

Laboratory#6 – Sediment Particle Size Distribution and Turbidity Flows

Although this laboratory will pertain to oceanic sediments similar processes can also be observed on land and other aquatic systems (i.e., lakes, wetlands). This reading should supplement your understanding of the processes that affect particle size distribution across a marine system (i.e., barrier reef). Next week's laboratory exercises will focus on demonstrating some of these principles as well as give you an experience at quantifying particle size distributions across a barrier reef.

Sediments

Sediment, by definition, is any loose or fragmented material. Hence, loose sand, shells and their fragments, dead leaves, and mud can all be categorized as sediment. All sediments have a source from which they originate. **Pelagic** sediments are those found in the open ocean and whose origin cannot be traced to a specific landmass. They include red clay, radiolarian ooze, diatom ooze, and calcareous (nanofossil or foraminefera) ooze (see images of selected biogenic tests – see page 8 of Laboratory#5). **Terrigenous** sediments are those whose origin is traceable to a specific land (terra) area. They include a series of variously colored muds, volcanic debris, coral muds, and **turbidity flow** deposits. **Lithogenous** sediments are derived from weathering of rock (lithos) material, but their source cannot be readily identified. Red clay in the abyssal ocean is lithogenous. Much of the sediment on the sea floor of the open ocean is lithogenous clay that was transported thousands of miles from its origin.

Calcareous sediments are found over oceanic rises and platforms, whereas red clays are typically distributed in the deep ocean basins. Siliceous biogenic deposits (radiolarian or diatom oozes) are more common in high biological productivity zones at high latitudes, in the equatorial Pacific and Indian oceans, and beneath areas of coastal upwelling (e.g., off western South America). Glacial marine sediments, as would be expected are most common at high latitudes. Coccolithophores and foraminefera produce CaCO_3 and diatoms and radiolarians produce SiO_2 . The coccolithophores and the diatoms are the plants (and photosynthesize); the foraminefera and the radiolarians are the animals.

Pelagic sediments are **biogenic**, i.e., of biological origin. Other components are **authigenic** (i.e., formed in place), some are **hydrogenetic**, i.e., formed by direct precipitation from seawater, and finally, others yet are **hydrothermal**, i.e. formed as a result of hydrothermal activity on the seafloor. Those that do not fall in these last three categories would be considered **detrital**, i.e., they are the detritus of living or non-living matter. It is interesting to note that pelagic sediment can contain biogenic, terrigenous or lithogenous, glacial, and **volcanogenic** sediments. The latter, as the name implies are derived from volcanic activity and include wind-blown ash, submarine pyroclastic flows, hyaloclastite formed by fracturing of volcanic rocks erupted beneath the sea, and reworked volcanic debris. Additionally there can be a small contribution from **cosmogenic** material that falls directly on the ocean surface from outer space. You will note that the various classification schemes for sediments tend to overlap, and the particular scheme used will depend largely on the focus of the researcher doing the describing.

Important contributors to marine biogenic sediments are two plant-like organisms and two simple animals. One plant and one animal produce tests (shells) made of calcium carbonate (CaCO_3), the other plant and animal produce tests of silica (SiO_2).

The source of sediments can involve the life cycle of plants or animals (i.e., leaves, logs, shells), or **chemical weathering** (such sediments are reaction products) or physical weathering (mechanical breakdown) of rocks. All sediment has a **provenance**; this is the *place* from which it (and its components) was (were) originally derived. Sediment always has a parent material, the weathering of which creates the sediment. Sediment is typically eroded and transported from its provenance, most usually by water or wind, but also by ice.

Influence of Currents on Particle Size Distribution

The **settling velocity** of particles is inversely related to their size. Large diameter particles settle faster than fine particles. Additionally, water velocities necessary to carry large particles in suspension are greater than those needed to keep fine particles suspended. Therefore, when currents slow down, larger particles sediment out first and are left behind, whereas smaller particles are carried further. For example, large boulders are usually found in steep mountain streams, but sands and clays travel much farther, often only settling out when they reach the ocean. Fine clays are actually so easily kept in suspension that they can be carried very far into the ocean. The Hjulstrom's curve (Figure 1) addresses the preferential sediment particle size transport over changing current velocities. Marine geologists have long observed that the preferential transport and deposition of sediments leads to depositional features similar to those found in **turbidity flows** (see figure 2).

