Marine Sediments

Alan P. Trujillo
Harold V. Thurman
Chapter Overview

• Marine sediments contain a record of Earth history.
• Marine sediments provide many important resources.
• Marine sediments have origins from a variety of sources.
Marine Sediments

• Provide clues to Earth history
  – Marine organism distribution
  – Ocean floor movements
  – Ocean circulation patterns
  – Climate change
  – Global extinction events
Marine Sediments

- **Texture** – size and shape of particles
- **Sediment origins**
  - Worn rocks
  - Living organisms
  - Minerals dissolved in water
  - Outer space
- **Sediments lithify into sedimentary rock**
# Classification of Marine Sediments

<table>
<thead>
<tr>
<th>Type</th>
<th>Composition</th>
<th>Sources</th>
<th>Main locations found</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithogenous</td>
<td>Rock fragments</td>
<td>Rivers; coastal erosion; landslides</td>
<td>Continental shelf</td>
</tr>
<tr>
<td>Continental margin</td>
<td>Quartz sand</td>
<td>Glaciers</td>
<td>Continental shelf in high latitudes</td>
</tr>
<tr>
<td></td>
<td>Quartz silt, Clay</td>
<td>Turbidity currents</td>
<td>Continental slope and rise; ocean basin margins</td>
</tr>
<tr>
<td>Oceanic</td>
<td>Volcanic ash</td>
<td>Wind-blown dust; rivers</td>
<td>Abyssal plains and other regions of the deep-ocean basins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volcanic eruptions</td>
<td></td>
</tr>
<tr>
<td>Biogenous</td>
<td>Calcareous ooze (microscopic)</td>
<td>Coccolithophores (algae) Foraminifers (protozoans)</td>
<td>Low-latitude regions; sea floor above CCD; along mid-ocean ridges and the tops of volcanic peaks</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>Shells and coral fragments (macroscopic)</td>
<td>Warm surface waters</td>
<td>Continental shelf; beaches</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Macroscopic shell-producing organisms</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coral reefs</td>
<td>Shallow low-latitude regions</td>
</tr>
<tr>
<td></td>
<td>Siliceous ooze</td>
<td>Cold surface waters</td>
<td>High-latitude regions; sea floor below CCD; upwelling areas where cold, deep water rises to the surface, especially that caused by surface current divergence near the equator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diatoms (algae) Radiolarians (protozoans)</td>
<td></td>
</tr>
<tr>
<td>Hydrogenous</td>
<td>Manganese nodules (manganese, iron, copper, nickel, cobalt)</td>
<td>Precipitation of dissolved materials directly from seawater due to chemical reactions</td>
<td>Abyssal plain</td>
</tr>
<tr>
<td></td>
<td>Phosphorite (phosphorous)</td>
<td></td>
<td>Continental shelf</td>
</tr>
<tr>
<td></td>
<td>Oolites (CaCO₃)</td>
<td></td>
<td>Shallow shelf in low-latitude regions</td>
</tr>
<tr>
<td></td>
<td>Metal sulfides (iron, nickel, copper, zinc, silver)</td>
<td></td>
<td>Hydrothermal vents at mid-ocean ridges</td>
</tr>
<tr>
<td></td>
<td>Evaporites (gypsum, halite, other salts)</td>
<td></td>
<td>Shallow restricted basins where evaporation is high in low-latitude regions</td>
</tr>
<tr>
<td>Cosmogenous</td>
<td>Iron–nickel spherules</td>
<td>Space dust</td>
<td>In very small proportions mixed with all types of sediment and in all marine environments</td>
</tr>
<tr>
<td></td>
<td>Tektites (silica glass)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iron–nickel meteorites</td>
<td>Meteors</td>
<td>Localized near meteor impact structures</td>
</tr>
</tbody>
</table>
Marine Sediment Collection

- Early exploration used dredges.
- Modern exploration
  - Cores – hollow steel tube collects sediment columns
  - Rotary drilling – collects deep ocean sediment cores
Drill Ship JOIDES Resolution
Marine Sediment Collection

