

Marine Sediments

INTRODUCTION

There are two basic methods used for classification of marine sediments: genetic and descriptive. **Genetic classifications** distinguish sediments according to the **process** by which they originate. Marine sediments originate by three basic processes: **biological**, **chemical**, or **physical**. **Descriptive classifications** distinguish sediments by differences in **texture** or **composition**. Useful textural properties of sediments include grain **size**, grain **shape**, and grain **roundness**. Compositional classifications consider differences in **mineral content**, **chemical composition**, or, in the case of biogenic sediments, the most abundant **biological constituent**.

GENETIC CLASSIFICATIONS

The most fundamental way of classifying sediments is according to their origin. The four commonly used categories are:

Terrigenous = sediments derived from weathering of the continents or from volcanic activity (**volcanogenic** sediments). Erosion by rain, rivers and glaciers (**glacial marine** sediments) delivers sediments from the continents to the oceans where they are deposited.

Biogenous = sediments that originate by biological processes such as the secretion (growth) of skeletal materials by marine organisms. Only a small fraction of biogenous sediment is actually organic matter. Most biogenous sediment is biologically produced inorganic matter, including skeletal remains of both microscopic, single-celled organisms, and macroscopic, multi-cellular organisms.

Hydrogenous = inorganic sediments that originate by the precipitation of minerals from seawater.

Cosmogenous = inorganic sediments that originate by the accumulation of materials from outer space. There are two main types of cosmogenous sediments. 1) "Cosmic spherules" form when sand-sized particles of interplanetary dust melt as they enter the upper atmosphere at speeds of about 12 km/sec. These small spherical objects can be removed from deep-sea sediments with strong magnets. 2) Impact deposits form when large asteroids or comets impact the Earth at speeds of 15 to 60 km/sec. The enormous explosions blast meteorite material great distances. One impact 65 million years ago (that killed all the dinosaurs and many other species) left a sediment layer over the entire surface of the Earth.

Terrigenous sediments are by far the most abundant by volume & mass, followed by the biogenous sediments. Hydrogenous materials are found to be only a small portion of marine sediments, and cosmogenous materials are very rare except near ancient meteorite impacts.

DESCRIPTIVE CLASSIFICATIONS BASED ON GRAIN SIZE

A useful descriptive classification of sediments is based on grain size. In addition to being useful to describe sediments, particle size is also important in determining the methods of transportation and accumulation of sediments within the oceans. Size classes of sediments are defined as follows:

<u>Size Class</u>	<u>Diameter</u>
Boulder:	greater than 25 cm
Cobble:	6.4 to 25 cm
Pebble:	4 mm to 6.4 cm
Granule:	2 mm to 4 mm
Sand:	1/16 mm to 2 mm
Silt:	1/256 mm to 1/16 mm
*Clay:	1/4096 mm to 1/256 mm
Colloidal:	particles smaller than 1/4096 mm (clay)

(*Note that the term clay refers to a size class in the grain size classification. You should be careful not to confuse this with the group of minerals known as the clays. Clay minerals are a common component of terrigenous sediments and, as you might guess, they are typically clay-sized.)

Sedimentary rocks classified by size might have names such as sandstone, siltstone, claystone, or pebble conglomerate.