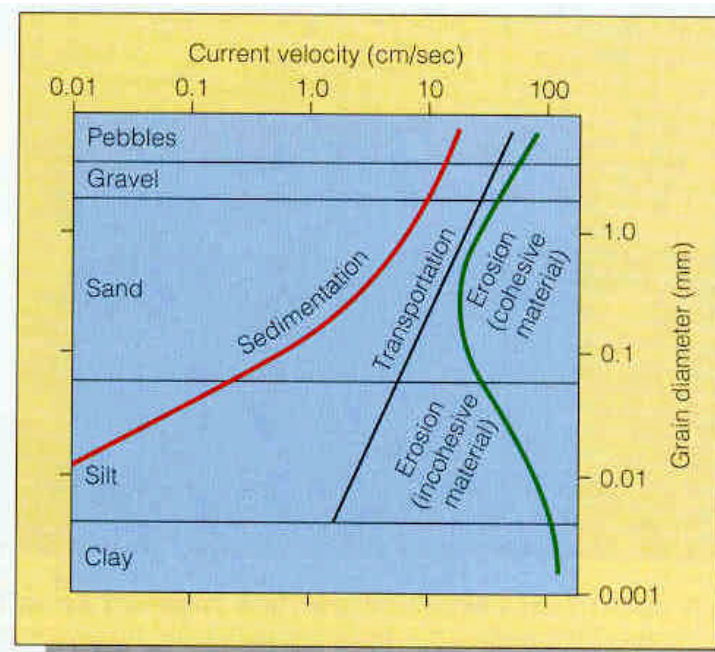


Figure 1 - Hjulstrom's curve showing velocities of currents required for erosion, transportation and deposition of sediment particles of different size. Note that the cohesiveness of smaller particles overcomes grain size control during erosion. Mud, which is a mixture of silt and clay, is cohesive and resists erosion to a greater extent than would be expected just based on the size of its constituent particles.

Transportation of sediment sorts the materials by size and by density. Sediment with material of many different sizes (or densities) is known as “**poorly sorted**”, whereas sediment composed primarily of material of very similar size (or density) is called “**well sorted**”. The processes of transportation also sort and mechanically weather material so that well sorted sediments are typically composed of well-rounded grains (they were abraded during transport), whereas poorly sorted sediments will have more angular (sharp corners) shapes.

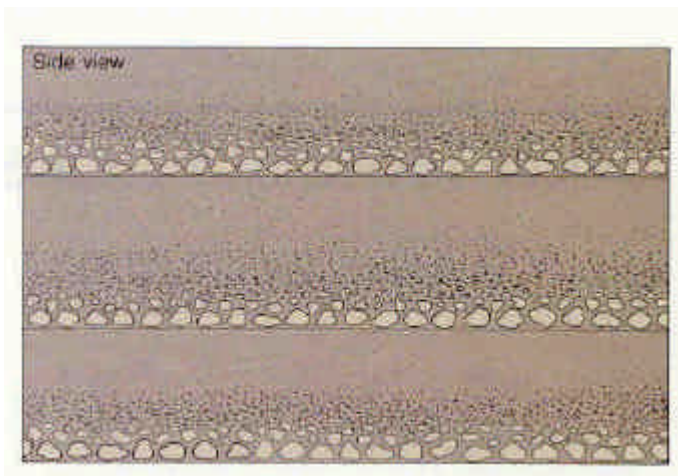
Sediment will generally be classified by either the size of its particles, a description of its components, the process by which it was formed, or some combination of these three. Probably the most successful method of sediment classification combines description and process of formation. Ultimately, however, the aim of sediment classification is to understand processes and relationships.

Classification based on particle size

Grain size is expressed most commonly using the Wentworth Classes, named in honor of C.K. Wentworth, the geologist who originally devised this scale in 1922. The most commonly used grain-size classes used by sedimentologists are:

- Gravel: grains larger than 2 mm diameter
- Sand: grains from 1/16 mm to 2 mm diameter
- Silt: grains from 1/256 mm to 1/16 mm in diameter
- Clay: grains less than 1/256 mm

This relationship between settling velocity and particle size will be demonstrated during your laboratory, and you will be asked to compare your results to those shown in Table 1.



Graded bedding as is commonly formed by turbidity flows in the ocean. In this image three series of graded deposits are evident. Note that this is normal grading, with the fine particles (slow settlers) on top, and the coarse particles (fast settlers) on the bottom.

Figure 2 - Graded bedding typical of turbidity flows/sedimentation events.

Type of Particle	Diameter	Settling Velocity	Time to Settle 4 km (2.5 mi)
Boulder	>256 mm (10 in.)	—	—
Cobble	64–256 mm (>2 1/2 in.)	—	—
Pebble	4–64 mm (1/6–2 1/2 in.)	—	—
Granule	2–4 mm (1/12–1/6 in.)	—	—
Sand	0.062–2 mm	2.5 cm/sec (1 in./sec)	1.8 days
Silt	0.004–0.062 mm	0.025 cm/sec (1/100 in./sec)	6 months
Clay	<0.004 mm	0.00025 cm/sec	50 years ^a

^aThough the theoretical settling time for individual clay particles is usually very long, under certain conditions clay particles in the ocean can interact chemically with seawater, clump together, and fall at a faster rate. Small biogenous particles are often compressed by organisms into fecal pellets that can fall more rapidly than would otherwise be possible. A fecal pellet is shown in Figure 5.11.

Table 1 – Relationships between particle size and settling velocity.

