. The Hjülstrom diagram (Figure 1) represents a well-known relationship between grain size and current velocity.

These basic principles allow us to measure grain size and density for an ancient deposit and infer the energy of the formation event for that geologic area. For example, deposits in West Texas and Central Mexico trace their origin to a 65 million year old tsunami.

Ocean Sediments

Study of ocean-floor sediments allows us to learn specific information about the formation of these areas. Continental shelves are shallow and close to continental sediment supply. The deep sea shelves are far from continental sediment supply and see virtually zero wave energy.

The expectation is that, due to the greater energy in the shallow water, larger material will be moved in shallow depths, but not out into the ocean, so we would expect grain size to decrease off-shore across shelves. Indeed, reality matches expectation in that most continental shelves are covered with coarse sand.

Effects of Geologic History

Sea level has varied in the past with the rise and fall of continental glaciers. Up to a mile of ice covered Canada, Siberia, and Scandinavia. The water in this ice came from the oceans, thus lowering sea levels. Eventually, as sea levels rose again, coarse material was deposited across the oceanic shelves. This "relic" sediment, accumulated at an earlier time and under different conditions, comprises up to 70% of all shelf sediment.

As these shelves were near sea level and exposed to the energy of the waves, a number of other factors can play a role. Tidal forces mobilize the sediment once or twice daily. Waves can also erode shelf sediment, thereby permitting transportation through additional currents. Rivers flowing across what is now a shelf either deposited sand, gravel, or deltas, or eroded slope canyons, increasing deposition in deep ocean areas.

Lake Sediments

Grain-size variations in lake sediments reflect changes in the processes and energy of sediment transport. Particle sizes are closely linked to turbulence, wave energy, and proximity to shoreline; increased grain sizes generally correspond to higher energy conditions of sediment production or transport.

Tracing Climate Change

Variability of sediments in lake core samples suggests that grain-size variation in sediments is an effective proxy for environmental change in the area. The absence of precise ages for the cores may allow only tentative correlations of the fluctuations to climatic events.

Making assumptions about sediment accumulation rate, different sediment levels can be correlated to a time period. If this assumption is valid, increases in sand size or content may indicate a period of lower lake levels corresponding to an arid or warm period. Conversely, decreases in sand content may reflect periods of wet and cold climates.

Prevalence of ostracodes can also be used to infer lake-level changes. Ostracodes are small, shelled crustacea commonly preserved in sediments. Because many ostracode species have narrow ecological limits controlled by temperature, salinity, oxygen, food and other factors, they can provide an important tool for paleoceanographic reconstruction.

Sediment Formation

Sediments originate from one of five general sources. Each can be identified by specific chemical and physical characteristics, including particle size.

Terrigenous sediments are derived from the land (terra). Rocks weather to small particles and are transported to the ocean. This is called erosion. Much of it is deposited in river deltas.

Biogenic sediments are the shells and skeletal remains of living organisms. Only the "hard parts" are preserved, typically $CaCO_3$ and silica. These skeletons dominate the sediment in many places.

Authigenic sediments are formed in place by hydrothermal deposits at mid-ocean ridges and vents. Water circulates though the crust, dissolving minerals and bringing dissolved ions to the ocean floor. This water cools and the minerals precipitate out, leaving mineral-rich sediments. The most common are ferro-manganese nodules that have large potential economic value (Mn, Co, Ni, Cu and other trace metals).

Volcanogenic particles (ash) are produced by most volcanic eruptions, but can be transported large distances by wind. Major eruptions can affect sediments on a global scale.

Cosmogenous particles are produced from fragmented meteorites and products of their impacts. Although a small portion of the total, they are important tracers of "events".

Environmental Applications

Particle size of sediments is a primary factor in determining how efficiently it retains contaminants. Finer sediments will trap these contaminants for a longer period of time. Larger particles have greater interstitial spaces, allowing the contaminants to be washed out and continue in the water stream, having a continued effect on the biosystem.

A profile of ocean or lake floor sediments is important to study the conditions necessary to suspend bottom material and to measure the transport of suspended sediment between different areas. Accurate modeling of the transport and fate of both nutrients and anthropogenic pollutants requires knowledge of the concentration and the particle size distribution of suspended particulates. Re-suspension events have the capacity to inject considerable amounts of particulate material (along with their associated nutrients and/or pollutants) into the water.

Also, changes in the size distribution can be evidence of bio-organisms that disturb the sediment, causing a breakdown in sediment size. This can be related back to the amount of nutrients available to the organisms.