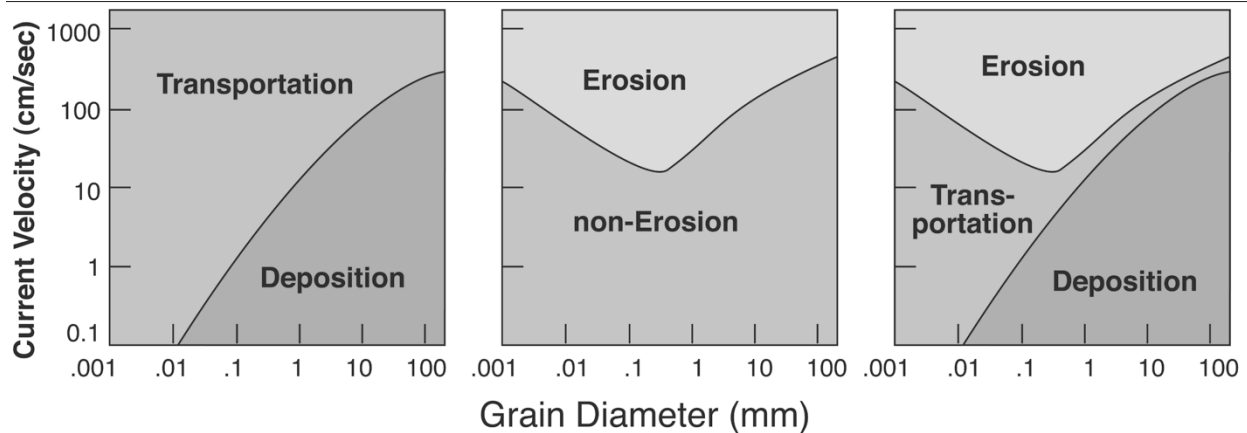


Figure 1. Plot of current velocity vs. sediment size for deposition, transportation, and erosion of sediments. Smaller sediment sizes can be transported by slower currents. For a given sediment size, once current velocity drops below a given level, sediment grains will be deposited. Sediment deposits can also be eroded. Interestingly, the most easily eroded sediments are sands. More fine-grained sediments tend to be cohesive and are difficult to erode, particularly clays. The current velocity required for erosion is always greater than the minimum velocity necessary for transport.

The grain size of a sediment gives an indication of the energy of the environment where the grains were transported and deposited. The smallest grains (clay) sink very slowly through water, and can remain suspended by slight turbulence in flowing water. They tend to accumulate only under conditions where water is not flowing rapidly. They can also be transported large

distances by wind. By contrast, larger grains (gravel, pebbles, etc.) sink rapidly, and can only be pushed along the bottom by fast-flowing water, such as might be found in a fast-flowing stream or where waves break against a beach. These larger grains can thus accumulate in relatively high flow-energy environments. Sand and silt, being intermediate in size, can be moved by moderate flows. Sand, like gravel, sinks relatively quickly, and is mostly transported along the bottom of the water column. Silt and clay can move in suspension (within the water). Both can also be transported limited distances by strong winds.

Generally speaking, **terrigenous** sediments deposited on the deep sea floor far from continental margins are fine-grained materials (silt- or clay-sized) transported by the wind, that have fallen out of the air and settled slowly through the water column. The biogenous fraction of the sediment on the deep-ocean floors, however, ranges in size from clay to sand. The sedimentation rate on the deep sea floor (far from continental margins) of the Pacific and Atlantic Oceans typically ranges from about 1 to 25 mm/1000 years. Coarser terrigenous materials (sand-sized and larger grains) are mostly restricted to marginal areas adjacent to the continents, where rates of sedimentation are much higher.

DETAILED GENETIC CLASSIFICATIONS INCLUDING COMPOSITION

Another type of descriptive classification is based on the composition of the grains making up the sediment. The following provides a survey of compositional variation within the three broad genetic groupings of marine sediments discussed previously.

TERRIGENOUS SEDIMENTS: Most terrigenous sediments are minerals and rock fragments derived from weathering of the continents. Those found near the continents are mostly delivered to the oceans by rivers, but they also come from wave erosion of coastal rocks and sediments. These sediments are transported along the continental shelf by waves and near-shore currents. Eventually, they can be transported down the continental slope by gravity flows (slumps, slides, turbidity currents). It is very common for terrigenous sediments to accumulate in submarine canyons until they collapse and flow down the canyon as turbidity currents that flow out onto the continental rise and even all the way out to the abyssal plains. Deposits of these flows are called **turbidites**. In the deep-ocean basins, far from the continents, terrigenous sediments are usually fine-grained, silt- and clay-sized particles transported by the wind called **abyssal clays**. At high latitudes, glacial marine sediments are deposited at the fronts of glaciers, or in the deep ocean when icebergs drop sediment as they melt (this is known as "**ice rafted**" sediment). **Volcanogenic** sediment is volcanic debris deposited near sites of volcanism, such as near convergent-margin volcanic arcs, or around hot-spot volcanoes like Hawaii.