• National Science Foundation (NSF) – formed Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) in 1963
  – Scripps Institution of Oceanography
  – Rosenstiel School of Atmospheric and Oceanic Studies
  – Lamont-Doherty Earth Observatory of Columbia University
  – Woods Hole Oceanographic Institution
Marine Sediment Collection

• Deep Sea Drilling Project (DSDP) – 1968
  – *Glomar Challenger* drilling ship
  – Core collection in deep water
  – Confirmed existence of sea floor spreading
    • Ocean floor age
    • Sediment thickness
    • Magnetic polarity
Marine Sediment Collection

• DSDP became Ocean Drilling Project (ODP) in 1983
  – JOIDES Resolution replaced Glomar Challenger

• Integrated Ocean Drilling Program (IODP)
  – Replaced ODP in 2003
  – Chikyu – new exploration vessel in 2007
    • Expedition to Japan Trench after 2011 earthquake
Paleoceanography and Marine Sediments

• **Paleoceanography** – study of how ocean, atmosphere, and land interactions have produced changes in ocean chemistry, circulation, biology, and climate
  – Marine sediments provide clues to past changes.
Marine Sediment Classification

- Classified by origin
- Lithogenous – derived from land
- Biogenous – derived from organisms
- Hydrogenous or Authigenic – derived from water
- Cosmogenous – derived from outer space
Lithogenous Sediments

• Eroded rock fragments from land
• Also called terrigenous
• Reflect composition of rock from which derived
• Produced by weathering
  – Breaking of rocks into smaller pieces
Lithogenous Sediments

- Small particles eroded and transported
- Carried to ocean
  - Streams
  - Wind
  - Glaciers
  - Gravity
- Greatest quantity around continental margins
Lithogenous Sediment Transport
Lithogenous Sediments

• Reflect composition of rock from which derived
• Coarser sediments closer to shore
• Finer sediments farther from shore
• Mainly mineral quartz ($\text{SiO}_2$)
Lithogenous Quartz and Wind Transport
Grain Size

- One of the most important sediment properties
- Proportional to energy of transportation and deposition
- Classified by Wentworth scale of grain size
## Wentworth Scale of Grain Size

<table>
<thead>
<tr>
<th>Size range (millimeters)</th>
<th>Particle name</th>
<th>Grain size</th>
<th>Example</th>
<th>Energy of the depositional environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 256</td>
<td>Boulder</td>
<td>Coarse-grained</td>
<td>Coarse material found in streambeds near the source areas of rivers</td>
<td>High energy</td>
</tr>
<tr>
<td>64 to 256</td>
<td>Cobble</td>
<td>Coarse-grained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 to 64</td>
<td>Pebble</td>
<td>Coarse-grained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 to 4</td>
<td>Granule</td>
<td>Coarse-grained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/16 to 2</td>
<td>Sand</td>
<td>Coarse-grained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/256 to 1/16</td>
<td>Silt</td>
<td>Coarse-grained</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/4096 to 1/256</td>
<td>Clay</td>
<td>Fine-grained</td>
<td>Beach sand</td>
<td>Low energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Feels gritty in teeth</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Microscopic; feels sticky</td>
<td></td>
</tr>
</tbody>
</table>
Texture and Environment

• Texture indicates environmental energy
  – High energy (strong wave action) – larger particles
  – Low energy – smaller particles
• Larger particles closer to shore
Sorting

- Measure of grain size uniformity
- Indicates selectivity of transportation process
- Well-sorted – all same size particle
- Poorly sorted – different size particles mixed together
Sediment Distribution

• **Neritic**
  – Shallow-water deposits
  – Close to land
  – Dominantly lithogenous
  – Typically deposited quickly

• **Pelagic**
  – Deeper-water deposits
  – Finer-grained sediments
  – Deposited slowly
Neritic Lithogenous Sediments

• Beach deposits
  – Mainly wave-deposited quartz-rich sands
• Continental shelf deposits
  – Relict sediments
• Turbidite deposits
  – Graded bedding
• Glacial deposits
  – High-latitude continental shelf
  – Currently forming by ice rafting
Pelagic Deposits