Increasing sediment loads entering lakes and rivers owing to widespread deforestation and erosion are increasing the need for understanding of the effects of influent sediment composition on a biosystem. Experiments have been conducted investigating the effects of exposure to sediments of differing particle size ranges on survival of plant and animal life in lakes and rivers.

It was found that survival rates decreased with decreasing sediment particle size. This suggests that runoff from areas that produce fine-grained sediments have greater detrimental effects on the ecosystem and require greater attention.

Traditional Particle Analysis

Traditional particle size measurement techniques include sieves for the larger size ranges, usually above 63 µm (230 mesh size). Sieves are limited in resolution (number of sieves = number of data channels), are slow and operator intensive, and are limited for measuring the smaller size classes. Pipette or sedimentation is used for the finer fractions. This is also a slow technique with significant operator dependency of the results.

Both are affected by particle shape influences. Particles pass through a sieve on the second smallest dimension, so a needle-like particle will be reported as the smaller dimension, not the length. Flat particles, like clay, will sediment in an orientation that gives the greatest hydrodynamic resistance, like a leaf falling. This will be reported as a much finer particle than the average of all dimensions. Care must be taken when interpreting results or correlating historical data to new analytical techniques.

Modern Analysis Methods

Modern automated analytical techniques used for sizing sediments include laser diffraction and digital image processing. These new techniques are fast, easy, operator independent, have a much broader range, and have a much higher resolution with many more data channels.

The higher resolution of these techniques allows for significantly more information to be obtained from a sample. Small changes in the mode may not be picked up by widely-spaced sieves, but are easily resolved along with more details of the total size distribution. The significantly greater speed of these techniques allows a much greater number of samples to be analyzed, providing more detailed information about an area of interest.

Laser Diffraction Analysis

Laser diffraction measures light scattered from the particle as it passes through the measurement cell. The angle of scatter is related to the size of the particles. The measurement is essentially instantaneous, although total analysis times are on the order of seconds for most samples. The HORIBA LA-960V2 has proven popular for this application because of its wide size range (0.01 - 3000 µm), speed, stability, and ease of use.

In addition, the software is able to display the results directly in the Phi Scale or in sieve size channels to correlate to historical data (Figure 3).

The large number of samples necessary to get a comprehensive profile of an area has made automation options popular. The Slurry AutoSampler can accommodate 30 samples and completely automates the sample analysis task. Once configured properly, this automation can also significantly improve reproducibility by removing any remaining operator-dependency.

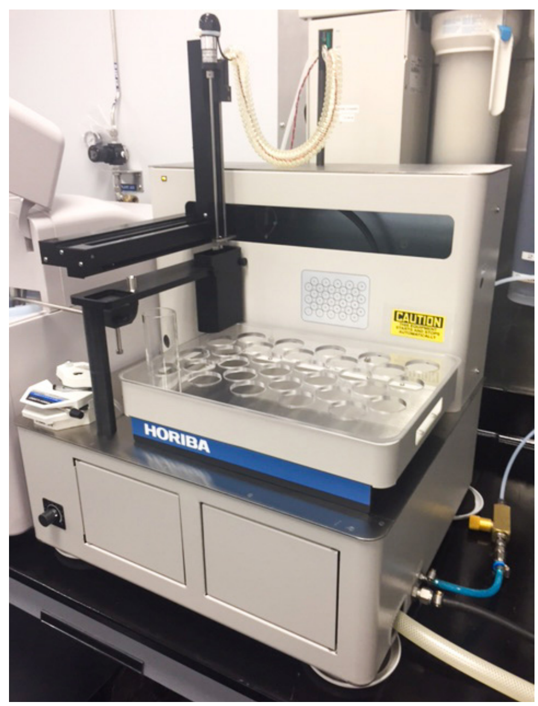

Figure 2. LA-960V2 Slurry AutoSampler

Sample Preparation and Testing Methods

Depending on the source, samples may need to be pretreated with 30% H_2O_2 to remove organic materials or 1 Molarity NaOH to remove biogenic silica (diatoms). Samples are generally dispersed in deionized water for analysis. Finer grades with clay fractions may require additional surfactant (usually 0.1% sodium hexametaphosphate) and ultrasonic treatment to disperse agglomerates.

Owing to the wide range of sizes seen in a given sample, care must be taken that sufficient sample concentration is used across all sizes. Particularly with the larger particle size ranges, the number of particles will be very low when compared to an equivalent volume or mass of smaller particles. The resultant light transmittance values may not represent the total sample breadth.

There must be sufficient sample so that if the large particles were removed and analyzed separately, there would be enough material to provide sufficient detector signal to get an accurate measurement. This may give laser transmittance values outside of the default range. Method development will need to include tests at different sample concentrations and secondary confirmation using other methods, like microscopy or sieving.