HYDROGENOUS SEDIMENTS: The most common hydrogenous sediments are **Manganese nodules**. These are black, lightweight objects that show concentric layering. They are commonly found on the deep sea floor in regions of slow sedimentation (e.g. the deep-ocean basins). The nodules, on average, are composed of 64% MnO_2 , 33% Fe_2O_3 , and 3% of mixed Ni, Co, and Cu. Note how some of the specimens provided appear to have nucleated and grown layer upon layer by accretion around a shark's tooth or piece of bone. Refer to the display case for more information on manganese nodules and the techniques used for mining them.

Another important type of hydrogenous sediment is **hydrothermal** sediment. Hydrothermal sediments are produced at mid-ocean ridges. Cold seawater percolates through fissures near the ridge crest. This water is then heated by hot rocks under the ridge, and it leaches metals out of the basaltic oceanic crust. These **hydrothermal fluids** then flow back out of the ridge through fissures and **vents**. Temperatures of these fluids have been measured at greater than 300°C, and they are known to support unusual biological communities that live at the interface between cold ocean water and the hot vent fluids. As the metal-rich hydrothermal fluids mix with seawater and cool, oxides of Mn and Fe precipitate and are deposited at the ridge crest. These deposits also contain economical deposits of gold (Au) and other important metals.

BIOGENOUS SEDIMENTS: The common biogenous sediments of the **deep sea** consist mostly of the skeletons, or "**tests**" of **single-celled, microscopic** organisms comprising some of the **plankton** (floating organisms which will be the subject of next week's lab). When planktonic organisms die, their skeletal materials can sink to the ocean floor. Large areas of the ocean floor are covered by biogenous sediments. These deposits of the deep sea are called **oozes** when they contain **more than 30% biogenous material**. The most common biogenous sediments include:

Siliceous oozes ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$; silicon dioxide): The biogenic form of silica is **opal**, while the inorganic form is quartz. Opal contains significant amounts of water bound up in its structure.

Calcareous oozes (CaCO_3 ; calcium carbonate; calcite and aragonite): Many marine organisms construct skeletons of the calcium carbonate mineral **calcite**. **Aragonite** (Mother of Pearl) is a less common biogenic form of CaCO_3 . Aragonite and calcite are *polymorphs* of CaCO_3 , meaning they have different crystal structures but the same chemical composition (other examples of *polymorphs* include graphite and diamond, different crystal forms of pure carbon). Aragonite, although common in the shells of planktonic molluscs (the **pteropods**), is easily dissolved by seawater and is not commonly preserved in deep-ocean sediments. Aragonite (pteropod) oozes are only preserved in relatively shallow, warm, tropical waters.

Phosphates ($\text{Ca}_5(\text{PO}_4)_3(\text{OH},\text{F})$; calcium phosphate): The common skeletal mineral composing the bones and teeth of vertebrates (e.g. fish, marine mammals, birds) is biogenic apatite. In contrast to aragonite, **apatite** is a very stable mineral that does not degrade easily under normal conditions. Apatite is usually a minor component of deep-sea sediments.

Most plankton live within or just below the **photic zone** (the thickness of the photic zone varies, but is typically 100 to 300m in the open ocean). Many plankton are **algae** that form the base of the food chain and require sunlight for **photosynthesis**. The most common **microscopic algae** or **phytoplankton** contributing to deep sea oozes are:

Diatoms, which secrete pillbox-shaped or elongate (pennate) tests of opal. **Diatomite** is the name for a fine-grained, whitish sedimentary rock composed of mostly the tests of diatoms.