- Fine-grained material
- Accumulates slowly on deep ocean floor
- Pelagic lithogenous sediment from
  - Volcanic ash (volcanic eruptions)
  - Wind-blown dust
  - Fine-grained material transported by deep ocean currents
Pelagic Deposits

- **Abyssal Clay**
  - At least 70% clay sized particles from continents
  - Red from oxidized iron (Fe)
  - Abundant if other sediments absent
Biogenous Sediment

• Hard remains of once-living organisms
• Two major types:
  – Macroscopic
    • Visible to naked eye
    • Shells, bones, teeth
  – Microscopic
    • Tiny shells or tests
    • Biogenic ooze
• Mainly algae and protozoans
Biogenous Sediment Composition

- Two most common chemical compounds:
  - Calcium carbonate (CaCO$_3$)
  - Silica (SiO$_2$ or SiO$_2$·nH$_2$O)
Silica in Biogenous Sediments

• Diatoms
  – Photosynthetic algae
  – Diatomaceous earth

• Radiolarians
  – Protozoans
  – Use external food
Silica in Biogenous Sediments

- **Tests** – shells of microscopic organisms
- Tests from diatoms and radiolarians generate *siliceous ooze*. 
Diatomaceous Earth

• Siliceous ooze lithifies into diatomaceous earth.

• Diatomaceous earth has many commercial uses.
Calcium Carbonate in Biogenic Sediments

- **Coccolithophores**
  - Also called nannoplankton
  - Photosynthetic algae
  - **Coccoliths** – individual plates from dead organism
  - **Rock chalk**
    - Lithified coccolith-rich ooze
Calcium Carbonate in Biogenic Sediments

- **Foraminifera**
  - Protozoans
  - Use external food
  - Calcareous ooze
Distribution of Biogenous Sediments

- Depends on three processes:
  - Productivity
    - Number of organisms in surface water above ocean floor
  - Destruction
    - Skeletal remains (tests) dissolve in seawater at depth
  - Dilution
    - Deposition of other sediments decreases percentage of biogenous sediments
Pelagic Deposits

- Siliceous ooze
- Accumulates in areas of high productivity
- Silica tests no longer dissolved by seawater when buried by other tests
Neritic Deposits

- Dominated by lithogenous sediment, may contain biogenous sediment
- **Carbonate Deposits**
  - Carbonate minerals containing $\text{CO}_3$
  - Marine carbonates primarily *limestone*
    - $\text{CaCO}_3$
  - Most limestones contain fossil shells
    - Suggests biogenous origin
  - Ancient marine carbonates constitute 25% of all sedimentary rocks on Earth.
Carbonate Deposits

- **Stromatolites**
  - Fine layers of carbonate
  - Warm, shallow-ocean, high salinity
  - Cyanobacteria
- Lived billions of years ago
- Modern stromatolites live near Shark Bay, Australia
Calcareous Ooze

- **CCD** – *Calcite compensation depth*
  - Depth where \( \text{CaCO}_3 \) readily dissolves
  - *Rate of supply* = *rate at which the shells dissolve*
- **Warm, shallow ocean** saturated with calcium carbonate
- **Cool, deep ocean** undersaturated with calcium carbonate
  - **Lysocline** – depth at which *a significant amount of CaCO}_3 begins to dissolve rapidly*
Calcareous Ooze and the CCD