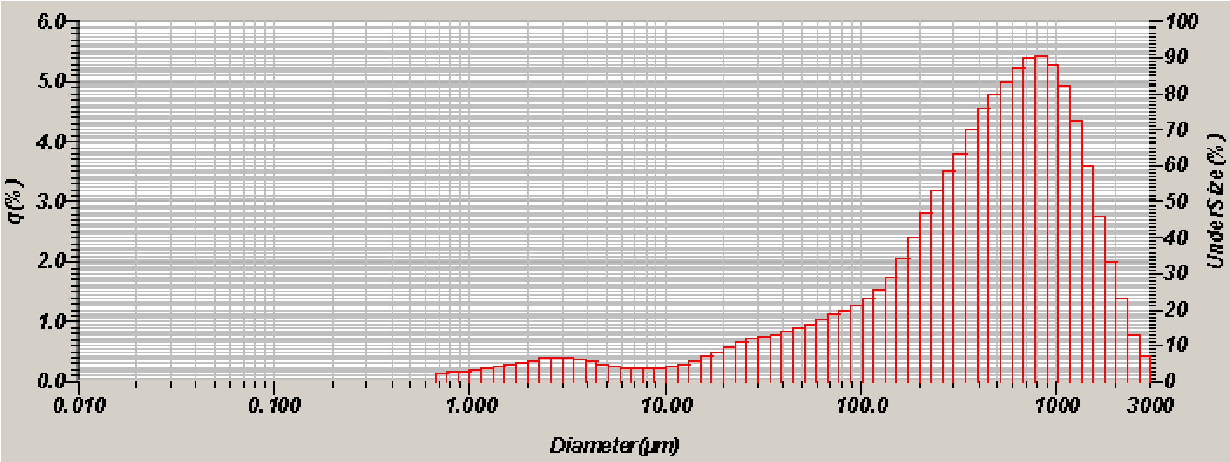

Figure 3. Lake sediment sample measured on the LA-960V2

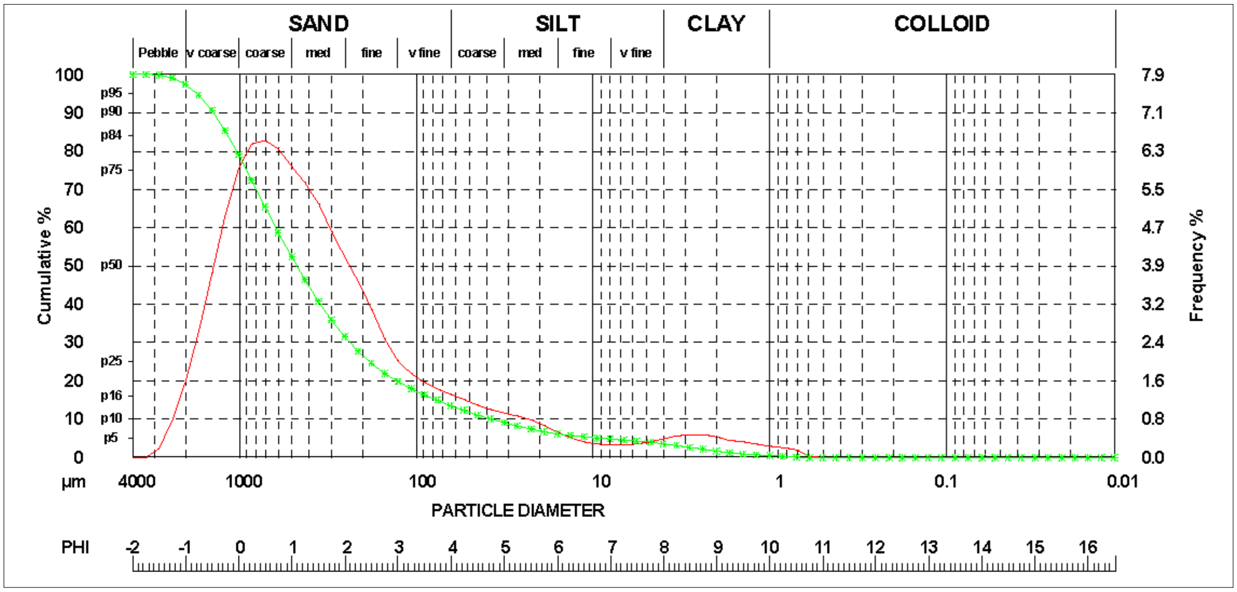

Figure 4. LA-960V2 Phi Scale Graph