Coccolithophores, which produce subspherical skeletons of CaCO_3 consisting of numerous circular plates (or coccoliths). Individual plates, which average less than 5 micrometers (=

5×10^{-6} m) in diameter, are continually grown and discarded throughout the life of the organism. **Chalk** is the name for a fine-grained sedimentary rock composed of coccoliths.

The most common microscopic animals or **zooplankton** contributing to deep-sea oozes are:

Foraminiferans which, have a variety of coiled, chambered, often spinose, tests of CaCO_3 . The Globigerina, which possesses a bulbous chambered test of CaCO_3 is a common planktonic foraminiferan found in deep sea oozes.

Radiolarians, which have small, mostly spherical tests of SiO_2 (opal).

DISTRIBUTION OF MARINE SEDIMENTS (See Figure 2)

The overall pattern of distribution of marine sediments is controlled by 3 processes: 1) production, 2) dilution and 3) destruction (or preservation). These are particularly important when considering biogenous sediments. Naturally, sediments cannot be deposited if they are not produced. Also, a sediment type can be diluted by another more abundant sediment type – we usually classify a sediment by its most abundant or conspicuous component. For example, biogenic oozes are rarely found on the continental slope & rise because biogenous components are drowned out by large inputs of terrigenous sediment deposited by turbidity currents. Destruction (or preservation) is important for biogenic sediments, as under many conditions calcareous or siliceous skeletal material will be dissolved.

Terrigenous sediments are usually dominant along continental margins and in the deeper portions of the ocean basins. High accumulation rates of terrigenous sediments near the continental margins essentially overwhelm the biogenic contribution to sediments. Terrigenous glacial marine sediments dominate at high latitudes.