Calcification is the process of calcium carbonate precipitation by marine organisms. Calcareous ooze is composed of the calcium carbonate secreted by calciferous organisms such as forams and radiolaria. These organisms excrete the calcium carbonate as a biologic ooze into the oceans. As the ooze sinks to the sediments of the ocean floor and continues to accumulate, it is referred to as cemented ooze. The most common carbonate sediments are composed of calcareous ooze. This ooze is a product of the calcification processes that occur throughout the ocean. The calcification processes are very complex and involve the interaction of many different organisms. The most common calcification processes are the formation of aragonite and calcite. Aragonite is a form of calcium carbonate that is very soluble and is often found in the oceans. Calcite is a form of calcium carbonate that is not soluble and is often found in the ocean floor. The calcification processes are very complex and involve the interaction of many different organisms. The most common calcification processes are the formation of aragonite and calcite. Aragonite is a form of calcium carbonate that is very soluble and is often found in the oceans. Calcite is a form of calcium carbonate that is not soluble and is often found in the ocean floor. The calcification processes are very complex and involve the interaction of many different organisms. The most common calcification processes are the formation of aragonite and calcite. Aragonite is a form of calcium carbonate that is very soluble and is often found in the oceans. Calcite is a form of calcium carbonate that is not soluble and is often found in the ocean floor. The calcification processes are very complex and involve the interaction of many different organisms. The most common calcification processes are the formation of aragonite and calcite. Aragonite is a form of calcium carbonate that is very soluble and is often found in the oceans. Calcite is a form of calcium carbonate that is not soluble and is often found in the ocean floor. The calcification processes are very complex and involve the interaction of many different organisms. The most common calcification processes are the formation of aragonite and calcite. Aragonite is a form of calcium carbonate that is very soluble and is often found in the oceans. Calcite is a form of calcium carbonate that is not soluble and is often found in the ocean floor. The calcification processes are very complex and involve the interaction of many different organisms. The most common calcification processes are the formation of aragonite and calcite. Aragonite is a form of calcium carbonate that is very soluble and is often found in the oceans. Calcite is a form of calcium carbonate that is not soluble and is often found in the ocean floor. The calcification processes are very complex and involve the interaction of many different organisms. The most common calcification processes are the formation of aragonite and calcite. Aragonite is a form of calcium carbonate that is very soluble and is often found in the oceans. Calcite is a form of calcium carbonate that is not soluble and is often found in the ocean floor.
Calcareous Ooze and the CCD

• Scarce calcareous ooze below 5000 meters (16,400 feet) in modern ocean
• Ancient calcareous oozes at greater depths if moved by sea floor spreading
Sea Floor Spreading and Sediment Accumulation

1. Calcareous ooze deposited on MOR above CCD
2. Calcareous ooze is covered and protected
3. Sea floor spreading moves calcareous ooze beneath the CCD into deep water
Distribution of Modern Calcium Carbonate Sediments
### Table 4.3 Comparison of Environments Interpreted from Deposits of Siliceous and Calcareous Ooze in Surface Sediments

<table>
<thead>
<tr>
<th></th>
<th>Siliceous ooze</th>
<th>Calcareous ooze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water temperature above</td>
<td>Cool</td>
<td>Warm</td>
</tr>
<tr>
<td>sea floor deposits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main location found</td>
<td>Sea floor beneath cool surface water in high</td>
<td>Sea floor beneath warm surface water in low</td>
</tr>
<tr>
<td></td>
<td>latitudes</td>
<td>latitudes</td>
</tr>
<tr>
<td>Other factors</td>
<td>Upwelling brings deep, cold, nutrient-rich water</td>
<td>Calcereous ooze dissolves below the CCD</td>
</tr>
<tr>
<td></td>
<td>to the surface</td>
<td></td>
</tr>
<tr>
<td>Other locations found</td>
<td>Sea floor beneath areas of upwelling, including</td>
<td>Sea floor beneath warm surface water in low</td>
</tr>
<tr>
<td></td>
<td>along the equator</td>
<td>latitudes along the mid-ocean ridge</td>
</tr>
</tbody>
</table>
Hydrogenous Marine Sediments

- Minerals **precipitate** directly from seawater
  - Manganese nodules
  - Phosphates
  - Carbonates
  - Metal sulfides

- Small proportion of marine sediments
- Distributed in diverse environments
Manganese Nodules

- Fist-sized lumps of manganese, iron, and other metals
- Very slow accumulation rates
- Many commercial uses
- Unsure why they are not buried by seafloor sediments
Manganese Nodules
Phosphates and Carbonates

• Phosphates
  – Phosphorus-bearing
  – Occur beneath areas in surface ocean of very high biological productivity
  – Economically useful as fertilizer

