Classification of Marine Sediments

Marine sediments fall into the following four general categories, based on their origin (how they formed):

1. **Terrigenous** (also known as *lithogenous*): Inorganic sediments derived from land, consisting of rock and mineral fragments.

2. **Biogenous**: Organic sediments composed of the hard remains (shells, bones, teeth) of marine plants and animals.

3. **Hydrogenous**: Seafloor deposits formed in place by chemical reactions within seawater. Also sometimes called *authigenic* sediments (self-forming).

4. **Cosmogenous**: Sediments consisting of extraterrestrial debris, such as tiny meteorites and interplanetary dust that filters down through the Earth’s atmosphere.

By weight and volume, the first two categories above account for the vast majority of ocean bottom sediments. Terrigenous and biogenous sediments are the subject of this lab. The following sections provide some additional background detail on these two sediment classes.

**Terrigenous Sediments**

Terrigenous sediments are usually sub-classified by either grain size or mineral type, or both.

*Table 3-1* (below) shows a standard grain size classification scheme, the Wentworth scale:
Table 3-1. The Wentworth scale of sediment sizes.

<table>
<thead>
<tr>
<th>Name</th>
<th>Grain diameter (millimeters)</th>
<th>Grain diameter (micrometers)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boulder</td>
<td>&gt; 256**</td>
<td>256 × 10³</td>
</tr>
<tr>
<td>Cobble</td>
<td>64–256</td>
<td>64–256 × 10³</td>
</tr>
<tr>
<td>Pebble</td>
<td>4–64</td>
<td>4–64 × 10²</td>
</tr>
<tr>
<td>Granule</td>
<td>2–4</td>
<td>2–4 × 10³</td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very coarse</td>
<td>1.0–2.0</td>
<td>1000–2000</td>
</tr>
<tr>
<td>Coarse</td>
<td>0.50–1.0</td>
<td>500–1000</td>
</tr>
<tr>
<td>Medium</td>
<td>0.25–0.50</td>
<td>250–500</td>
</tr>
<tr>
<td>Fine</td>
<td>0.125–0.25</td>
<td>125–250</td>
</tr>
<tr>
<td>Very fine</td>
<td>0.062–0.125</td>
<td>62–125</td>
</tr>
<tr>
<td>Silt</td>
<td>0.004–0.062</td>
<td>4–62</td>
</tr>
<tr>
<td>Clay</td>
<td>&lt;0.004**</td>
<td>&lt;4**</td>
</tr>
</tbody>
</table>

* Size scale developed by C. K. Wentworth in 1922.
† One micrometer equals one one-thousandth (0.001) of a millimeter. It is the metric unit commonly used to measure fine-grained sediments and microscopic organisms.

As might be expected, larger-grained, heavier terrigenous particles settle to the bottom first, and therefore are concentrated closest to the source (land). Finer-grained, lighter particles, like silts and clays, remain suspended in the seawater for a longer period of time (sometimes months or years), and therefore can settle to the ocean bottom at much greater distances from the continents. This differential in settling according to particle size provides a natural sorting mechanism for terrigenous sediments, dependent on distance from the continental source.

Sediment mineral types are also variable, depending on the source. Deposits off mountainous coasts differ from those off coastal plains and river valleys, and are also different from sediments derived from glacial terrains, such as Greenland and Antarctica. A significant component of deep ocean bottom sediment is a reddish or brownish mud consisting of clay with a high iron content. This red clay achieves its rusty color through very slow oxidation of iron by dissolved oxygen in the seawater as the particles slowly settle to the bottom. Red clay is typically only found at depths greater than about 4,500 m (15,000 feet).

**Biogenous Sediments**

Biogenous deposits, known as oozes, are sub-classified into two principal groups according to their biochemical makeup.

1. **Siliceous oozes**: Remains of organisms whose hard shells or skeletons are composed of silicon dioxide (SiO₂, also called silica), which is essentially the chemical makeup of ordinary glass. The two most dominant types of marine organisms producing siliceous oozes are microscopic single-celled algae known as diatoms, and microscopic single-celled protozoans (animal-like) called radiolarians.
2. Calcareous ooze: Remains of organisms whose hard shells or skeletons are composed of calcium carbonate (CaCO₃), which is also the chemical makeup of coral reefs, chalk, and our own bones. Many types of marine life produce calcareous deposits, but one of the most common and widespread is a single-celled animal-like protozoan called foraminifera.