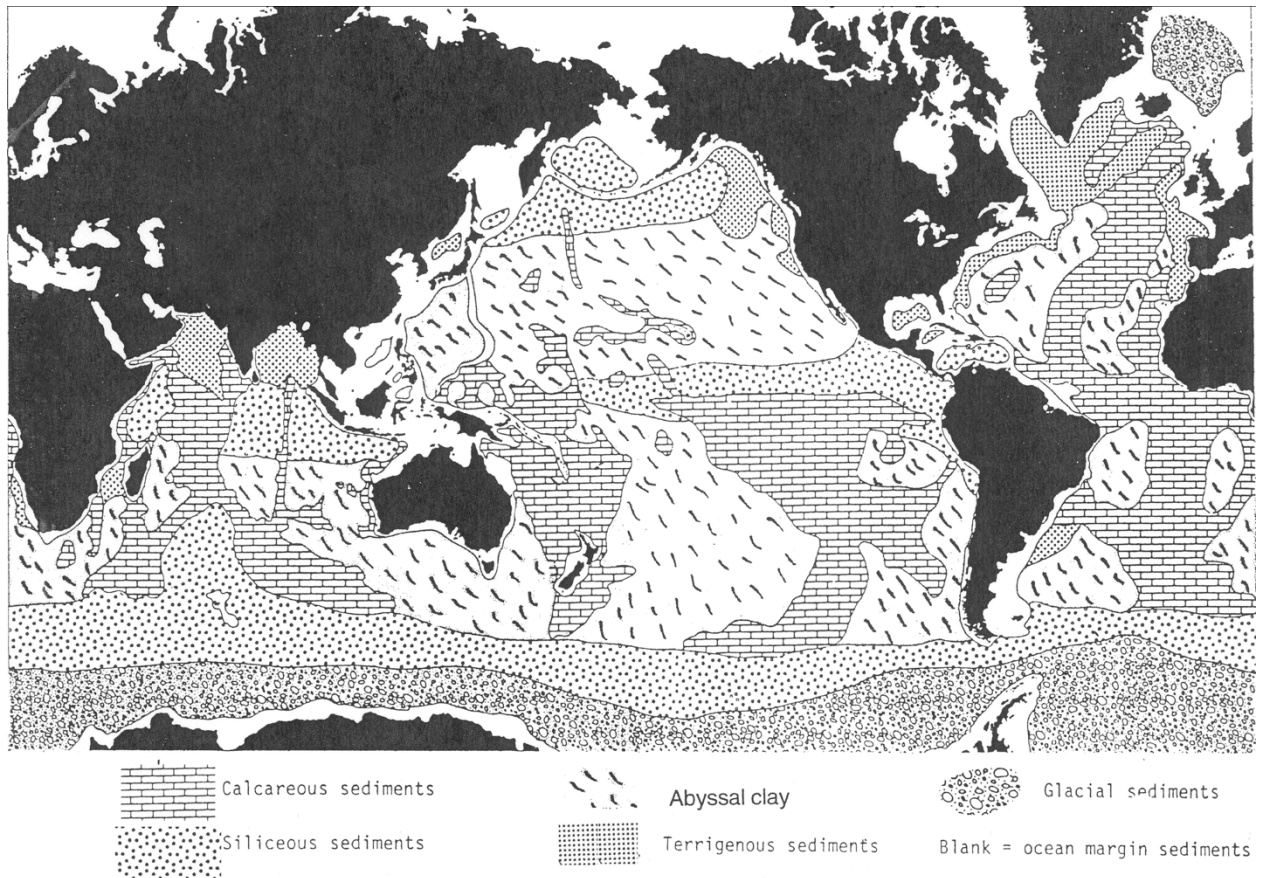


Figure 2. Distribution of the principal types of sediment on the ocean floor.

The distribution of **calcareous oozes** (>30% calcite) is controlled by the preservation (destruction) of biogenic calcite. Deep, cold waters with high CO₂ concentrations are corrosive for calcite (see Fig 3), and calcareous oozes are not preserved below depths of about 4500 m (on average). The depth below which calcite is completely dissolved is known as the **Calcite Compensation Depth** (or CCD). Thus, calcareous oozes are found in the shallower regions of the ocean floor (on the ocean ridges, on shallow plateaus, in back-arc basins, and on seamounts). One exception for this is in the Equatorial Pacific where high biological productivity in surface waters has depressed the CCD to depths greater than 5000 m.

The distribution of **siliceous oozes** (>30% opal) is controlled by preservation of biogenic opal. Seawater tends to dissolve opal and it is preserved only when it is buried. Thus, siliceous oozes are found only underneath regions of high surface productivity where biogenic opal accumulates rapidly enough to bury itself before it dissolves. Siliceous oozes are found under the Antarctic Divergence, in upwelling Equatorial regions, and in the North Pacific where old, nutrient-rich deep waters upwell.

The terrigenous **abyssal clays** are the default sediment of the deep ocean basins. These are fine grained and accumulate extremely slowly, and are found in regions where other sediment types do not occur (and cannot dilute them). Thus they are found far from the continental margins (where turbidites and glacial sediments dominate), at great depths (below the

CCD), and away from areas of high surface water productivity (where siliceous oozes accumulate)