• Carbonates
  – Aragonite and calcite
  – Oolites
Metal Sulfides

- Metal sulfides
  - Contain:
    - Iron
    - Nickel
    - Copper
    - Zinc
    - Silver
    - Other metals
  - Associated with hydrothermal vents
Evaporites

- Minerals that form when seawater evaporates
- Restricted open ocean circulation
- High evaporation rates
- Halite (common table salt) and gypsum
Evaporative Salts in Death Valley
Cosmogenous Marine Sediments

- Macroscopic meteor debris
- Microscopic iron-nickel and silicate spherules (small globular masses)
  - Tektites
  - Space dust
- Overall, insignificant proportion of marine sediments
Marine Sediment Mixtures

- Usually mixture of different sediment types
- Typically one sediment type dominates in different areas of the sea floor.
Pelagic and Neritic Sediment Distribution

- Neritic sediments cover about $\frac{1}{4}$ of the sea floor.
- Pelagic sediments cover about $\frac{3}{4}$ of the sea floor.
Pelagic and Neritic Sediment Distribution

• Distribution controlled by
  – Proximity to sources of lithogenous sediments
  – Productivity of microscopic marine organisms
  – Depth of water
  – Sea floor features
Pelagic Sediment Types

- Atlantic Ocean
  - Calcareous ooze
  - Abyssal clay
  - Siliceous ooze

- Pacific Ocean
  - Calcareous ooze
  - Abyssal clay
  - Siliceous ooze

- Indian Ocean
  - Calcareous ooze
  - Abyssal clay
  - Siliceous ooze

World Ocean (all oceans combined)
- Calcareous ooze
- Abyssal clay
- Siliceous ooze

© 2014 Pearson Education, Inc.
Sea Floor Sediments Represent Surface Ocean Conditions

• Microscopic tests sink slowly from surface ocean to sea floor (10–50 years)
• Tests could be moved horizontally
• Most biogenous tests clump together in fecal pellets
  – Fecal pellets large enough to sink quickly (10–15 days)
Worldwide Marine Sediment Thickness

- Sediment is thinnest where ocean floor is young along mid-ocean ridges.
- Thick sediment accumulates on continental shelves especially near mouths of major rivers.

Thickness in Meters

© 2014 Pearson Education, Inc.
Resources from Marine Sediments

• Both mineral and organic resources
• Not easily accessible
  – Technological challenges
  – High costs
Energy Resources

• Petroleum
  – Ancient remains of microscopic organisms
  – More than 95% of economic value of oceanic nonliving resources

• More than 30% of world’s oil from offshore resources

• Future offshore exploration will be intense
  – Potential for oil spills
Offshore Drilling Platform
Energy Resources

• Gas Hydrates
  – Also called clathrates
  – High pressures squeeze chilled water and gas into icelike solid
  – Methane hydrates most common
Energy Resources

• Gas hydrates resemble ice but burn when lit
• May form on sea floor
  – Sea floor methane supports rich community of organisms
• Most deposits on continental shelf
Energy Resources

• Release of sea floor methane may alter global climate.
• Warmer waters may release more methane.
• Methane release may cause underwater slope failure.
  – Tsunami hazard
Energy Resources

• Gas hydrates may be largest store of usable energy.
• Rapidly decompose at surface pressures and temperatures
Other Resources

• Sand and gravel
  – Aggregate in concrete
  – Some is mineral-rich
Other Resources

• Evaporative salts
  – Gypsum – used in drywall
  – Halite – common table salt
Other Resources

• Phosphorite – phosphate minerals
  – Fertilizer for plants
  – Found on continental shelf and slope
Other Resources

• Manganese nodules
  – Lumps of metal
  – Contain manganese, iron, copper, nickel, cobalt
  – Economically useful
Distribution of Sea Floor Manganese Nodules

- Extensive coverage of nodules locally exceeding 90%
- Common nodules, sometimes patchy
Other Resources

• Rare Earth elements
  – Assortment of 17 metals
  – Used in technology, e.g., cell phones, television screens, etc.

• Sea floor may hold more rare Earth element deposits than found on land
End of CHAPTER 4
Marine Sediments