Siliceous ooze may be found at any depth, but calcareous ooze are generally found only at depths shallower than the calcium carbonate compensation depth, or CCD, which varies in depth as a function of latitude, but averages about 4,500 m (16,000 feet). Below this threshold depth, calcium carbonate readily dissolves, which precludes the accumulation of significant quantities of calcareous sediments. If calcareous sediment layers are found in bottom sediments where the water depth is greater than the CCD, it indicates that those deposits must have accumulated when that part of the ocean bottom was shallower, and that the calcareous sediment was subsequently covered up by another sediment layer before exposure to seawater at that depth could dissolve it.

**Sediment Sampling**

Samples of ocean bottom sediments can be collected by a number of different methods. Visual observations of sediments can be made by manned submersibles or remotely operated cameras. Indirect measurements of sub-bottom sediment layers can be obtained using a technique known as seismic sampling, in which sound waves originating at a surface vessel are bounced off distinct sediment layers.

Actual samples can be obtained by two-sided scooping shovels known as grab samplers or clamshell samplers. The disadvantage of clamshell samplers is that the resulting sample is greatly disturbed, and retains little of its original layering when it is dumped out. **Core samples** are obtained by punching a hollow tube into the bottom sediments, then retrieving the tube and its contents, in which the sediments are found in their original layered configuration. **Gravity corers** simply use weights at the top of the tube to push the tube into the sediment (Figure 3-1, at right). **Piston corers** can obtain cores from deeper sediment layers by using a small pressure driven piston to punch the tube farther into the sediment than gravity would carry it. Finally, very deep sediment cores can be obtained using a hollow rotary drill, such as was done by the Glomar Challenger as part of the Deep Sea Drilling Project.

In this lab, we will examine some core sample data, and try to draw some conclusions about the sedimentation processes, rates of deposition, and origin of materials implied by the data from each core.
Online Oceanography 101
Laboratory Exercise #3
Materials of the Sea Floor

Questions to Answer

To answer Questions #1-8, you will need to use Table 3-2 and Figure 3-2 below.

Table 3-2. Core sample data.

<table>
<thead>
<tr>
<th>Core #</th>
<th>Description</th>
<th>Percent CaCOs in top 10 cm</th>
<th>Water depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fragments of volcanic rock, small amount of ooze</td>
<td>--</td>
<td>1500</td>
</tr>
<tr>
<td>2</td>
<td>10 m of ooze, some volcanic fragments and volcanic ash in top 1 m</td>
<td>90%</td>
<td>2000</td>
</tr>
<tr>
<td>3</td>
<td>10 m of ooze</td>
<td>80%</td>
<td>3000</td>
</tr>
<tr>
<td>4</td>
<td>9 m of ooze</td>
<td>75%</td>
<td>4000</td>
</tr>
<tr>
<td>5</td>
<td>3 m of reddish clay over 3 m of <em>Globigerina</em> ooze</td>
<td>15%</td>
<td>5000</td>
</tr>
<tr>
<td>6</td>
<td>8 m of red clay</td>
<td>3%</td>
<td>6000</td>
</tr>
<tr>
<td>7</td>
<td>9 m of red clay</td>
<td>5%</td>
<td>7000</td>
</tr>
<tr>
<td>8</td>
<td>1 m of fine sand over 60 cm of graded sand over 3 m of red clay</td>
<td>15%</td>
<td>4500</td>
</tr>
<tr>
<td>9</td>
<td>6 m of alternating gray clays and brown silts with some fine to coarse sand layers; base layer of gravel at bottom of core</td>
<td>--</td>
<td>1000</td>
</tr>
<tr>
<td>10</td>
<td>4 m of coarse sand and gravel</td>
<td>--</td>
<td>500</td>
</tr>
<tr>
<td>11</td>
<td>7 m of silt interspersed with sand and gravel layers</td>
<td>--</td>
<td>1500</td>
</tr>
<tr>
<td>12</td>
<td>9 m of gray silt with fine sand layers</td>
<td>--</td>
<td>3000</td>
</tr>
<tr>
<td>13</td>
<td>10 m of gray and brown clay, several fine sand and silt layers</td>
<td>--</td>
<td>4000</td>
</tr>
<tr>
<td>14</td>
<td>10 m of brownish ooze, with a few silt and sand layers</td>
<td>50%</td>
<td>3000</td>
</tr>
<tr>
<td>15</td>
<td>10 m of brownish ooze</td>
<td>70%</td>
<td>2000</td>
</tr>
<tr>
<td>16</td>
<td>Basalt rock fragments, volcanic ash</td>
<td>--</td>
<td>1500</td>
</tr>
</tbody>
</table>
Figure 3-2. Map of hypothetical ocean basins showing locations of the sediment cores listed in Table 3-2. Contours indicate sea-floor depths in meters. Note that the "Pacific-like" Ocean A has deep trenches at the base of the continental shelf (an active continental margin), whereas the "Atlantic-like" Ocean B has a broad, passive continental margin.