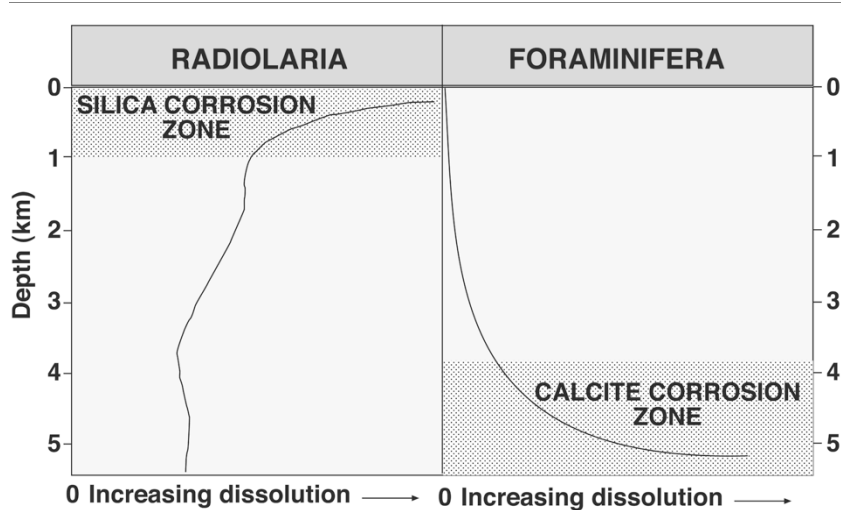


Figure 3. Comparison of dissolution profiles of radiolaria and planktonic foraminifera. Opal dissolves most quickly in surface waters, while deep waters are most corrosive for calcite.

PLATE TECTONICS AND MARINE SEDIMENTATION

Plate tectonics exerts a strong influence on the distribution pattern of deep-marine sediments. For instance, mid-ocean ridges are shallow, usually poking above the CCD. As a result, sediments near the ridge are dominated by calcareous oozes (Figure 4). As it moves away from the ridge, older oceanic lithosphere cools and becomes more dense. Eventually, the ocean floor spreads away from the ridge crest and sinks to depths below the CCD, where only abyssal clays are preserved. This pattern may be modified if the plate motion brings a region of the ocean floor under areas of high surface water biological productivity (e.g., under regions of Equatorial divergence and upwelling). When that happens, abyssal clays may be buried by siliceous (or even calcareous) oozes.

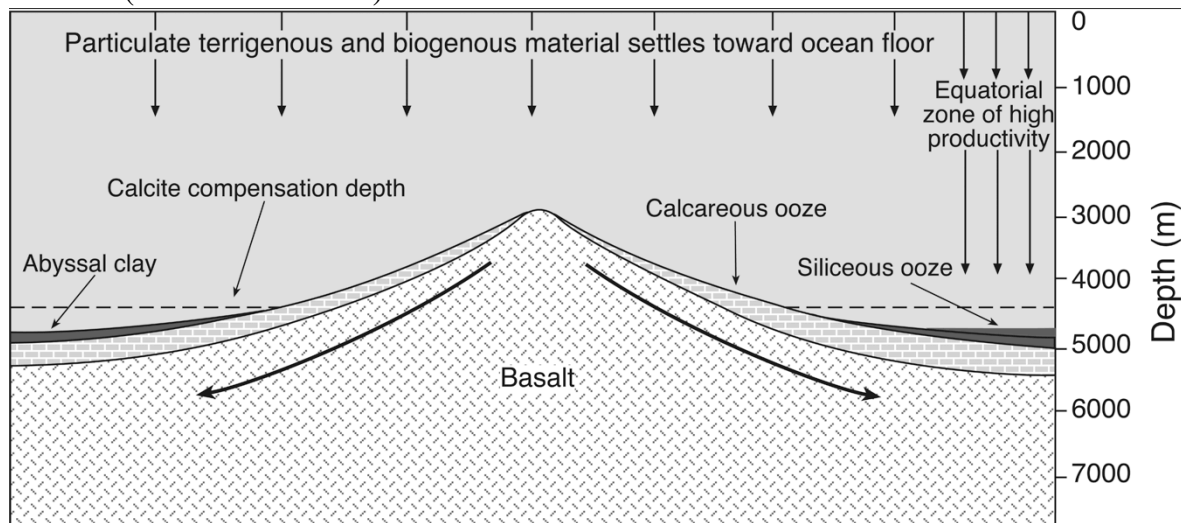


Figure 4. Sea-floor spreading and sediment accumulation. New basaltic crust is forming at the ocean ridge system. As the crust spreads away from the ridge it cools and sinks to lower depths. At the ridge crest, carbonates will accumulate, but as crust gets older and sinks below the CCD, carbonates will get buried by clays. An exception to this occurs when the lithosphere moves under a region of high biological productivity and siliceous oozes can accumulate.