The Reef System

Worldwide, there are three basic types of reef structure – barrier reef, patch reef, and atoll. This exercise will focus on the first type, the barrier reef (specifically that found at Coconut Island, Hawaii). Barrier reefs have a distinctive structure (Figure 3). The **reef front** is the area that faces the open ocean (the left side of the figure). It is usually the deepest section of the barrier reef, and experiences increased wave energy as you approach the **reef crest**. The crest is the shallowest section facing the open ocean, where breaking waves cause the highest energy found on the barrier reef. Often, large chunks of coral are found in the sediment of the reef front due to wave action breaking apart the coral found on the crest. Often times, portions of the reef crest are exposed during low tides. Behind the reef crest is the **reef flat**, which has lower energy than the reef front and reef crest (the waves have already broken). The reef flat is generally quite shallow. In the deeper water behind the reef flat lies the **back reef** section. This is well protected and has the lowest level of wave energy. It is usually somewhat deeper than the reef flat, and can be populated by sea grasses and other plants not found in the higher energy zones.

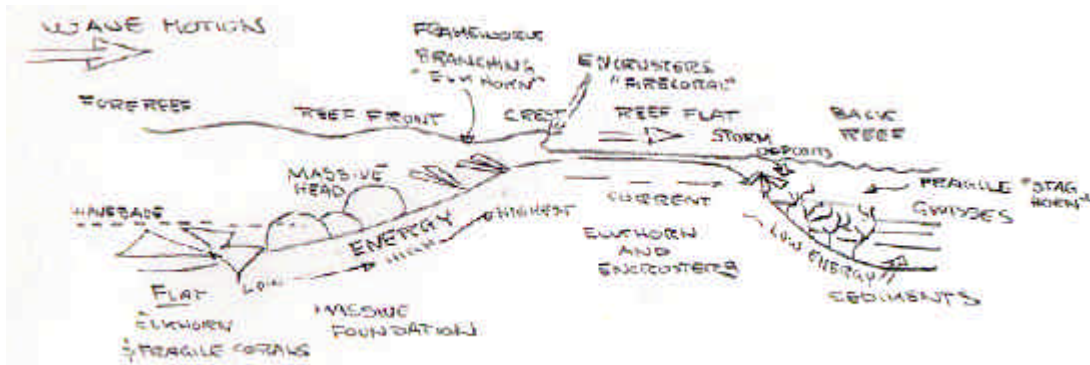


Figure 3 – Schematic of barrier reef structure.

When one examines the distribution of coral forms and types, these directly reflect the energy distribution across the reef. The most robust species are found in the reef front and reef crest, with the more delicate species in the back reef. Similarly the sediment grain size distribution is also a function of the energy level found in various sections of the reef. The smallest particles take the longest to settle, with larger particles settling quickly. Based on this, you should be able to predict which areas of the reef have the largest grain size and which have the smallest.

Geologists have performed grain size analyses on sediments of barrier reefs all over the world. They have found that the different regions of a barrier reef are typified by different grain size distributions in the sediments. Using this knowledge, they can reconstruct the paleoenvironment of fossilized reefs. Questions they would like to answer include the following: Which section was the fore reef? Where was the reef crest? Have the species found in any given region (i.e., fore reef, back reef, etc.) changed significantly in geologic history? How is this related to past sea level? They do this by comparing the known grain size distributions with those found in sedimentary rocks.

Keep in mind that this process isn't as easy as it may seem. Often times, you can't simply look at a fossilized reef bed and be able to say that it was part of a barrier reef. This is only possible when you can look at a cross-section of the reef (like in a road cut) and already know the local geologic history. Usually, all you have is a sediment core that is only a few centimeters in diameter (remember also that sea level is currently much higher than it has been for most of geologic history – a lot of these cores are taken in shallow water). In this case, you can look at the sediment core as a continuum of geologic history, with the most recent events recorded at the top of the core, and the oldest events at the bottom. [There are many potential problems with this assumption. Can you think of any?] By analyzing various layers down the core, you can study the progression of sea level, and determine how it has affected the physical and ecological structure of the reef bed that you are studying. Such an exercise is quite complicated and is beyond the scope of this lab. However, you should be aware of how this kind of work is done.

The field of sedimentology is a large branch of geology and there are many terms employed by its practitioners. Many of these terms are beyond the scope of this laboratory, but we will introduce a few that are used to describe some of the common sedimentary structures. Some structures formed when sediments were originally deposited, but many others formed through post-depositional processes. Because sediments are deposited in layers the most obvious sedimentary structure is **stratification**. Most of the **strata**, or layers, accumulate nearly horizontally. Strata that are very thin (<1 cm) are known as **laminations**, whereas thicker strata (>1cm) are called **beds**. Surfaces between strata are called **bedding planes**; they represent exposure surfaces that existed between individual sedimentary deposition events. Although most sediment strata are deposited nearly horizontally, some stratification is inclined. Inclination of strata is known as **cross-stratification** (see figure below). Sediment transport in a single direction as a result of the action of water or wind leads to the formation of **asymmetrical ripple marks** or of **dunes**. Individual strata of sediment may also be **graded**. Graded deposits typically form when sediment-laden currents slow down as they enter either a body of standing water (e.g., a stream entering a lake) or reach the bottom of a steep rise (e.g., turbidity deposits at the edge of the continental rise).