1. Using data from Table 3-2, plot the percentage of calcium carbonate versus depth for each of the sediment cores (except the cores that show a "—" in the calcium carbonate column) on the graph below. Label each point with its sample number, and note whether it came from Ocean A or Ocean B.
2. Give an explanation for the sharp reduction in percentage of calcium carbonate below a depth of 4000 m in the above data.

3. a) Using Table 3-2 and Figure 3-2, plot a depth profile of each line of cores (1-9 in Ocean A, 10-16 in Ocean B) on the graph below.

   b) For each depth point plotted, use colored pencils to draw a colored circle (or multiple circles) around each point to indicate the main types of sediment found in the core at that location. Use red for clays (any type), blue for oozes, yellow for gravel, sand or silt, and black for volcanic rock or basalt. You will use this graph to help answer several of the following questions (but do not submit it to me).

   ![Graph showing depth profile of cores for Ocean A and Ocean B]

   Note: This line represents the continent between Ocean A and Ocean B.

4. Referring to the figures and table above, explain how and why the sediments change as the continent is approached. (Consider texture, composition, origin, etc.)
5. Speculate as to why there are no red clays found in the Ocean B sediment cores. (Hint: Red clays are formed by oxidation [rusting] of iron particles in the sediment, and such particles must be exposed to seawater for a long time for that to occur. What is it about Ocean B that might prevent that from occurring?)

6. Why do we not find any biogenous oozes in sediment cores 8 and 9 in Ocean A and cores 10-13 in Ocean B?

7. Look at the description of the layers in core 5, which was taken at a water depth of 5000 m in Ocean A. *Globigerina* oozo is a calcareous ooze. Given that the depth of this core is below the CCD, how would you explain the existence of that calcareous layer?

8. There are silts and sands in core 14 in Ocean B at 3000 m, but none in core 3, which was taken at the same depth, in Ocean A. Suggest the reason for this difference.

9. Red clay on the deep-sea floor accumulates at an average rate of about 1 millimeter per 1,000 years. Biogenous oozes often accumulate at rates that are ten times faster than red clay.

   a) Calculate how much time would be required to deposit 5 centimeters of red clay.

   b) Calculate how much total accumulation time would be represented by a core 10 meters in length if it contained 5 meters of red clay and 5 meters of ooze.
10. Off the coast of southern California, a special form of sea floor has developed because of the complex plate boundary in that area. The resulting topography, shown in the figure below, is called a continental borderland, and is a checkerboard of deep basins, shallow banks, and islands. In the deep basins some representative sedimentation rates are as follows:

- San Pedro Basin: 54 cm per 1,000 years
- Santa Catalina Basin: 29 cm per 1,000 years
- San Nicolas Basin: 12 cm per 1,000 years

Study the figure and explain why such differences in sedimentation rates exist.
11. **Microscope Observations.**

**HYBRID CLASS:** We will set up microscopes in the lab room and use real ocean sediment samples for this part of the lab.

**ONLINE CLASS:** Microscope photographs of several ocean sediment samples are below; color versions are posted to our course site.

Study each sample carefully. Record the following information for each sample.

- **Sample number, and magnification level.**

- **Observations:** Describe what you see. Your description should include information about the sample’s particle size (compared to the other samples; note that the magnification is not the same for all of the samples), and texture (shape and roughness of the particles), and color. Also feel free to include subjective descriptions (such as “they look like little cockroaches” or “looks like salt and pepper”).

- **Thought question:** One question that occurs to you looking at the sample. (“I wonder why...?”)

- **Interpretation:** Based on the information above, how do you think the sample might have formed? (First, is it primarily terrigenous or biogenous? Where might it have been deposited: active continental margin, passive continental margin, tropical beach, abyssal plain,...? Etc.) Explain the evidence for your hypothesis. Be as specific as you can, without conjecturing beyond the given evidence.

**Note:** Blank data tables are provided below for your notes, but you will likely need additional room for your full answers.